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FUZZY LOGIC CONTROL FOR ENERGY MANAGEMENT SYSTEM OF A HYBRID ELECTRIC VEHICLE

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MECHANICAL ENGINEERING

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by

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14926

Dissertation submitted in partial fulfilment of

the requirements for the

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CERTIFICATION OF APPROVAL

Fuzzy Logic Control for Energy Management System of a Hybrid Electric Vehicle

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Ahmad Idhwan Bin Abd Jalil

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A project dissertation submitted to the

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(MECHANICAL)

Approved by,

____

(MUI'NUDDIN BIN MAHARUN)

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TRONOH, PERAK

JANUARY 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or personal.

AHMAD IDHWAN BIN ABD JALIL

ABSTRACT

The Hybrid Electric Vehicle (HEV) electric motor is typically powered by a battery pack through power electronics. The fuel consumption in HEV is already lower compared to conventional vehicle. However, there will be a need to control the distribution of torque between the engine and electric motor to further minimize the fuel consumption. With reference to this issues, the purpose of this project is to create a complete HEV using a MATLAB/Simulink tool. From the model created, it will be equipped with a controller for energy management system. The method used is by taking the driver command, the state of charge (SOC) of the battery, the vehicle speed, percentage of throttle and engine efficiency as inputs, a fuzzy logic control for parallel HEV has been developed in a controller to effectively control the torque distribution between Internal Combustion Engine (ICE) and electric motor which is known as In-Wheel Motor (IWM). This research also discusses the methodology for designing a base vehicle model using MATLAB/Simulink. Prior to modelling HEV model, the base vehicle model was validated in terms of the fuel consumption to verify the model. The verified built base model will then be modified to become HEV model by virtually installing IWM at the rear wheels together with a controller inside the trunk. The proposed energy management strategy is implemented on a parallel HEV model and it is then simulated to a selected drive cycles. Since the distribution of torque in HEV model is varied according to the rules set, the fuel consumption is reduced significantly as compared with conventional base vehicle model. The simulation results reveal that, the HEV model built from conventional vehicle model has a significant improvement of 23% in terms of fuel economy as well as maintaining battery SOC within its operation range.

ACKNOWLEDGEMENT

In the name of Allah, the most Gracious and the most Merciful, without His permission this project will not be possible.

First and foremost, I would like to take this opportunity to give my heartily appreciation to my supervisor, Mr. Mui'nuddin for his advices, support and guidance throughout the completion of this Final Year Project entitled "Fuzzy Logic Control for Energy Management System of a Hybrid Electric Vehicle". He has supported and encouraged me with his patience and knowledge. His precious help of constructive comments and suggestion have contributed to the achievement of the research's objectives. Not to forget, special thanks to my parent and family members for their continuous support and encouragement towards me all this while.

I would also like to give special thanks to my family and friends for their continuous support and encouragement towards me all this while completing this project.

Finally, thank you to Mechanical Engineering Department, Examiners and Coordinators of the Final Year Project for making this program a success. They have been very helpful and considerate throughout the whole project. Hopefully, this project will provide the readers with more knowledge and understanding towards the behavior of energy management system in hybrid vehicle.

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LIST OF ABBREVIATION

ADVISOR	Advance Vehicle Simulator
EMS	Energy Management System
FLC	Fuzzy Logic Control
GPS	Global Positioning System
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
IWM	In-Wheel Motor
SOC	State of Charge
UDDS	Urban Dynamometer Driving Schedule
NYCC	New York City Cycle
WOT	Wide Open Throttle

CHAPTER 1

INTRODUCTION

1.1 Background Study

The first section will briefly explain some theories of energy management system in HEV and also the relationship between HEV, energy management system and fuzzy logic. These three components are related with each other which then give a lot of benefits towards the development of hybrid vehicle nowadays.

1.1.1 Hybrid Electric Vehicle

Hybrid Electric Vehicle (HEV) is a type of transportation which uses a conventional Internal Combustion Engine (ICE) and also an electric motor as the main sources of propulsion power. The presence of electric motor is intended to achieve an efficient fuel usage. However, the usage of electric motor is a supplement to the main full size combustion engine which generally acts as a generator especially to reenergize a storage battery. The battery is usually charged by the engine which act as a generator and by energy recovered during braking, which is also known as regenerative braking. Regenerative braking is the energy recovery system by converting kinetic energy into electrical energy and it later can be stored inside the battery. HEVs are classified into two types of configuration, parallel hybrids and series hybrids. Both of them have the same hybrids features which are ICE, electric motor, and battery but they have different ways of configuration. The ICE based HEV has a smaller engine size, regenerative braking and more efficient engine operation. These advantages results in low fuel usage and emissions compared to conventional vehicles. In 1997, Toyota had introduced the Prius (FIGURE 1.1), the first HEV which uses ICE and it becomes the most sold HEV until now.

FIGURE 1.1: Toyota Prius – Most Sold HEV

1.1.2 Energy Management System

Energy management system (EMS) can be defined as a system to control or optimizing performance of generated system. It is very important to manage power strategy for the efficiency performance of HEVs. In this research, the strategy used is to minimize the amount of fuel used by the HEVs subjected to a certain selected drive cycle. At the same time, energy management system also proposed to minimize emission of burning fossil fuels such as carbon dioxide CO_2 and nitrogen dioxide NO_2 which could threaten public health. There is a strong upward trend in oil consumption around the world. As stated by US Department of Energy (DOE), there is about 15 million barrels of crude oil are being consumed which equal to 69% consumption are coming from transportation sector [11-12]. As shown in FIGURE 1.2 below is the projected growth of fuel consumption by transportation where 90% is expected to grow between 2000 and 2030.

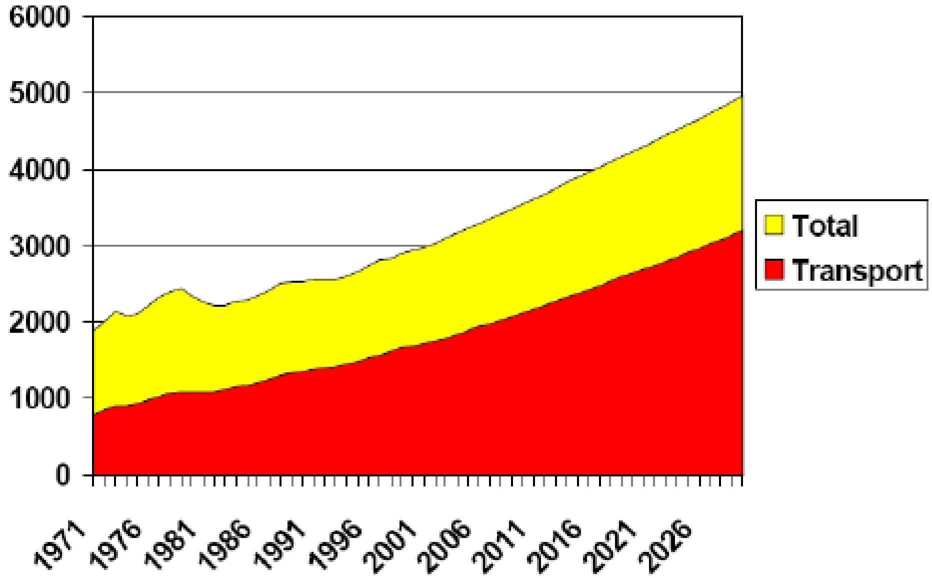

FIGURE 1.2: Globe Oil Consumption Perspective [12]

EMS also provide metering and monitoring functions that allow a control system to make decisions on the energy flow across a system. By having EMS, it provides insights of environmental conditions and recommendations to fine-tune the system for energy optimization and efficiency.

1.1.3 Fuzzy Logic Control

Fuzzy Logic Control (FLC) is a mathematical system that analyses analog input values in terms of logical variables. FLC consists of components which build its fundamental input-output relationship. It is contrary to conventional control techniques, and it is best utilized in complex defined processes that can be controlled by a skilled human operator. The FLC has shown great advantage in the area of control. It promotes the ability to discard tremendous amount of information and focus only on the information related to the task. In this way, the amount of information the controller has to deal is reduced to optimum level.

1.2 Problem Statement

Nowadays, HEVs have improved their performance in terms of commercial and domestic use during the last decades. However, the new major problem that arise is to face the increasing cost problem due to the rising gasoline prices. This issue brings major impacts towards country's economy and high fuel cost has been directly affect people's expenditure. At the same time, daily increase of fossil fuel consumption has become the contributing factor to environmental pollutions and threaten public health. Even by using HEVs, the torque distribution is not effective enough to save fuel. Besides, these excessive amount of harmful emissions would lead to greenhouse effect and global warming. In contrary, battery cell in HEV's only produce water and heat as emissions during operation which make pollution more controllable. Therefore, there is a need of effective energy management strategy should be proposed in order to overcome these problems.

1.3 Objectives

The FLC model built in this research is aimed to achieve two objectives based on the identified problem statement. The objectives are:

1. To develop a complete parallel Hybrid Electric Vehicle (HEV) model in MATLAB/Simulink.
2. To develop a rule-based control system (fuzzy logic) that minimize HEV fuel consumption subjected to a selected drive-cycle (UDDS, NY).

1.4 Scope of study

a. Parallel HEVs

   There are three possible setups for the drivetrain of HEVs, series, parallel and both series and parallel. This project will be focusing only on parallel drivetrain. Propulsion power is generated by both ICE and In-Wheel electric motor. This parallel configuration will use a smaller battery pack compared to series drivetrain. This type of drivetrain is efficient on highway since it has direct connection between engine and the wheels. Some early development of parallel hybrid vehicles are BMW 518, Citroen Xzara Dynactive and Saxo Dynavolt, Daimler-Chrysler ESX 3, and Fiat Multipla. FIGURE 1.3 below shows the illustration of arrangement in parallel HEVs.

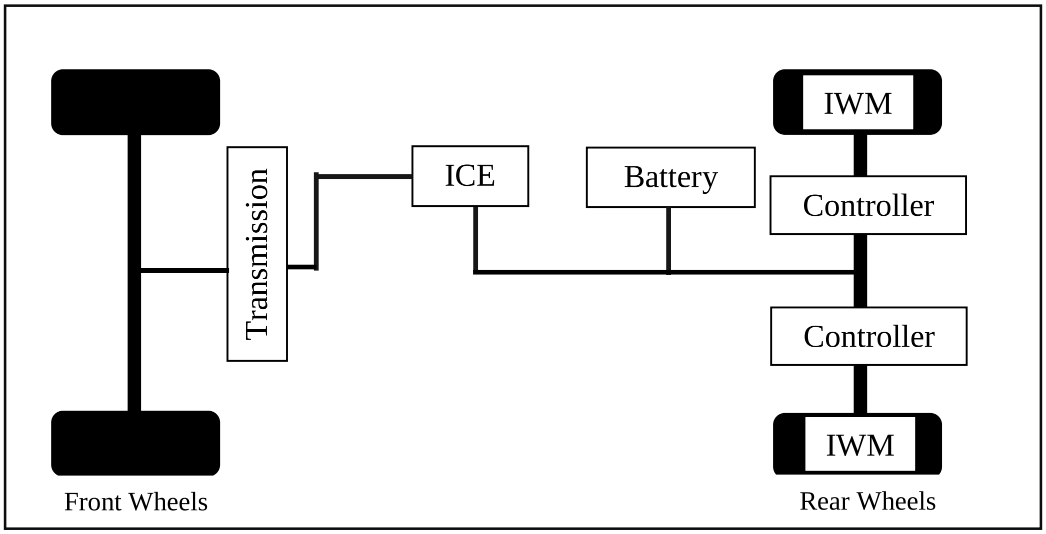

FIGURE 1.3: Parallel configuration of components in HEVs [10]

b. Rule based FLC

A set of fuzzy rules will be created to perform on the basis of the given set of input and output data. The processing stage of the controller will depend on the appropriate rules that is going to be set. The results generated will be the output which will be then converted into specific control output value.

c. Urban Dynamometer Driving Schedule (UDDS) and New York City Cycle (NYCC)

UDDS and NY are some examples of standard driving cycles that commonly used for testing vehicles for fuel economy purposes. UDDS represents city driving conditions and it is suitable for light duty vehicle testing. NYCC is normally applied for low speed stop-and-go traffic conditions. In order to obtain the drive cycle, UDDS and NYCC are selected to be carried out in this project because the features of each drive cycle are the most relevant to be analyzed in urban conditions. Both FIGURE 1.4 and FIGURE 1.5 illustrates UDDS and NYCC respectively.

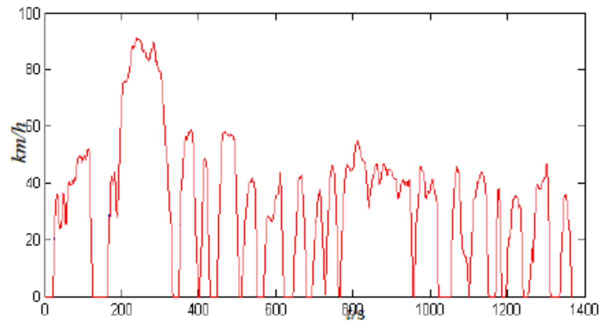

FIGURE 1.4: Information of UDDS road condition [5]

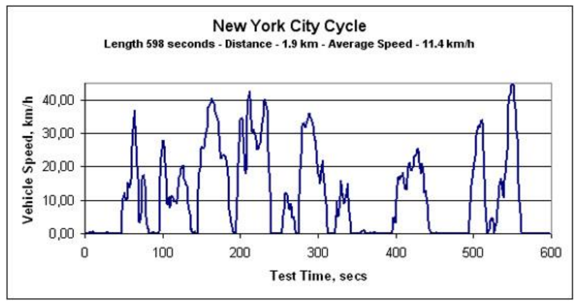

FIGURE 1.5: Information of NYCC road condition [5]

d. Perodua Myvi is selected as a conventional vehicle to get a drive cycle which will be used as an input for the controller. The technical specification [Appendix 1] has been referred for calculation purposes.

e. Graphical programming language tool for modelling, simulating and analyzing a dynamic modelling (MATLAB/Simulink). It consists of several number of blocks in HEV modelling. The control block consists of combination of some inputs which are engine efficiency, battery SOC, vehicle velocity and percentage of throttle.

1.5 Project Outline

This project is organized as follows, chapter 2 will discussed on the literature review for this research. The chapter basically covered general introduction of hybrid as well as other research work that is related.

Chapter 3 describes the methodology used to carry out this project. It includes the process flow of the project, key milestone, gantt chart as well as the software needed. Chapter 4 explained the sizing and modelling of the parallel HEV such as the battery storage system and electric motor. The details of the base vehicle model which includes the conventional vehicle's components are included in this section.

Chapter 5 will present the results of the simulations. The results include the simulation of energy management system which it will show the comparison of fuel consumption between base vehicle model and HEV model.

Chapter 7 will conclude the overall research work and provide some recommendations for further improvement of the vehicle model built in MATLAB/Simulink.

CHAPTER 2

LITERATURE REVIEW

2.1 Relationship between HEV, Fuzzy Logic and Energy Management System

Hybrid Electric Vehicle (HEV) is referred to a vehicle which does not rely only on the internal combustion engine only, but it also depends on the electric motor to provide propulsion power. Nowadays, hybrid cars gaining considerable attention in the world, including Malaysia. This is due to their efficient fuel consumption. Besides, there are some advanced technologies that people can benefited from HEV which are regenerative braking and recovery system whereby energy release during braking is converted into electrical energy and stored inside the battery. Efficient energy management system for HEVs was studied and developed in order to minimize the energy requirement.

Fuzzy Logic Control (FLC) is one of the methods to control energy flow for HEVs. One of the control systems is rule based control strategies. This control strategy is applicable in real time, simple, flexible and robust [1]. It is different compared to optimization control strategies where it is generally more complex [4]. Fuzzy logic is very useful to be used in a very complex system such as in advanced powertrain. It can be tuned and adapted to a certain situation as well as giving opportunity and freedom of control [2].

The EMS is one the critical factors to improve the efficiency of road-vehicles as well as protecting the environment. The EMS plays significant role in reducing fuel consumption and exhaust emission in HEV [6]. It is essential for the development of energy management in order to control the distribution of power between internal combustion engine and electric motor [7].

2.2 In-Wheel Motor

The additional propulsion for HEV comes from electric motor. The electric motor is attached to only both of the rear wheels instead all four wheels. It is quite difficult to install electric motor system into front drive wheel as the space is limited, plus the package interference with brake, steering and suspension structure [9]. This concept of retrofitting the electric motor inside the rear wheels is known as In-Wheel Motor (IWM) [8]. In this IWM system, it does not need a differential, drive shaft or other parts since the installment of IWM is directly attached to the wheel. Furthermore, the removal of drive shaft can reduce energy loss which then allows for a low electricity consumption required when running.

The size of IWM depends on the size of the rear wheels, which means that the size of IWM is based on the tire dimension of the vehicle (Perodua Myvi). Meanwhile, in this research, the IWM is designed in a way that the power output is the rim itself, which means the motor speed is actually the wheel speed. FIGURE 2.1 illustrates the actual image of IWM used in this research.

FIGURE 2.1: In-Wheel Motor

2.2.1 In-Wheel Motor Sizing

The power required by the IWM need to be calculated in order to meet the energy demand by the battery. The sizing is based on normal driving condition according to UDDS cycle. The power is calculated by using the formula below [10];

$$P = V(F_{rr} + F_g + F_d + F_a) \quad (2.1)$$

where;

$$F_{rr} = C_{rr}mg \text{ (Force required to overcome rolling resistance)} \quad (2.2)$$

C_{rr} is the coefficient of rolling resistance, m is mass (kg) and g is the gravity.

$$F_g = mgsin\theta \text{ (Force required to undergone ascend movement)} \quad (2.3)$$

$$F_d = 0.5\rho C_d A v^2 \text{ (Force required to overcome aerodynamic drag)} \quad (2.4)$$

ρ is the air density, C_d is coefficient of drag, A is frontal area and v is vehicle velocity.

$$F_a = ma \text{ (Force required by the vehicle to accelerate)} \quad (2.5)$$

2.3 Battery Storage System

As mentioned earlier in this research, HEV has more than one energy sources. A battery is an alternative source which can power the electric motor. The battery could be charged during vehicle operation via regenerative braking. The type of battery used in this project is lead-acid battery. The usage of this type of battery is because it is commonly used by previous researchers and low cost per watt-hour. In order to determine the required capacity for the battery, the energy of it need to be calculated by using the formula below [10];

$$E = \frac{P \times T}{\pi} \quad (2.6)$$

where E is energy required, P is power required by IWM (road load), T is time taken, and π is SOC.

Meanwhile, to calculate the voltage, V of the battery is using the formula below;

$$V = P/I \tag{2.7}$$

The mass of the battery is calculated as below;

$$M_b = \frac{E\ (Wh)}{specific\ energy\ (\frac{Wh}{kg})} \tag{2.8}$$

2.4 Reviews from previous research studies

There are many research studies that have been done to improve the energy management system inside HEV. Basically, most of the fuzzy logic control systems are designed to manage power flow between Internal Combustion Engine (ICE) and electric motor. According to researcher E. M. Natsheh et. al. [3] who had presented a study on 'Hybrid Power System Energy Controller Based on Neural Network and Fuzzy Logic', they mentioned that the purpose of having fuzzy logic control is to distribute the power among the ICE and battery which stores the electric for electric motors. In their study, the proposed method of generating fuzzy logic control is by controlling stack temperature in order to prolong proton exchange membrane fuel cell (PEMFC) life. The model is tested under different operating conditions and the results showed that the control strategy provided give a proper tool to optimize both energy consumption and performance. FIGURE 2.2 shows fuzzy logic control which has been used to make a decision for optimizing operation of the PEMFC. They stressed that energy flow management is needed to increase operating life of PEMFC to sustain energy flow.

The results of the study concludes that hybrid system operates excellent performances under various conditions, and could maintain the state of charge (SOC) between 40%-80%. Generally, this paper shows that controlling the stack temperature could be an important controlled variable, which can prove the generating performance of PEMFC.

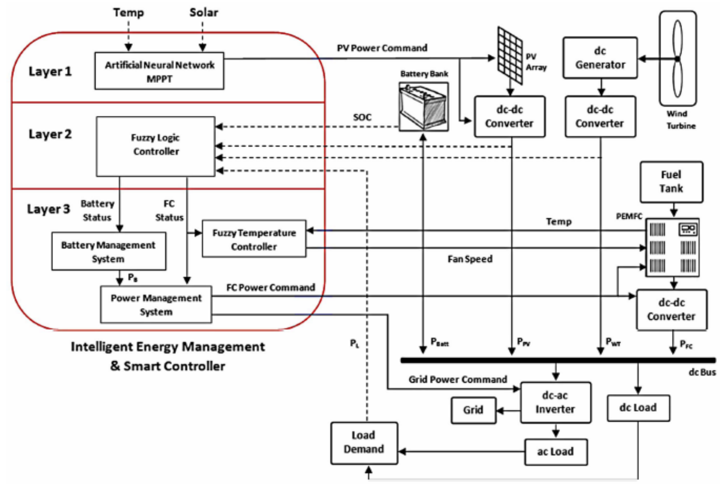

FIGURE 2.2: Block diagram of the proposed system [3]

There are many ways to manage fuel consumption of hybrid electric vehicles which mostly involve energy management system. Researcher H. Alipour et. al. [4] proposed a fuzzy logic controller that estimate trip distance with the assistant of GPS technology whilst managing the battery state of charge (SOC). The approach is observed and investigated by conducting simulations by using Advanced Vehicle Simulator (ADVISOR), a tool to simulate and analyze vehicle components that might affect fuel economy, performance and emissions. The approach that have been used is a simple rule base power management system. In this paper, the method that they used to minimize the fuel consumption is by knowing the trip length and provide it to the controller. The trip length is obtained from GPS data. By doing this, the engine operates freely and save the battery state of charge (SOC) until the end of the trip. The result of this study showed the proposed strategy reduced the fuel consumption about 5.7%. This indicates that the method used could be regarded as an applicable strategy for HEV power management system. However, the user of HEV need to plan his/her destination first before departing in order to get the total distance of the trip.

Researcher Y. Zhang et. al. [5] proposed a method of managing energy in Plug-in Hybrid Electric Vehicle instead of HEV itself. The author stressed that regenerative braking and electric motor were never enough to fully recharge the larger battery pack. Due to that reason, the author proposed a fuzzy logic to create a new form to charge the battery, and at the same time reducing exhaust emissions and reduce fuel consumption.

The fuzzy logic control used could distribute power and output torque between motor and internal combustion engine (ICE). In order to observe and analyze several drive cycle, simulation software platform, ADVISOR was used. The fuzzy logic controller model is represented in FIGURE 2.3.

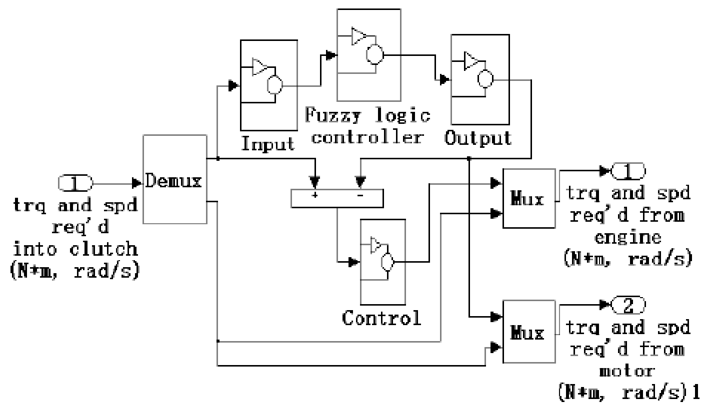

FIGURE 2.3: Fuzzy Logic Controller Model [5]

In this study, 27 rules were used to control the fuzzy controller whereby each rule represent different distribution of torque between ICE and electric motor. In short, the distribution of torque depends on the amount of SOC and the torque required by the vehicles. The results showed that when SOC is greater than 0.5, the motor will act as the major power source to drive the vehicle, while if SOC is less than 0.35, the ICE will act as the main power source to propel the vehicle. Meanwhile, the motor and ICE will both work together in case of SOC range is between 0.35 and 0.5. The strategy made an improvement of 13% in fuel economy side and 20% less in exhaust emission. This paper presents a very significant result where the proposed energy management strategy together with reasonable distribution of torque in ICE and motor could reduce exhaust emissions as well as improve fuel economy.

A research that is mostly closed related to this project is the thesis proposed by M. Maharun [7] where he had utilized the simulation of MATLAB/Simulink to analyze EMS of HEVs. In the thesis, a conventional vehicle was used and it is converted into HEV by retrofitting an In-Wheel Motor (IWM) at the rear of the wheels. A controller was built in MATLAB/Simulink by developing fuzzy logic. On top of that, the HEV model built in his research was based on the actual hybrid vehicle model and the configuration of drivetrain are also the same with this research. The simulation shows improvement in term of fuel consumption by 16% compared to conventional vehicle.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This project started with reviewing some previous studies which related to energy management system in hybrid vehicle. There are many methods in energy management in HEV, but for this project, the focus will be on a rule based system which is fuzzy logic control. Firstly, a base vehicle model is created in MATLAB/Simulink which comprises the conventional vehicle's components. A simulation is conducted purposely on the base model to validate it by comparing the model with the Advance Vehicle Simulator, ADVISOR. The satisfied base model will then be modified to become HEV model with a controller inside it. Then, the model will be simulated again to analyze the fuel consumption.

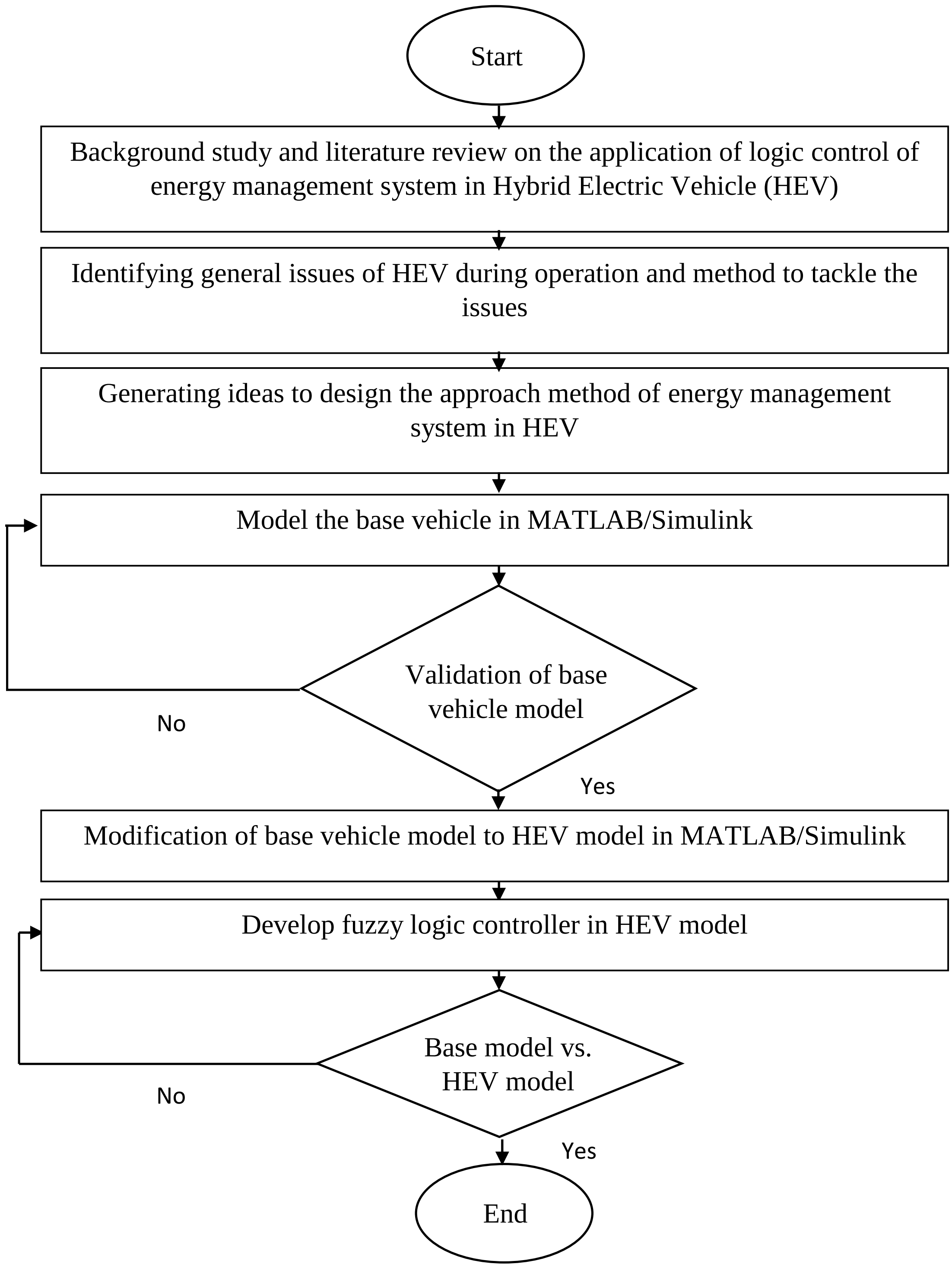

FIGURE 3.1: Research Methodology

3.2 Key Milestone

Highly achievable, satisfactory and relevant project milestone are very important aspects in order to keep this project on track. The milestones for this project in the first few weeks are summarized as follow:

a) Project Title Selection and Allocation (W1-W2)
   Students are allowed to select first three priority titles to the course MCB 4022 coordinator. Title selection and supervisor was confirmed on Week 2.
b) Meeting with supervisor (W3).
   Student might started their FYP1 supervising with respected supervisor. Project started with reading the journals and books that relevant to the project before discussing to extended proposal preparation. Weekly meetings were set with supervisor for progress update.
c) Preparation of Extended Proposal (W3-W7)
   Student starts to prepare extended proposal which includes Background of Study, Literature Review, Problem Statement, Objectives, Methodology and Project Milestones. The critical part is to analyze and criticize the chosen topic and area which contains relevant theories, hypotheses, facts, and data in Literature Review. Besides, student is required to identify the best method that will be used for the project. Meanwhile, Project Milestone keeps the student in the timeline.
d) Proposal Defense (W9)
   This is a critical activities before going into further development of this project. Examiner evaluated the topic and the proposal prepared by the students. Once the proposal is successfully defended, students might proceed with planned activities.
e) Project ongoing (W9-14)
   Activities started with extracting software ADVISOR from Mechanical Engineering Department to be used in MATLAB/Simulink. Then, it followed by several practices and activities to achieve the objectives.
f) Interim Report Submission (W14)
   A report containing the progress up until the end of the first part of the project to be submitted to the supervisor.

g) Project works continue (W1-W7)

Activities continued such as creating the base vehicle model that will be validated with ADVISOR for comparison.

h) Progress Report Submission (W7)

A report containing the progress up until the middle of the second part of the project, mostly covered with the result analysis from the base vehicle model created.

i) Poster Presentation (W10)

A poster presentation was carried out.

j) Project works continue (W10)

Activities continued by developing HEV model from the built base model. A rule based control system was developed by utilizing fuzzy logic to control the torque distribution.

k) Dissertation and Technical Report (W12)

Submission of final dissertation and technical paper to the examiner

l) Oral presentation (W14-W15)

Viva was carried out which involving the internal and external examiner.

The key milestones of the project is tabulated as shown in TABLE 1 and TABLE 2below:

TABLE 1: Key Milestone of Final Year Project 1

Final Year Project 1															
No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Project Title Selection		■												
2.	Extended Proposal submission						■								
3.	Proposal Defense									■					
4.	Draft Interim report submission													■	
5.	Interim Report submission														■

TABLE 2: Key Milestone of Final Year Project 2

Final Year Project 2															
No.	Item/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Project Work	■	■	■	■	■	■	■							
2.	Submit progress report							■							
3.	Project Work								■	■	■	■	■		
4.	Poster Pre-SEDEX										■				
5.	Submit Final Draft Report											■			
6.	Submit Dissertation (Soft bound)												■		
7.	Submit Technical Paper												■		
8.	Viva													■	
9.	Submit Project Dissertation (Hard bound)														■

3.3 Gantt Chart

TABLE 3: Gantt Chart of FYP1

	Months	Sept		October				November				December			
	Weeks/Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
STEP 1: Problem Understanding	Understanding Problem	■													
	Collecting Research papers	■	■												
	Project Outline		■												
	Project Kick Off		■												
STEP 2: Generating ideas	Study journals		■	■											
	Discussion with supervisor		■	■	■										
	Self-research				■										
	Formula Research				■										
STEP 3: Preparation of Extended Proposal	Background Study			■	■										
	Literature Review			■	■										
	Methodology Plan					■	■								
	Project Milestone					■	■								
Step 4: Experiment Start (MATLAB/Simulink)	Studying drive cycles							■	■						
	Calculate vehicle road load									■	■				
	Calculate In-Wheel motor sizing											■			
	Calculate battery sizing												■		
	Create Driver Model and Overview model												■		
Presentation	Proposal Defense								■						
STEP 5: Interim Report Preparation	Introduction											■			
	Summary of Future Work											■	■		
	Submission of Interim Draft Report													■	
	Submission of Final Interim Report														■

TABLE 4: Gantt Chart of FYP2

	Months	January		February				March				April			
	Weeks/Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
STEP 6: Create Base model in MATLAB/Simulink	Develop Driver model														
	Develop ICE Model														
	Develop Vehicle Dynamic model														
	Set Model Parameters														
	Run simulation														
	Base model validation														
Submission	Progress Report														
Step 7: Modification of Base model to HEV model	Develop battery model														
	Develop In Wheel motor model														
	Develop Vehicle Requirement model													**VIVA**	
	Run simulation														
STEP 6: Develop Fuzzy Logic Control Block	Develop Controller block set														
	Develop Fuzzy Logic Control														
	Simulate the result														
	Fuel economy evaluation														
Pre- SEDEX															
Submission	Draft Final Report														
	Dissertation (soft bound)														
	Technical Paper														
	Project Dissertation (Hard Bound)														

3.4 Software Required

The software that will be used throughout the project would be MATLAB/Simulink and ADVISOR. The ADVISOR is a simulation model for advanced vehicles. It is an object oriented programming language of Simulink. A base vehicle model will be created in MATLAB/Simulink before a hybrid vehicle is developed. Once the base vehicle model is ready to be simulate, it will be compared with the same component in ADVISOR. The ADVISOR model has a more complex system which consider a lot of factors for vehicle simulation. This advantage will provide a good platform to validate the base vehicle model created in MATLAB/Simulink.

CHAPTER 4

SIZING AND MODELLING

4.1 In-Wheel Motor Sizing

In this project, In-Wheel Motor (IWM) is attached on the rear wheels together with the controllers and a battery pack. The motor sizing is based on normal driving condition at 50 km/h and on a flat surface. The calculation of IWM sizing is based on summation of forces which are force to overcome rolling resistance, force required to ascend if there is any gradient, force to overcome the aerodynamic drag and force required to accelerate. At normal driving condition according to UDDS cycle,

$V = 50km/h$ ($13.89m/s$) for constant velocity

$a = 0$

Power required,

$$P = V\left(F_{rr} + F_g + F_d + F_a\right) \tag{4.1}$$

$F_g = 0$, *since the surface is assumed to be flat*

$P = 13.89[(0.013 \times 1118 \times 9.81) + (0.5 \times 1.23 \times 0.4 \times 2.13 \times 13.89^2) + (1118 \times 0)]$

$P = 3384.6W$

$\boldsymbol{P = 3.4kW}$

Power used for each motor,

$$\boxed{P_M = \frac{3.4\ kW}{2} = 1.7kW}$$

TABLE 5 below shows the summary of the specifications of electric motor.

TABLE 5: IWM Sizing

Type	Mars 0708 (Etek-R Comparable) Brush-type PM DC Motor
Inertia	0.0208 kgm^2
Mass	8.4 kg
Min Voltage	30 V
Max Current	150 A

4.2 Battery Specifications

A battery is a device which responsible to converts chemical energy into electrical energy and vice versa. Lead acid battery has become one of the most common battery used to power hybrid electric vehicle due to its low cost per watt-hour. The self-discharge is very low compared to other types of battery, which only lose about 5% of its charge per month if not in used [11].

Battery Sizing

In order to calculate the amount of energy required by the battery for average driving conditions, the formula shown below is used,

Energy Required,

$$E = \frac{P \times T}{\pi} \qquad (4.2)$$

$$T = \frac{D}{V} = \frac{100km}{\frac{50km}{h}} = 2.0h$$

$$\pi = \pi_m \times SOC = 0.9 \times 0.8 = 0.72 \qquad (4.3)$$

$$E = \frac{3.4\ kW \times 2.0}{0.72}$$

$$\boldsymbol{E = 9.4\ kWh}$$

The voltage of the battery is assumed to be at current, $A = 150A$ [10]

$$P = IV \tag{4.4}$$

$$V = \frac{3400}{150}$$

$$\boldsymbol{V = 22.6V \approx 24V}$$

From the values calculated above, the mass of the battery could be estimated,

$$M_b = \frac{3400Wh}{35wh/kg} \tag{4.5}$$

$$\boldsymbol{M_b = 97\ kg}$$

$$SOC = \frac{(Max\ capacity - Ah\ used)}{Max\ capacity} \tag{4.6}$$

The summary of battery sizing is shown in TABLE 6 below. From the calculated values, all features meet the standard performance of battery for HEV as represented by [11].

TABLE 6: Battery Sizing

Type	Lead Acid
Number of units	2
Specific energy	35 Wh/kg
Specific power	180 W/kg
Cycle durability	500 – 800 cycles
Nominal Cell Voltage	2 Volts per cell
Mass	97 kg
Energy Capacity	3.4 kWh
Voltage	24 V
Max Current	150 A

4.3 Additional HEV Model Mass

TABLE 7: Additional mass

Components	**Mass (kg)**
Electric motor	$30 \times 2 = 60$
Controller	12.2
Battery	97
Total	169.2

Therefore, the total mass of HEV modelling including the driver mass and vehicle mass = $169.2 + 1010 = \mathbf{1179.2kg}$

4.4 MATLAB/Simulink for vehicle modelling

In this section, the modelling of each main components of HEV will be illustrated accordingly. There will be two (2) main model to be created which are base vehicle model and HEV model. The base model consists of the conventional components including ICE model, driver model, vehicle requirement model and longitudinal vehicle dynamics model. Meanwhile, for the HEV, there are five main blocks to be built in MATLAB/Simulink: driver model, ICE model, battery model, IWM model, controller model and vehicle requirement model. FIGURE 4.1 and 4.2 illustrates a part of the draft overview of the model built in MATLAB/Simulink.

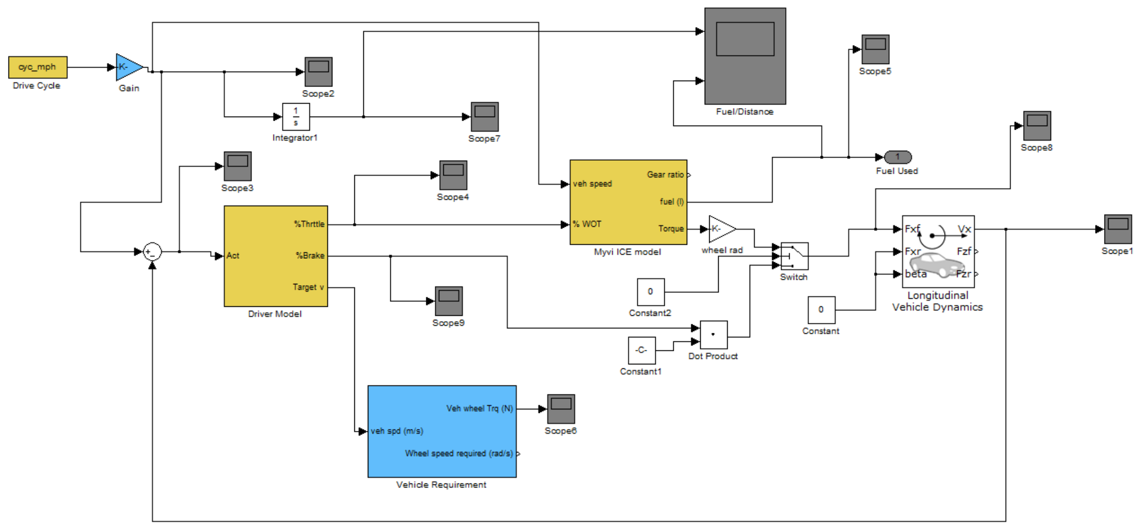

FIGURE 4.1: Overview of conventional base vehicle model

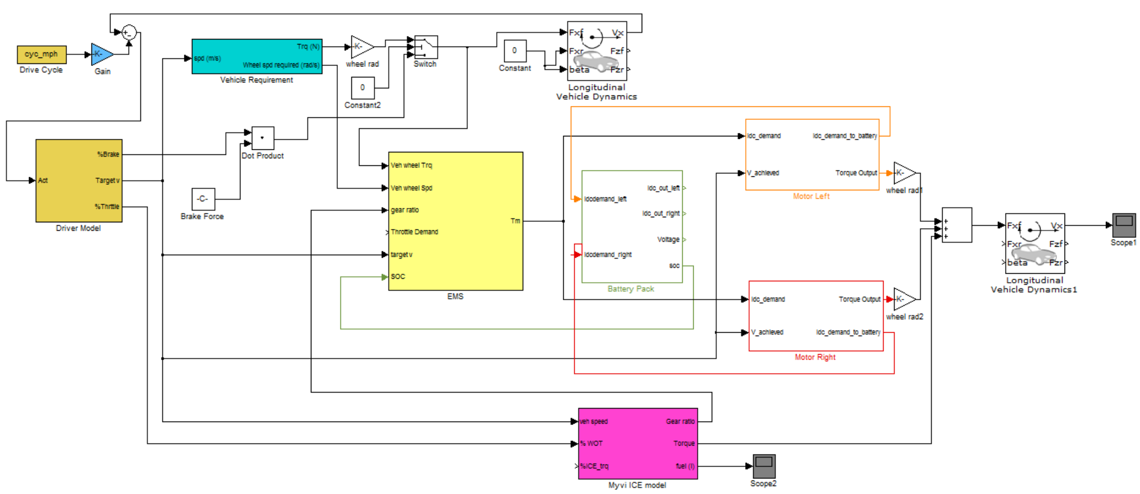

FIGURE 4.2: MATLAB/Simulink HEV model overview

4.5 Base vehicle model in MATLAB/Simulink

Base vehicle model is the model of conventional vehicle consisting of driver model, ICE model, vehicle requirement model, and longitudinal vehicle dynamics model. After the base model is completely built, the model will be simulated and the results will be compared to the simulation from ADVISOR model.

a) Driver Model

Driver model is created to determine the amount of torque required which will be distributed between electric motor and ICE. The driver model will receive the input velocity from the drive cycle [7]. The velocity from the drive cycle will be compared to the reference velocity which are built comes from longitudinal vehicle dynamic model.

Velocity error will be produced due to the difference between these velocities and the velocity input from the drive cycle. The difference will be received by PID controller and the output will be the percentage throttle and percentage braking. The value which are above 0 which is positive value will be treated as throttling while the value which are negative will be treated as braking percentage. FIGURE 4.3 illustrates the overview of the driver model block.

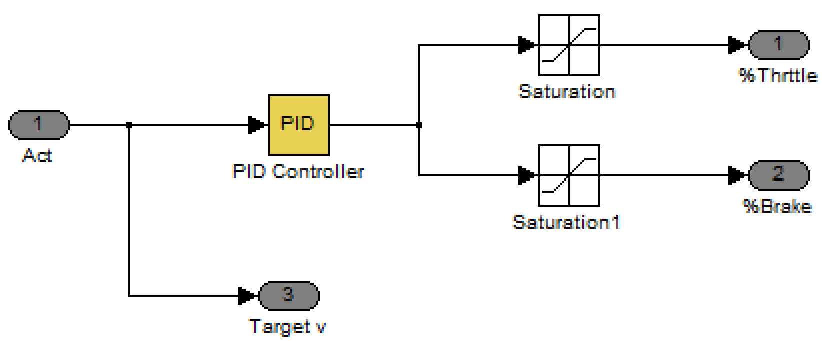

FIGURE 4.3: Driver Model

b) Vehicle Requirement Model

The vehicle requirement block model provide information for the controller to decide the ICE efficiency. This model will calculate the amount of wheel torque requires depending on the velocity input from the drive cycle. The torque is based on the summation of forces; the force required to overcome rolling resistance, force required to ascend, force required to overcome aerodynamic drag and force required to accelerate. These forces had been describe by few set of equations in the Section 2.2.1. FIGURE 4.4 illustrates the vehicle requirement block model.

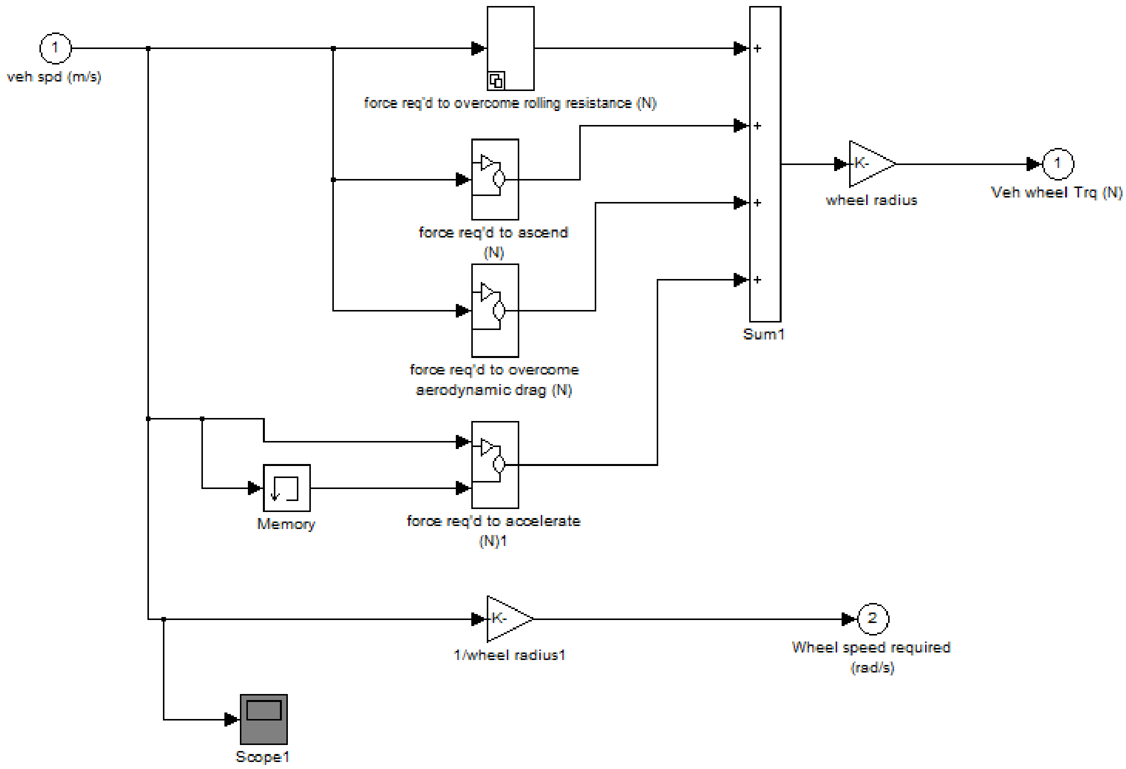

FIGURE 4.4: Vehicle requirement block model

c) ICE Model

The conventional engine model was designed based on the specification of Perodua Myvi. The ICE received power request from driver model and generate the torque accordingly. The original map of the actual engine was used to model the ICE. Test output of engine data for Perodua Myvi was taken from internet and used as a reference. FIGURE 4.5 shows the engine power versus speed and torque output versus speed graph for Perodua Myvi.

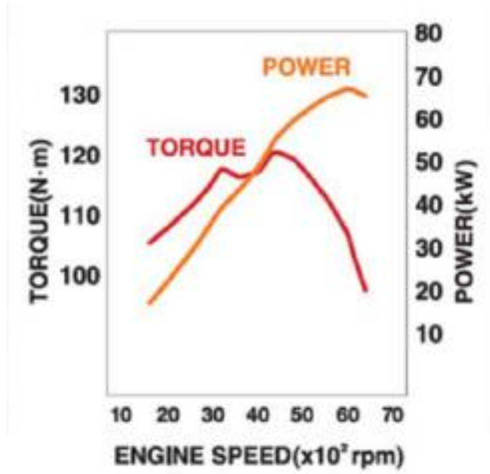

FIGURE 4.5: Graph of Torque and Power VS Engine Speed. [13]

TABLE 8: Perodua Myvi Technical Specs. [13]

Engine Type	K3-VE, petrol, inline 4-cylinder, 16V, DOHC with DVVT
Total displacement	1,298 cc
Bore X Stroke	72 x 79.7
Compression ratio	10
Max output	67 / 6,000
Max torque	120 / 4,400
Transmission	Forward 5-speed
Gear Ratio	1st : 3.182 2nd : 1.842 3rd : 1.250 4th : 0.865 5th : 0.750 Rev : 3.143
Final drive	4.267

The overall structure of the ICE model in MATLAB/Simulink provides the required torque in order to propel the vehicle. FIGURE 4.6 shows the ICE model structure built in MATLAB/Simulink.

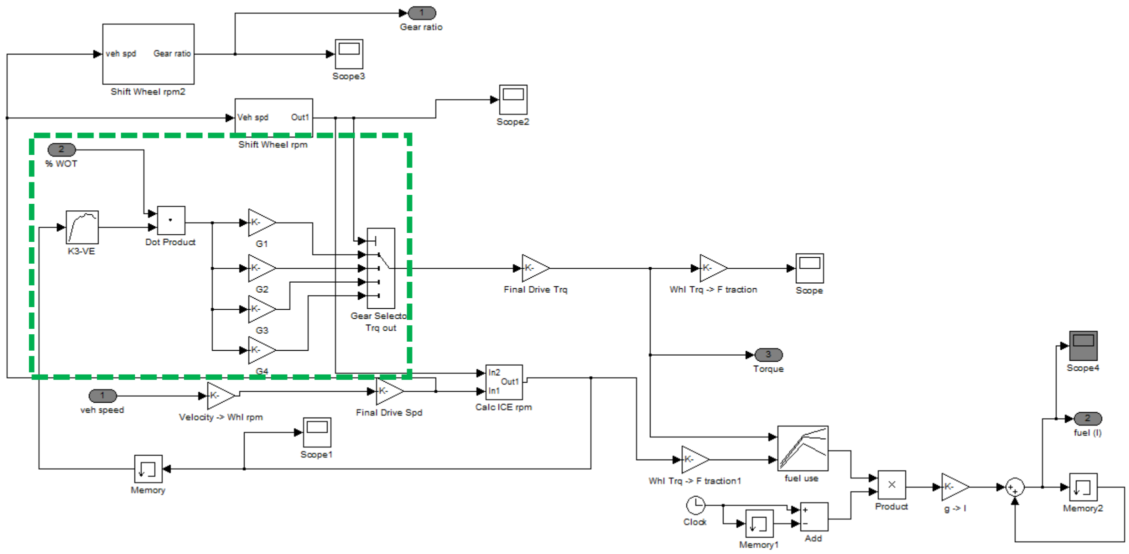

FIGURE 4.6: Perodua Myvi ICE Model

The block set within green dashed box in FIGURE 4.6 calculates the corresponding gear with respect to the current vehicle speed. The blocks in this model received the ICE speed and percentage of throttle from the driver model. The outputs of this model are the fuel used and wheel torque. For the base model, the engine is the only power source running to propel the vehicle. There is no other external torque supported to the vehicle. Unlike the HEV model, there is a distribution of torque between ICE and electric motor for vehicle propulsion.

d) Longitudinal Vehicle Dynamic Model

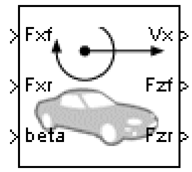

FIGURE 4.7: Longitudinal Vehicle Dynamic block

Longitudinal Vehicle Dynamics block is model consists of a two-axle vehicle, with four equally sized wheels, moving forward or backward along its longitudinal forces. The incline angle is set to be 0 since it was assumed that there is no elevation within the drive cycle. FIGURE 4.8 shows the dialog box and parameters which are set according to the specification of the vehicle.

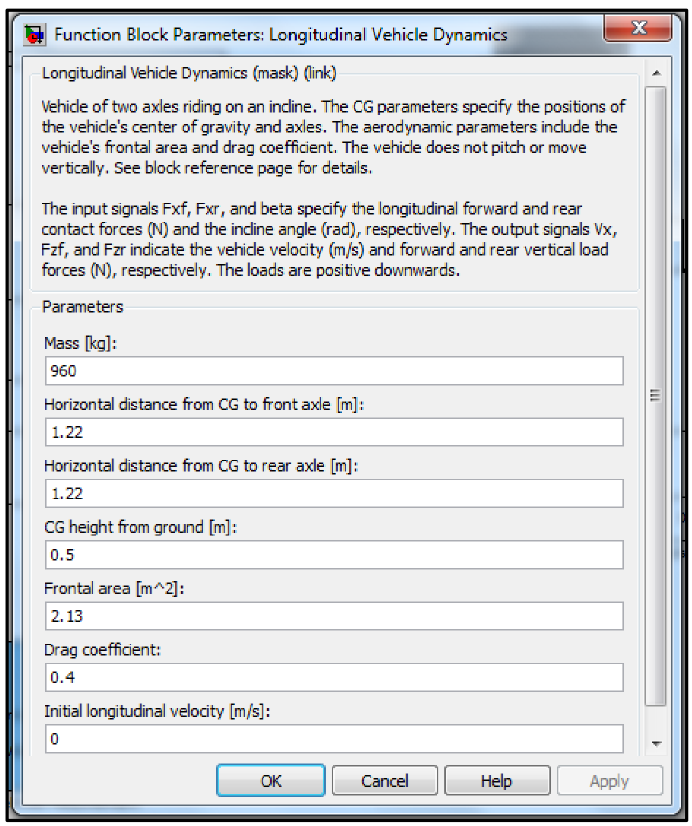

FIGURE 4.8: Longitudinal Vehicle Dynamics dialog box

The vehicle axles are configured to be paralleled and lie in a plane to the ground. The vehicle is assumed to be travelling on incline slope $\beta = 0$. FIGURE 4.9 and TABLE 9 define the vehicle motion model variables.

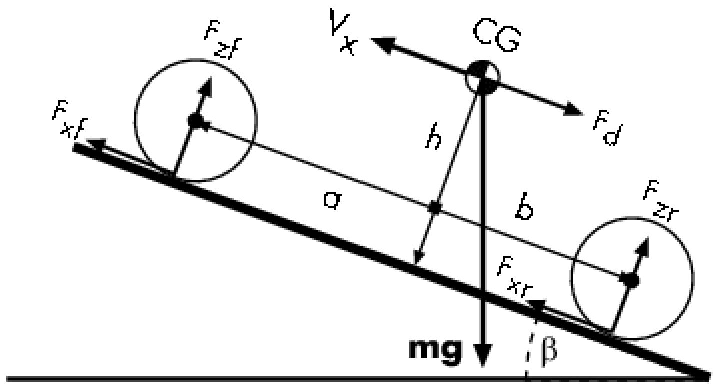

FIGURE 4.9: Vehicle dynamics and motion

TABLE 9: Vehicle model variables and constant

Symbol	Meaning and Unit
$g = -9.81$ m/s^2	Gravitational acceleration (m/s^2)
β	Incline angle (rad)
m	Vehicle mass (kg)
A	Effective frontal vehicle cross-sectional area (m^2)
h	Height of vehicle CG above the ground (m)
a, b	Distance of front and rear axles, respectively, from the vertical projection point of vehicle CG onto the axle-ground plane (m)
V_x	Longitudinal vehicle velocity (m/s)
F_{xf}, F_{xr}	Longitudinal forces on the vehicle at the front and rear wheel ground contact points, respectively (N)
F_{zf}, F_{zr}	Vertical load forces on the vehicle at the front and rear ground contact points, respectively (N)
C_d	Aerodynamic drag coefficient (N·s^2/kg·m)
ρ = 1.2 kg/m^3	Mass density of air (kg/m^3)
$\lvert F_d \rvert = ½C_d\rho AV_x^2$	Aerodynamic drag force (N)

4.6 Base vehicle model validation

After completing FYP1 with calculations and sizing components, a base vehicle model was created for validation purposes. Prior to modification of base vehicle model to become HEV model, some validation is required in order to have a strong result for HEV model. The parameter that will be considered for validation purpose is the fuel consumption of base vehicle model. The fuel consumption of base vehicle model will be compared with the model established in ADVISOR with the same specification of major block in both of the models.

The simulation is also meant to verify if the base vehicle model is strong enough to be converted to HEV model for fuel economy comparison. If the percentage error of the fuel consumption is too high (more than 10% error), the components in the base vehicle model need to be checked and simulate again until the result achieved good satisfactory. FIGURE 4.10 shows the overview of the base vehicle model in MATLAB/Simulink and FIGURE 4.11 shows model in ADVISOR.

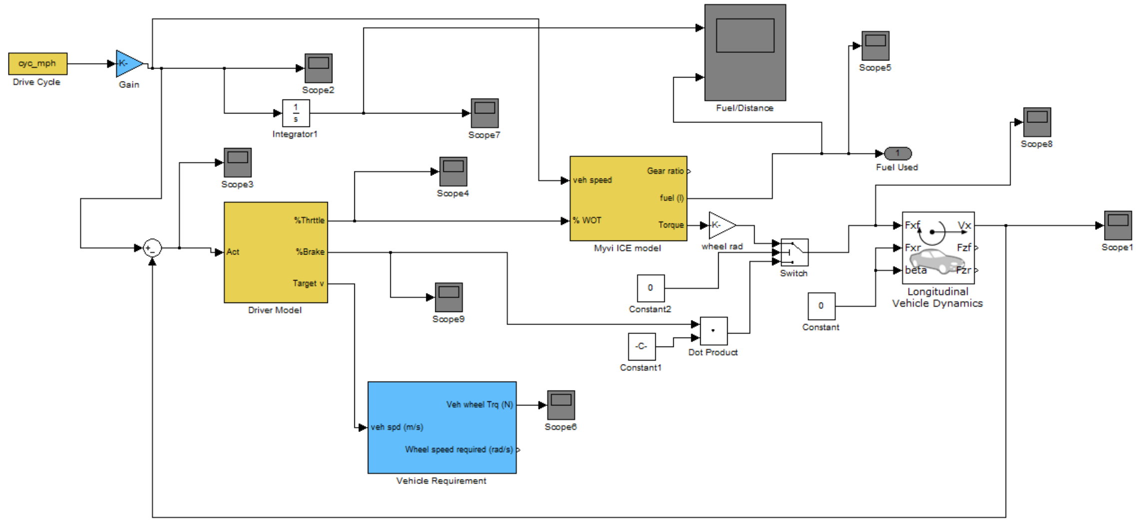

FIGURE 4.10: Base vehicle model in MATLAB/Simulink

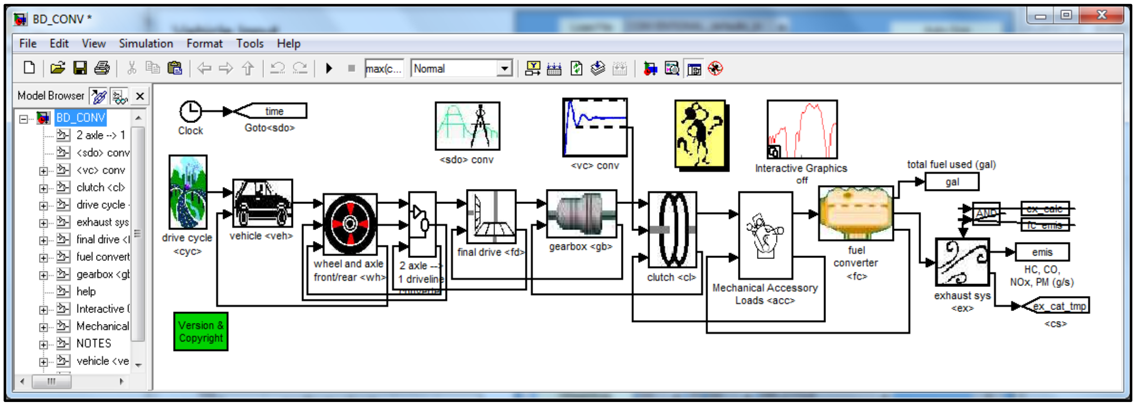

FIGURE 4.11: Vehicle model Block Diagram developed in ADVISOR

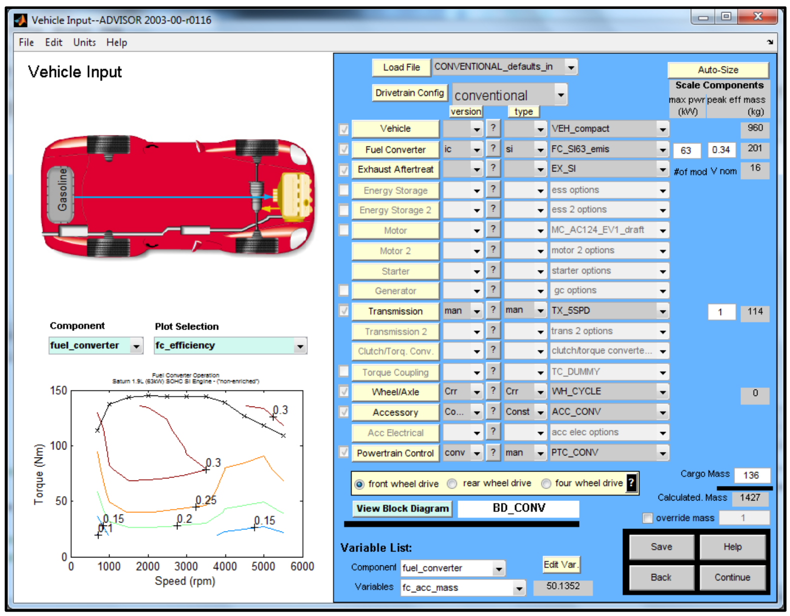

FIGURE 4.12: Vehicle input window in ADVISOR

The parameters of the vehicle in ADVISOR are filled in the input window (see FIGURE 4.12). The vehicle configuration and some other components are selected to be the same with the input in base vehicle model created in MATLAB/Simulink.

The vehicle operation details and parameters throughout the entire drive cycle can be illustrated in figures (see FIGURE 4.13).

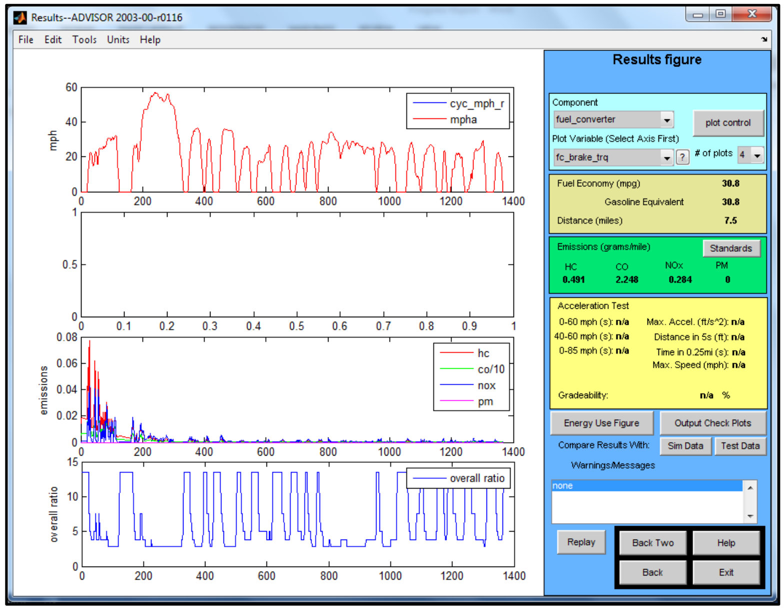

FIGURE 4.13: Result Simulation Window in ADVISOR

4.7 Drive Cycles for vehicle simulation

In this project, first of all, the simulation with UDDS and NYCC road conditions was made, then comparison was made between the results from the base model created in MATLAB/Simulink and ADVISOR. The information of UDDS and NYCC drive cycle is shown in FIGURE 4.14 and FIGURE 4.15.

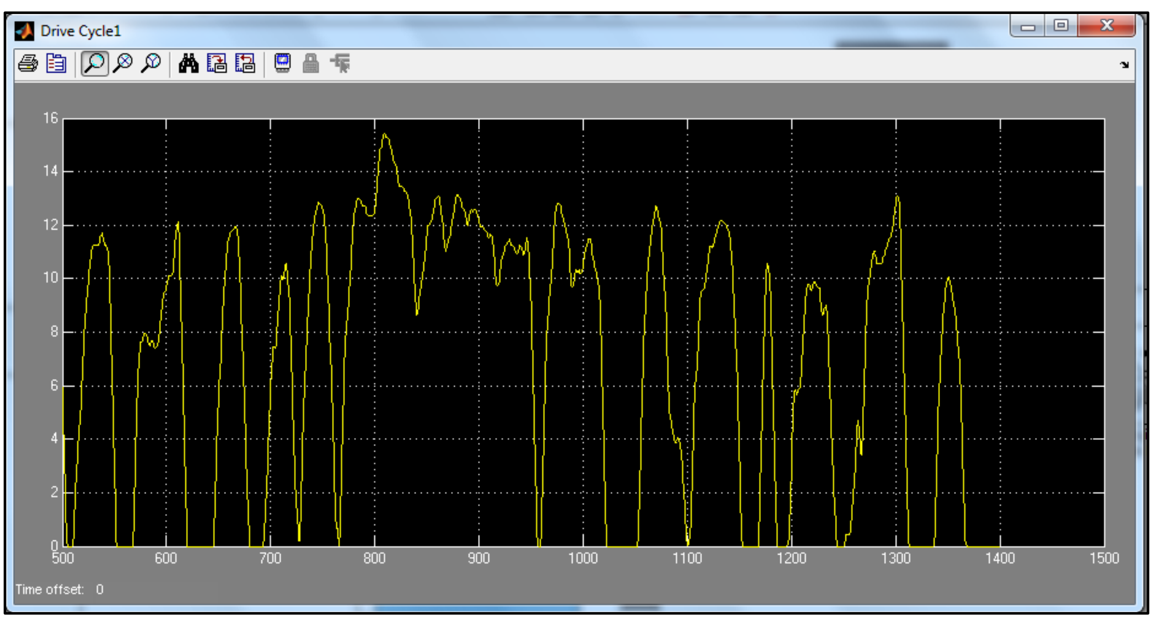

FIGURE 4.14: UDDS drive cycle

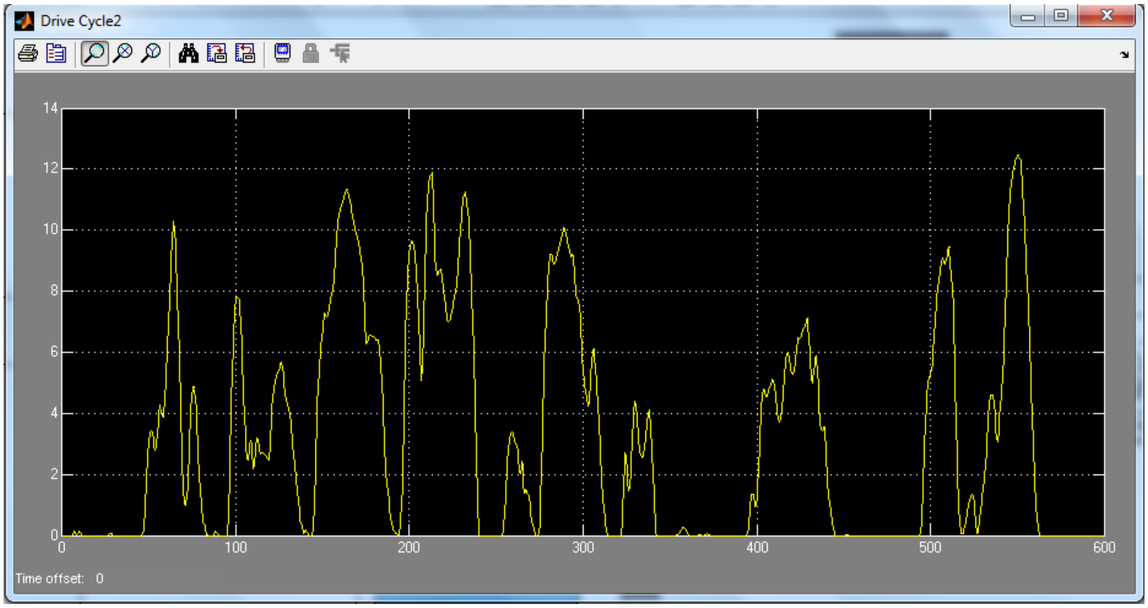

FIGURE 4.15: NYCC drive cycle

4.8 Simulation and validation results

After several trial and errors for improving the validation of base vehicle model, the results of getting percentage error less than 10% was achieved. As shown in TABLE 10, the base vehicle model was compared with ADVISOR model in terms of fuel consumption. Note that the specification of major components of base vehicle model are according to the library provided by ADVISOR.

TABLE 10: Validation of base vehicle model

Base vehicle model vs. ADVISOR				
Drive Cycle/Model	**Base Model**		**ADVISOR**	**Percentage error (%)**
UDDS	Distance (km)	12	12	0
	Fuel (L/100km)	6.92	7.60	8.9
NYCC	Distance (km)	1.90	1.90	0
	Fuel (L/100km)	12.10	13.01	6.9

For the UDDS drive cycle, the percentage error for fuel consumption between base vehicle model and ADVISOR is 8.9%. While the percentage error for fuel consumption in NYCC drive cycle is 6.9%. From the result that had been obtained, it can be concluded that the model created in MATLAB/Simulink is valid but not as detailed as in ADVISOR. The

ADVISOR model has a few more blocks which include more parameters to be considered for fuel economy simulation. In addition, some factors were still ignored during the modelling of base vehicle model, such as fuel temperature (which was set as constant instead of variable), brake temperature, and road elevation. It is recommended in the future research for considering these factors into detail manner to get a better results. All in all, the base vehicle model validation is accepted and will be modified into HEV model in the next section 4.7.

4.9 Modification of base vehicle model

As developed by researcher M. Maharun [7] and M. N. Iman [10], the built base vehicle model was further modified by virtually installing IWM at both of the rear wheels together with the controllers and a battery pack inside the trunk. In addition, the FLC was developed in MATLAB/Simulink by utilizing the fuzzy logic block. This control system will direct the distribution of torque between ICE and IWM based on rules created in fuzzy logic.

The difference between the base vehicle model and HEV model are that the HEV model has additional mass which represents the battery pack, a controller as well as IWM. On the other hands, the model would also improve performance in term of fuel consumption.

4.10 HEV modelling in MATLAB/Simulink

The HEV model in MATLAB/Simulink consisted of 3 additional main blocks. The blocks are the EMS block model, battery pack block model and IWM block model. As for EMS block model, it consisted a fuzzy logic controller inside the block which received several inputs for torque distribution purposes. FIGURE 4.16 shows the overview of HEV model created in MATLAB/Simulink.

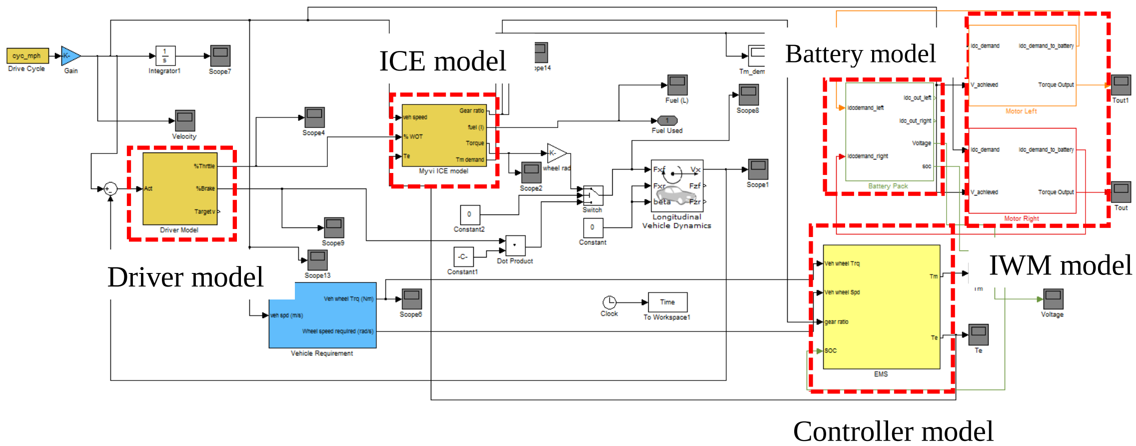

FIGURE 4.16: HEV model

4.10.1 Controller block

The controller block consists of fuzzy logic controller block. The fuzzy controller receives multiple inputs from calculated engine efficiency and battery SOC. The fuzzy controller will process the inputs and rules are to decide torque distribution between ICE and IWM. FIGURE 4.17 illustrates the figure of EMS block model.

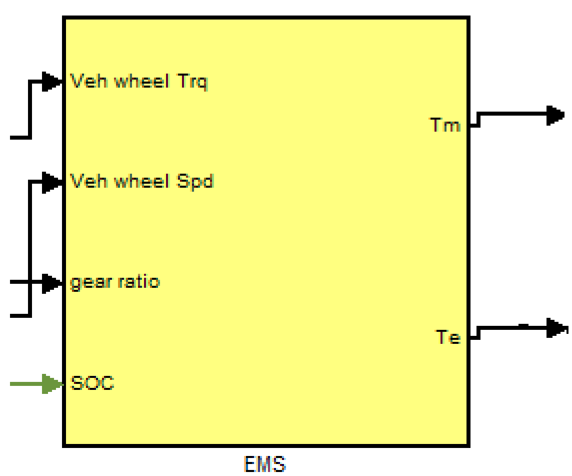

FIGURE 4.17: EMS block model

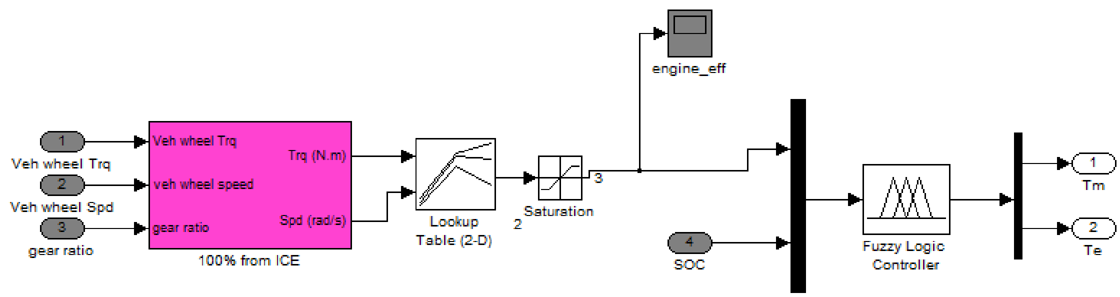

FIGURE 4.18: Inside EMS model

4.10.2 Torque distribution strategy

This section describes the torque control strategy for the distribution between IWM and ICE. The distribution system is managed in such two main rules as in [14].

1. The battery should never drop too low;
2. The major assistant of IWM for vehicle propulsion is in low velocity.

The output from the fuzzy logic controller are the percentage of torque distributed to IWM, T_m, and percentage of torque distributed to ICE, T_e. The input for the EMS model was set in FLC to decide the torque control strategy based on several rules set. The setting for the control is presented in TABLE 11.

TABLE 11: Torque distribution strategy

Motor assist mode	100% Engine mode
Engine efficiency < 0.20	Engine efficiency > 0.20
Weight of Throttle (WOT) > 30%	Weight of Throttle (WOT) < 30%
Achieved velocity < 6 m/s	Achieved velocity > 6 m/s

The rules consists of the command for the electric motor to assist the engine for vehicle propulsion.

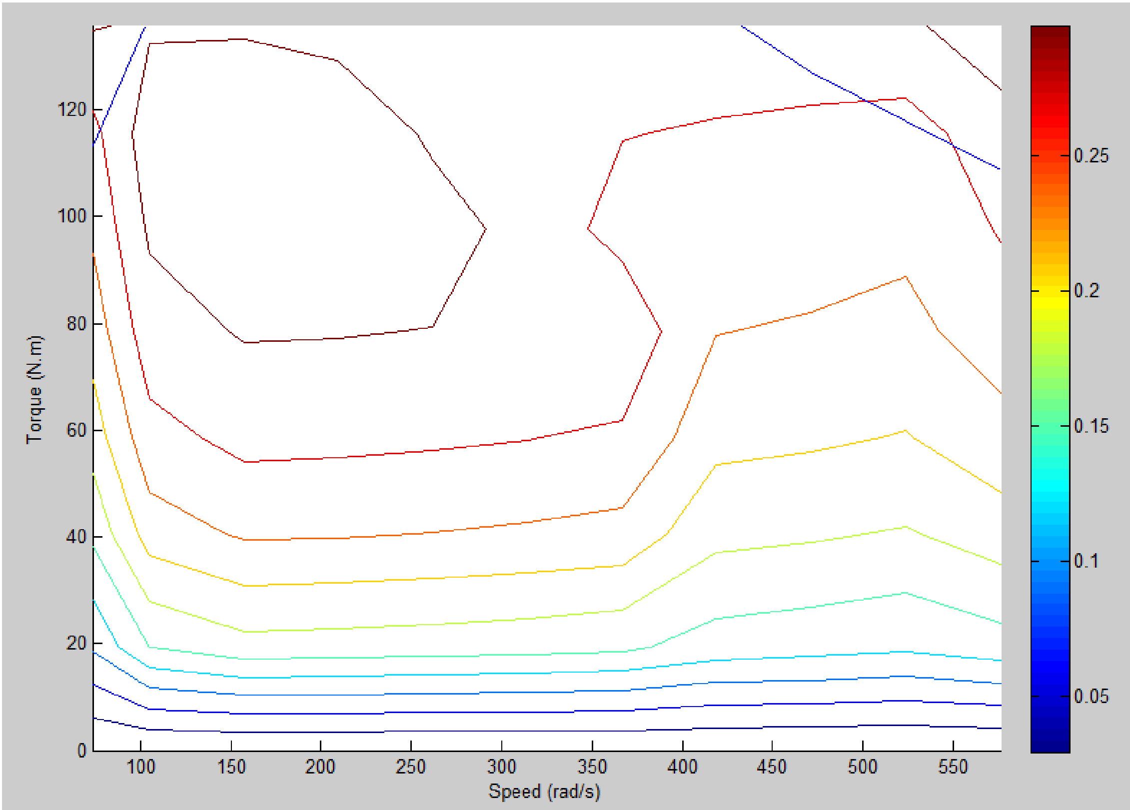

FIGURE 4.19: ICE efficiency

From the figure above, it shows that the maximum efficiency is about 0.25. Efficiency rule was set in order to ensure the engine operates at its maximum efficiency. It is done by utilizing the controller which control the distribution of power between IWM and ICE. The IWM could help to let the engine operate at its most efficient condition to reduce fuel consumption.

4.10.3 Energy Management Strategy (Fuzzy Logic)

Strategy A

The motor assist mode is expressed in FLC, with some membership function values. The requirement will be interpreted in the FLC controller with several rules set to represent the condition. Each value of each input was described and give certain value for the output to satisfy the rules set for torque distribution between ICE and IWM.

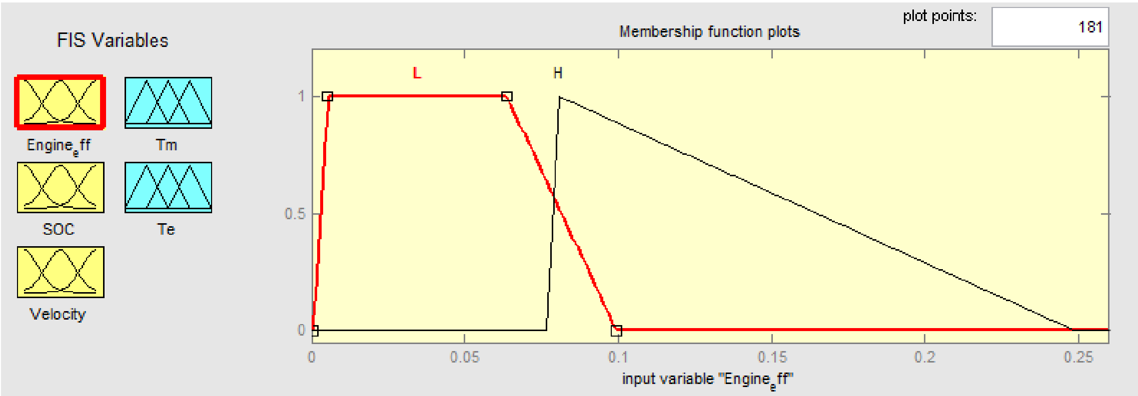

FIGURE 4.20: Engine efficiency input

As shown in FIGURE 4.20, a fuzzy set of ICE efficiency was set which is {L, H} and the domain is [0, 0.25]. IWM will provide major assistant when the efficiency of the engine is between [0, 0.07]. However, the assisting value (y-axis value) is decreasing as the efficiency become higher.

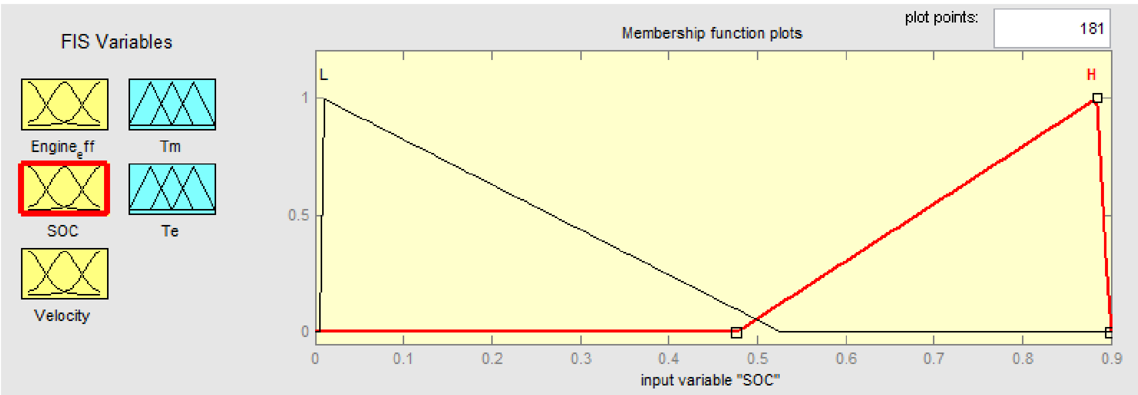

FIGURE 4.21: SOC input

Triangle membership function was utilized to define the value of SOC at any point of time. The SOC is considered higher, H if the range of the value is between [0.5, 0.9]. This domain is likely to be maintained throughout the drive cycle to ensure optimum level of vehicle performance.

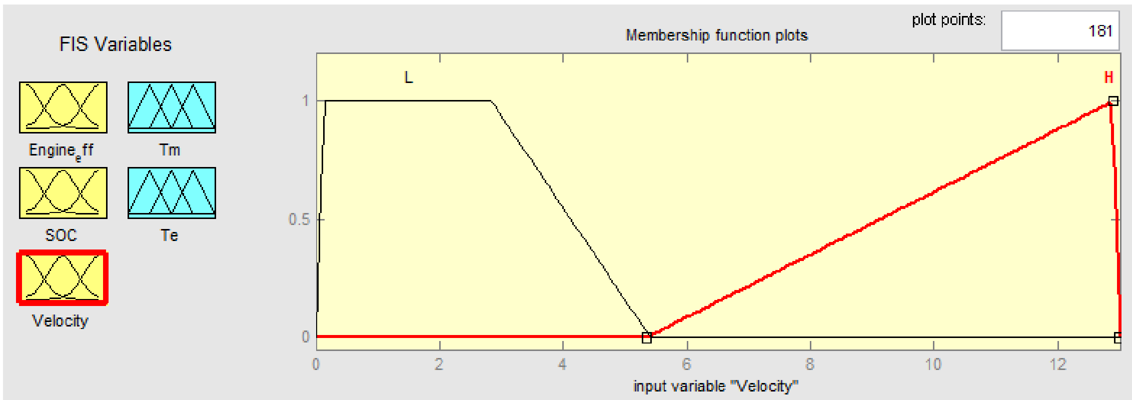

FIGURE 4.22: Velocity input

For the velocity input, strategy was described in such a way that the IWM will provide major assistant when controller detect the speed between 0 to 5 m/s (0 to 18 km/h). When the velocity is above 5 m/s, the torque will be distributed in increasing manner to the ICE. This is to illustrate that IWM will assist when vehicle is at low speed.

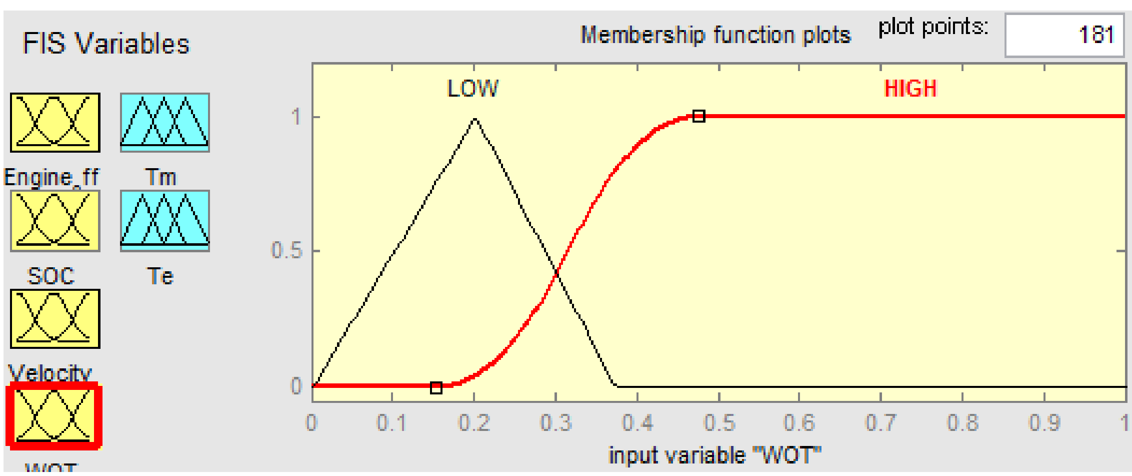

FIGURE 4.23: WOT input

FIGURE 4.23 presents the strategy used in fuzzy logic for WOT. It was set according to the amount of throttle demand by the driver. It was set in such a way that the IWM will assist the ICE for vehicle propulsion when it reaches 30% throttle.

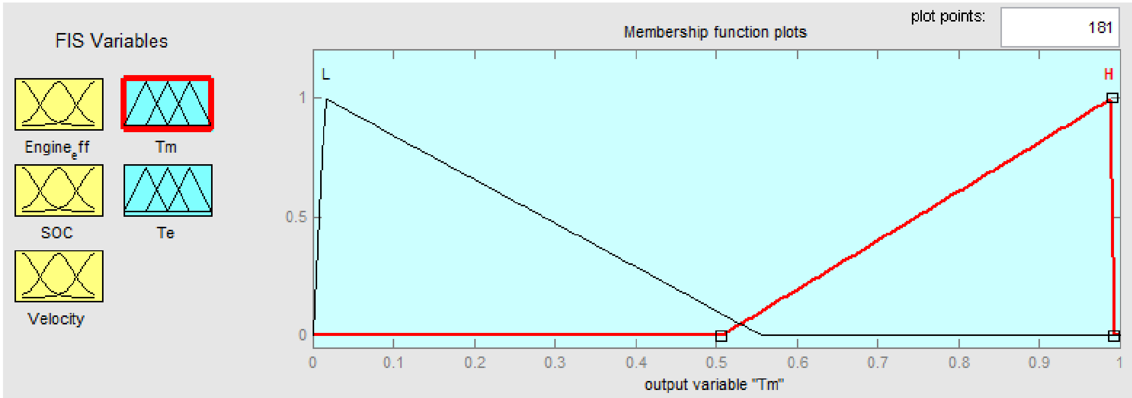

FIGURE 4.24: Torque motor output

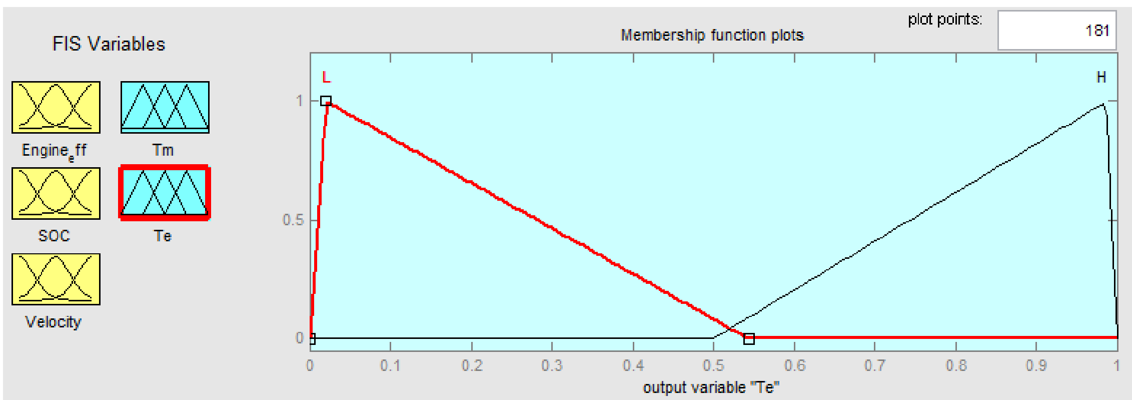

FIGURE 4.25: Torque engine output

For the output, the percentage of torque distribution by the FLC to the ICE and IWM was based on the rules set for the inputs. The value for both output is limited to 1 which indicates the value of 100%. The membership function for IWM torque and ICE torque is shown in FIGURE 4.24 and FIGURE 4.25.

4.10.4 Battery pack model

A set of lead-acid battery is the second energy provider for HEV model in this project. This type of battery is used due to cost constraint for the real modification of HEV model from base vehicle model. There are 2 units of lead acid battery which produce 24 Volt. The function of this block model is actually to calculate the current SOC for the battery and output current that provided by the battery. The lead acid battery model in ADVISOR which has the equivalent specifications was utilized as the battery model. The outputs of this block model are SOC, current and voltage. FIGURE 4.26 shows the overview of battery pack model.

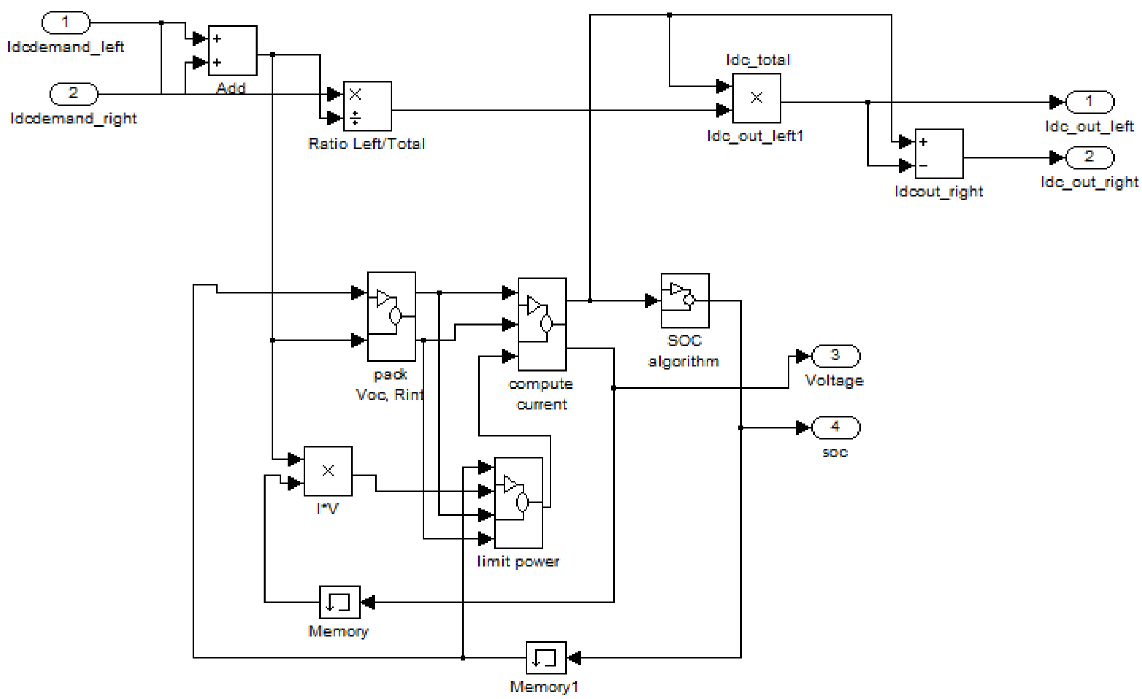

FIGURE 4.26: Battery pack model

4.10.5 IWM model

There are two (2) IWM models installed into base vehicle model to become HEV model. Both of them are retrofitted into the rear wheels. In this project, the design of IWM has been calculated, thus the value used for the IWM model was corresponding to the calculated value. These motor were independently controllable based on the required output. The following equation represents the torque output from the IWM;

$$T = K_t I_{demand} \quad (4.7)$$

The demand of current and torque at any point of time was controlled by the fuzzy logic controller (EMS block model) based on the conditions set. Both IWMs were attached to the wheel, the rotational speed of the wheel was assumed to be similar as the IWM rotational speed. The rotational speed input which corresponded from the torque constant is provided from the look-up table. The motor torque constant is calculated by dividing matrix of maximum torque over maximum current. FIGURE 4.27 shows the input setting for the look-up table.

$$K_t = \frac{mc\_\max\_trq}{mc\_\max\_crrnt} \tag{4.8}$$

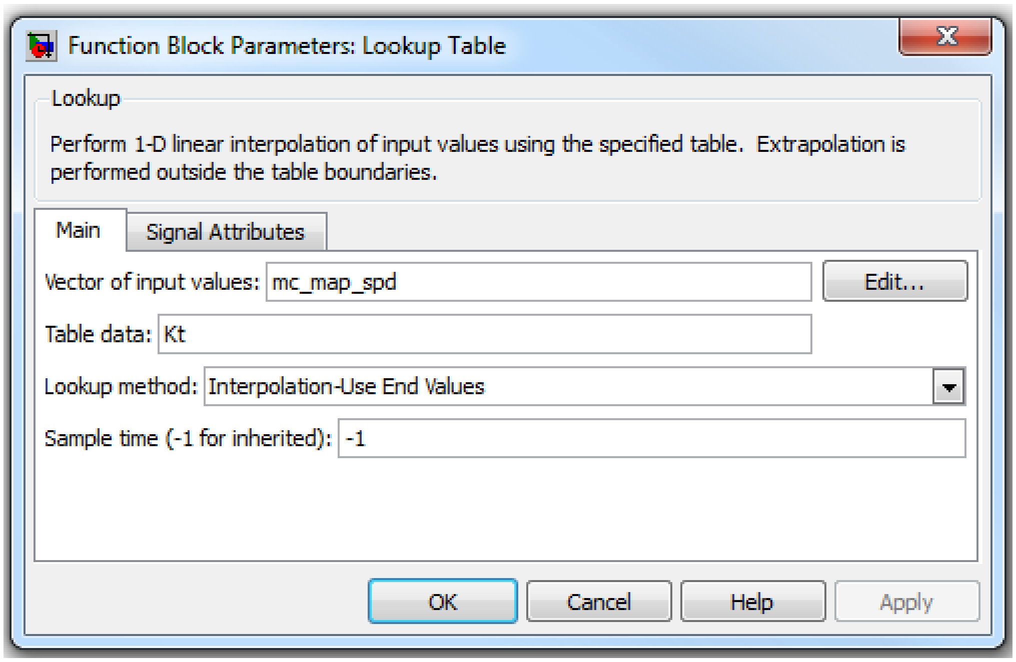

FIGURE 4.27: Motor toque constant look-up table

In order to calculate current SOC of the battery, the current demand to battery set need to be calculated. The current demand is another output from the IWM block model. It is calculated by dividing the current demand from the controller with the motor thermal efficiency. The motor thermal efficiency is obtained from 2D look-up table which contains the inputs of speed and torque demand. 2D look-up table window is shown in FIGURE 4.28.

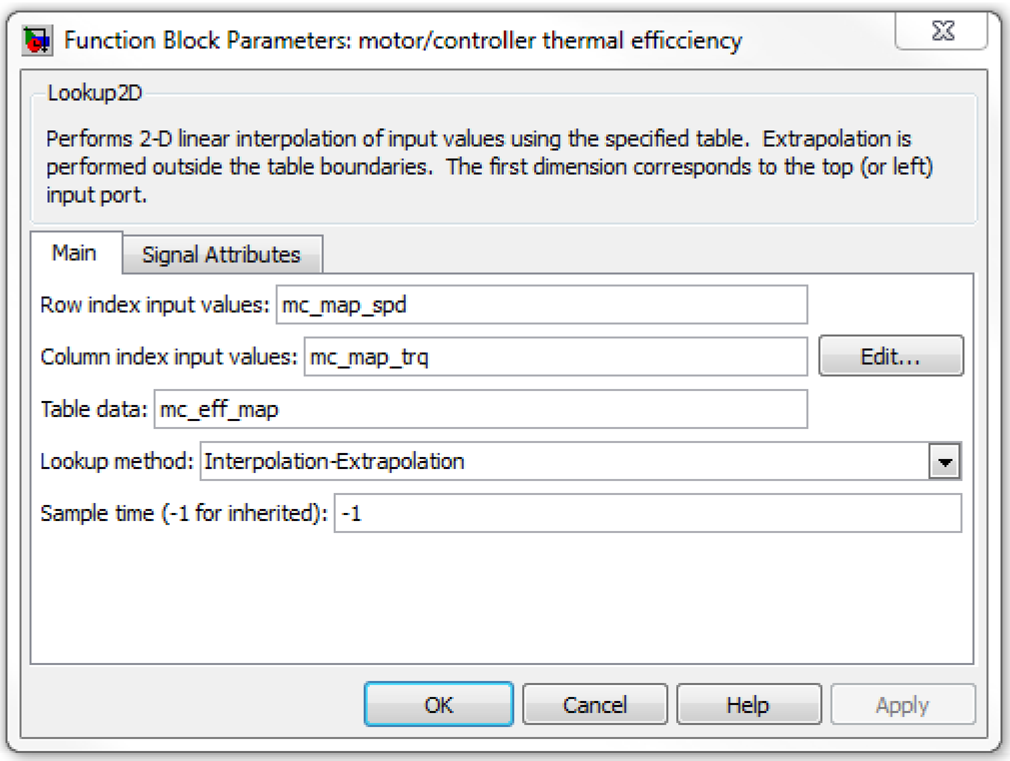

FIGURE 4.28: Look-up table for motor thermal efficiency

FIGURE 4.29 shows the configuration of the components inside IWM block model.

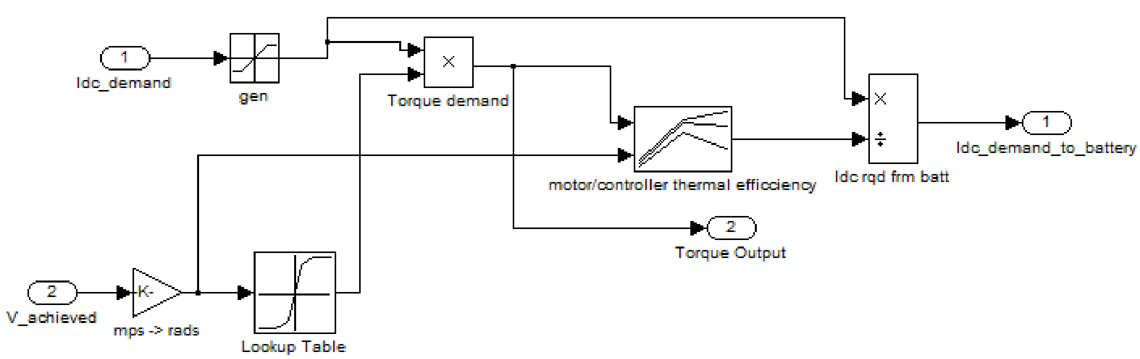

FIGURE 4.29: IWM block model

4.10.6 ICE model for HEV

The configuration of ICE model for HEV is slightly different compared to the base vehicle model. As mentioned, the torque distribution between ICE and IWM was done by controller block set. One of the output of the controller model is the percentage of torque distributed to the ICE, known as T_e. T_e is added as the input for the ICE model in HEV which will then be used to compute the amount of torque used by the engine as well as fuel economy. However, the engine specifications remain the same as in base vehicle model. The configuration of ICE model for HEV is shown in FIGURE 4.30.

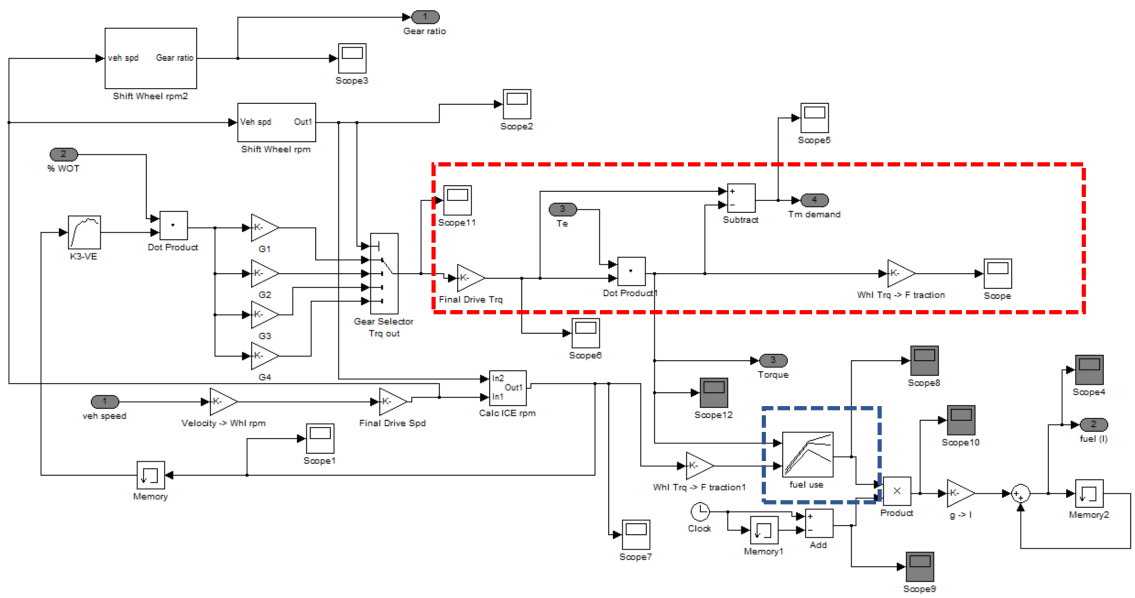

FIGURE 4.30: ICE model details

As shown in red dashed, the amount of torque distributed to the IWM is the product of total torque and percentage of T_e coming from the controller block set. The total torque required by the vehicle is the combination of torque motor and torque engine.

$$Total\ torque\ required = Torque\ motor + Torque\ engine \qquad (4.8)$$

$$Torque\ motor = T_e \times Total\ torque\ required \qquad (4.9)$$

The fuel consumption is calculated by getting the amount of torque distributed to the engine. The final torque produced from the ICE model was interpolated from 2D look-up table to calculate the fuel consumption by the engine (as shown in blue dashed).

CHAPTER 5

SIMULATION RESULTS

After the HEV model was completely built by modification from base vehicle model, it was then simulated to obtain results. The analysis was carried out by comparing the performance of HEV model and the base vehicle model. The effect of installing IWM together with a controller and battery pack model into the base vehicle model brought a significant improvement towards fuel consumption. The simulation was ran for both drive cycles, UDDS and NYCC. The simulation results were then compared with base vehicle model for fuel economy analysis.

5.1 Torque Distribution

As mentioned before in Chapter 4 Section 4.7.1, a controller was installed inside the HEV model to control the torque distribution between IWM and ICE. Unlike in base vehicle model, the total torque required by the vehicle to propel the wheel is solely supported by ICE, means there is no external assistance for energy provider. The result of torque distribution of HEV model for both drive cycles are shown in FIGURE 5.1 and FIGURE 5.2.

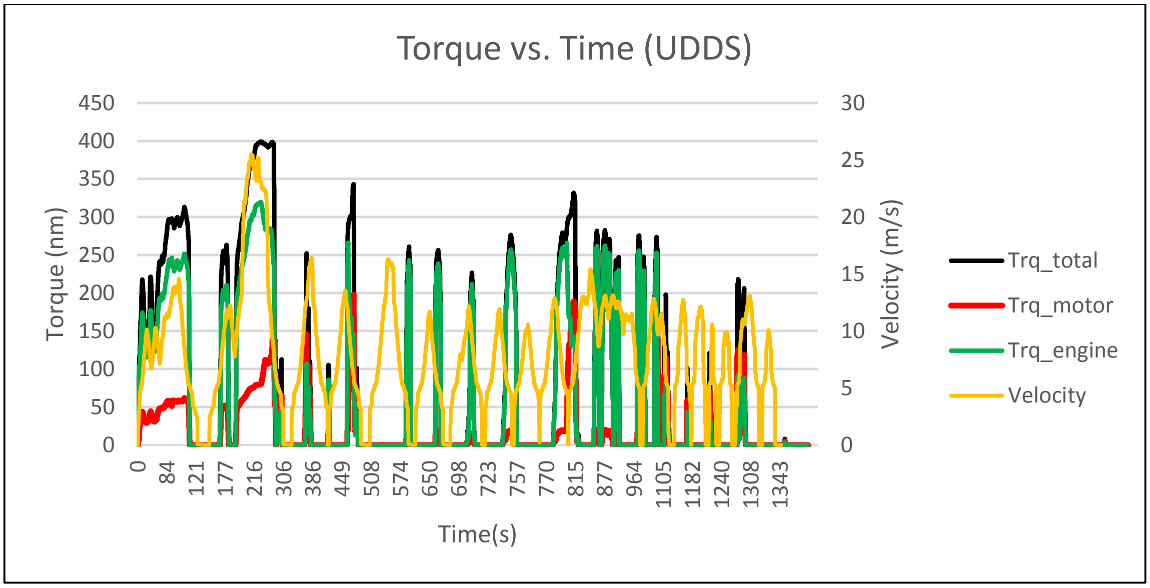

FIGURE 5.1: Torque distribution in HEV model (UDDS)

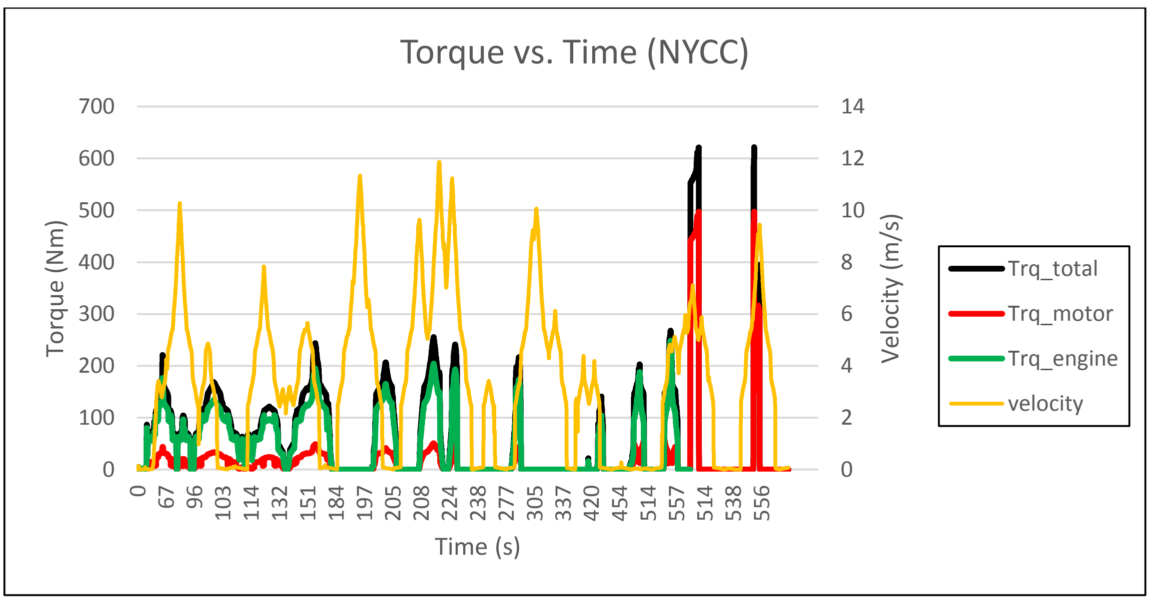

FIGURE 5.2: Torque distribution for HEV model (NYCC)

Based on the rules set in controller, amount of torque is distributed to IWM to assist the ICE for vehicle propulsion. The distribution of torque was determined by strategy set in fuzzy logic control and it also depends on the velocity of the vehicle set in the controller. As shown in FIGURE 5.2, the amount of assistance from electric motor is high when the velocity is increasing. This shows that at high velocity, more torque is needed to propel the wheels, thus more contribution needed from electric motor to assist ICE.

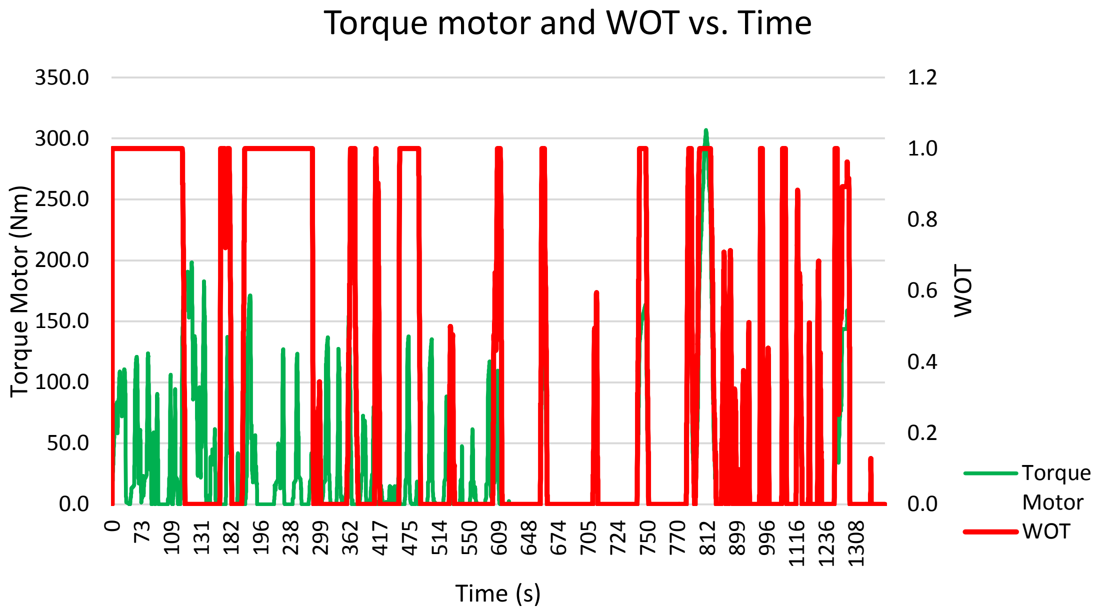

FIGURE 5.3: Torque distribution to motor according to WOT

The energy management system in HEV also includes the percentage of throttle from the driver as one of the inputs. Based on FIGURE 5.3, the Weight of Throttle (WOT) maintained at high value which is 1, between the early stage of drive cycle, 0 to 300s. It can be observed that the amount of torque distributed to electric motor is high during this interval. This pattern shows the behavior of the rules set from fuzzy logic controller whereby when the WOT achieve more than 0.30, motor assisting mode is activated.

5.2 SOC Comparison

For the result of the SOC of the battery, the simulation of HEV model managed to maintain a pattern of the ADVISOR result as what can be seen in FIGURE 5.4 and FIGURE 5.5 for both drive cycles respectively. However, due to the simple battery modelling in MATLAB/Simulink, the SOC obtained was not as accurate as the ADVISOR result but the pattern was still can be maintained which it was not dropped too low. It can be concluded that the results for SOC behavior throughout the drive cycle in HEV model was validated with the ADVISOR results.

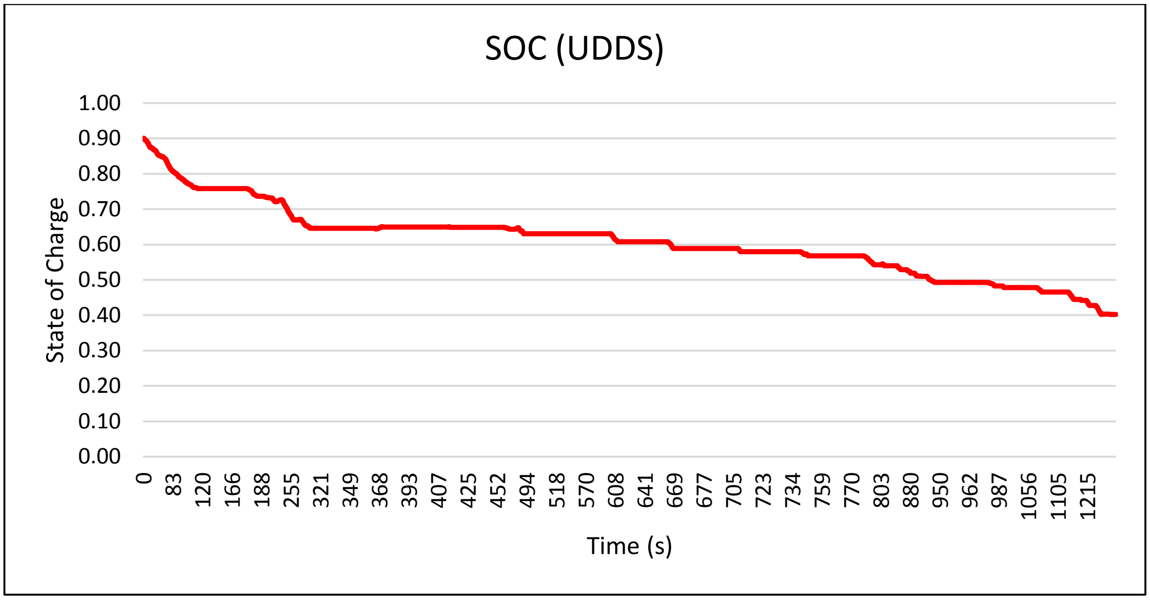

FIGURE 5.4: SOC in battery pack (UDDS)

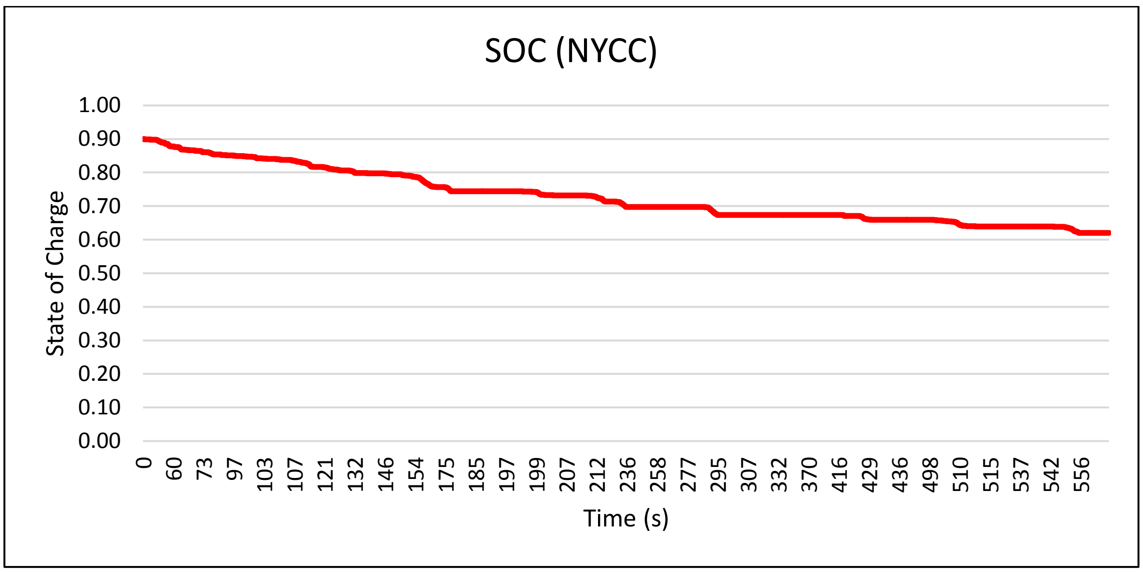

FIGURE 5.5: SOC in battery pack (NYCC)

5.3 Fuel Economy comparison

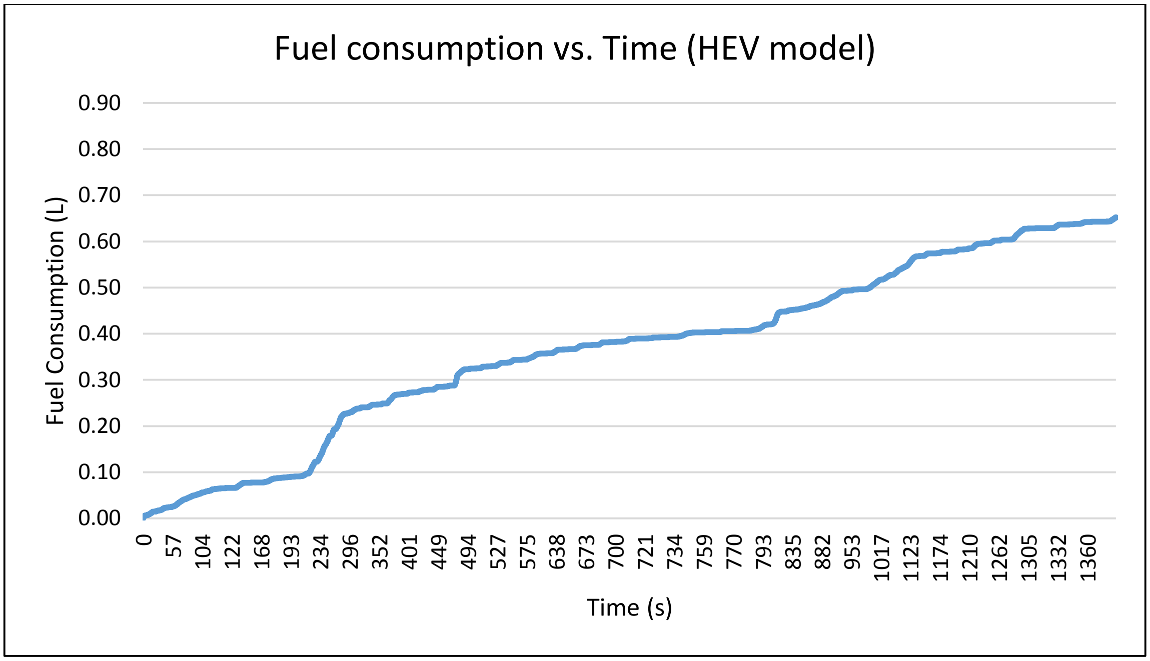

FIGURE 5.6: Fuel consumption for HEV model (UDDS)

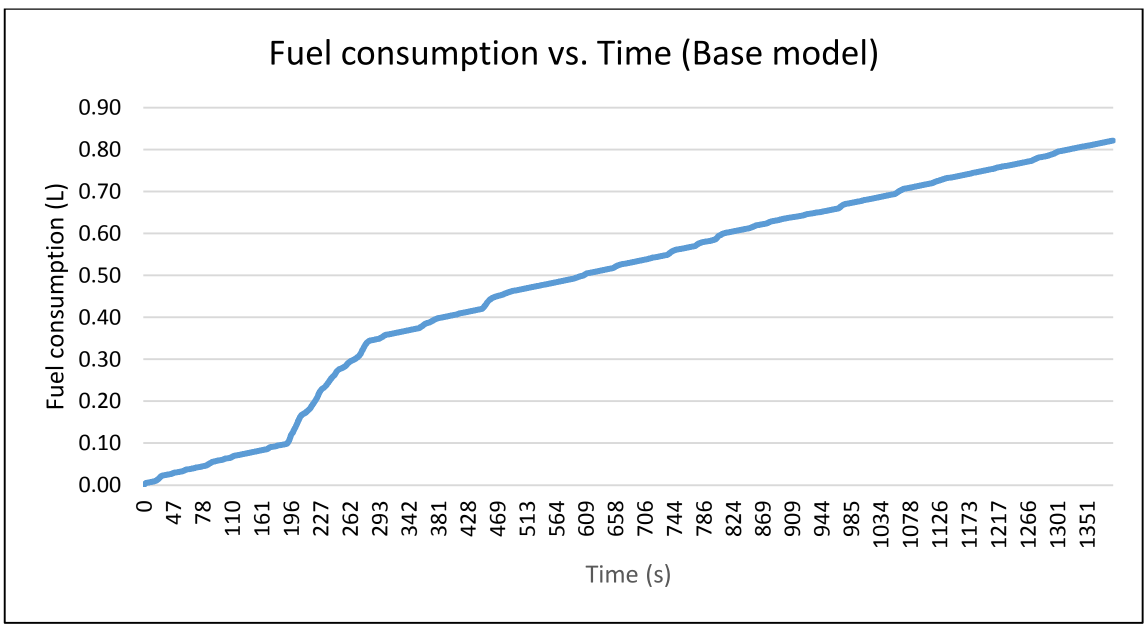

FIGURE 5.7: Fuel consumption for base vehicle model (UDDS)

From the figures above (FIGURE 5.6 and FIGURE 5.7), due to amount of reduced torque received by the engine, the fuel consumption for HEV model has also decreased. Along 12 km journey, HEV model requires only 5.42 L/100km compared to base vehicle model which consumed 6.92 L/100km. The percentage of improvement for fuel economy is 21.64%.

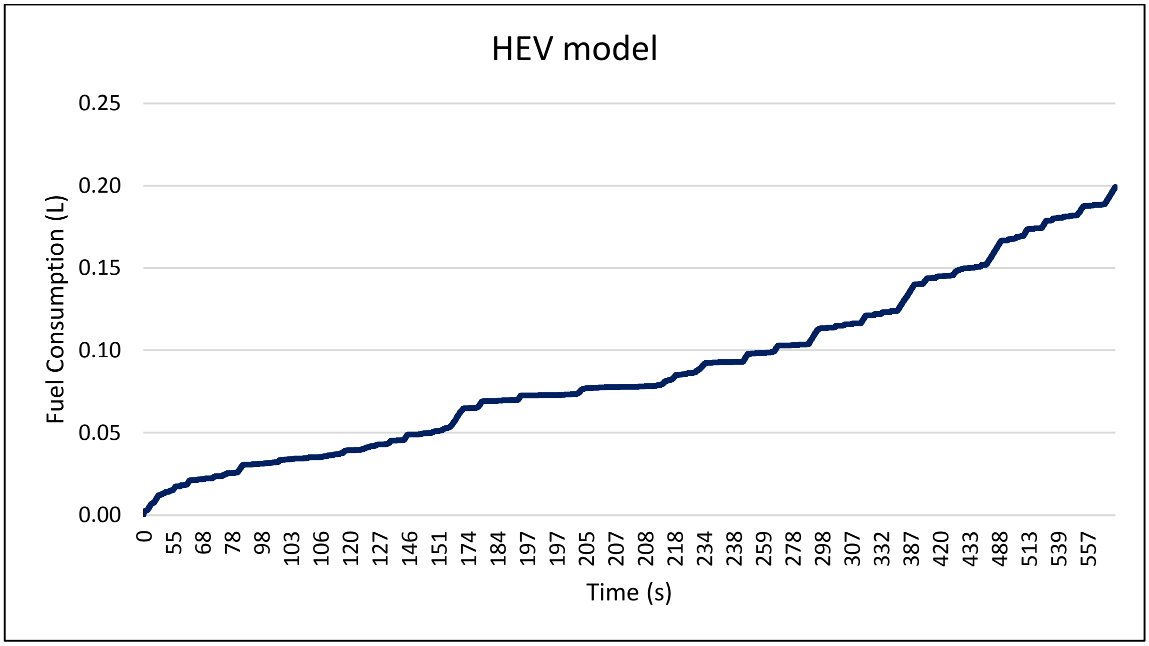

FIGURE 5.8: Fuel consumption for HEV model (NYCC)

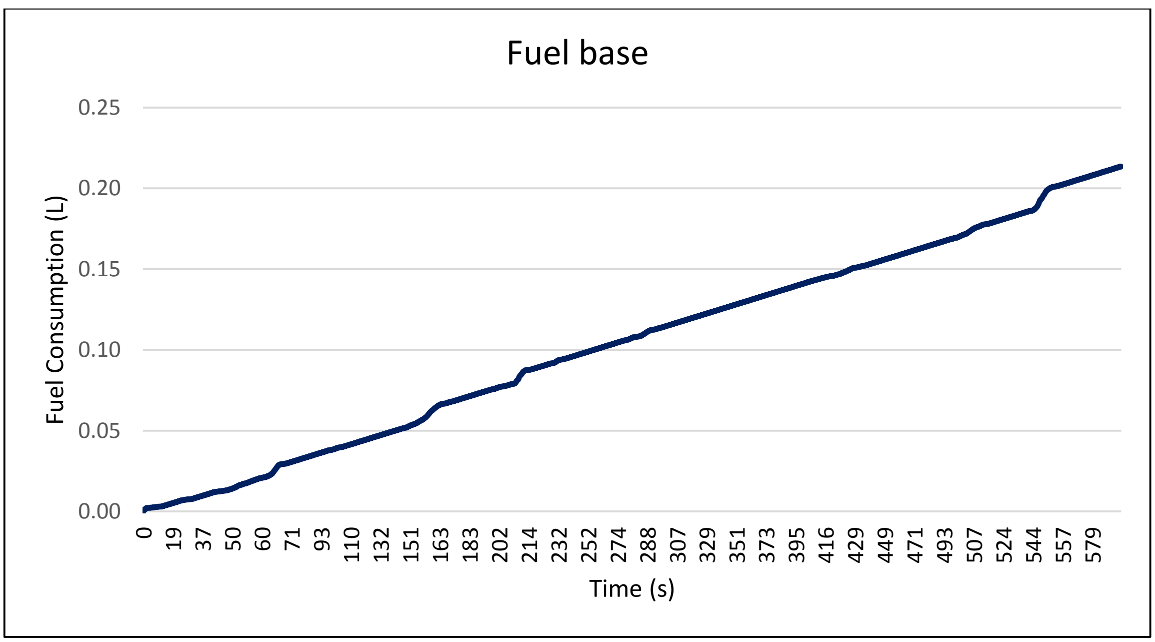

FIGURE 5.9: Fuel consumption for base vehicle model (NYCC)

Meanwhile, for NYCC drive cycle which covered a distance of 1.9km, the fuel consumed by HEV model is about 12.63 L/100km compared to base vehicle model which consumed more fuel, 15.79 L/100km. This reduction of fuel which is about 23.37% indicates a very significant improvement and at the same time reduced exhaust emission correspondingly.

TABLE 12: Simulation results of HEV model

Drive Cycle	**Base vehicle model**	**HEV model**		
	Fuel used (L/100km)	***Strategy***	***Fuel used (L/100km)***	***Fuel Efficiency (%)***
UDDS	6.92	Strategy A	5.42	21.64
		Strategy B	5.75	16.87
NYCC	15.79	Strategy A	12.1	23.37
		Strategy B	12.63	20.01

TABLE 12 summarized the simulation results for comparing the HEV model and base vehicle model in terms of fuel economy. The proposed Strategy A shows higher fuel efficiency which is 21.64% for UDDS drive cycle and 23.37% for NYCC drive cycle as compared to Strategy B. This was due to the different rules set in fuzzy logic for the controller which produce different pattern of torque distribution between ICE and IWM. The results show that the torque split strategy optimizes the efficiency of the engine as well as the performance.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Energy management strategy is very important to overcome the adverse effect of high fuel consumption in Hybrid Electric Vehicle (HEV). Therefore, the project with the title of "Fuzzy Logic Control of Energy Management System for Hybrid Electric Vehicle" is proposed to be implemented due to its importance in energy management strategy. The method of using fuzzy logic should be able to distribute the optimum amount of torque and power to both Internal Combustion Engine (ICE) and electric motor to propel the vehicle. Hopefully, this approach also help to reduce environmental pollution which mostly contributed by the exhaust emission.

In general, the target for this Final Year Project 1 is to be able to complete and calculate all parameters that need to be prepared for the MATLAB/Simulink HEV modelling. This target has been achieved after some equipment sizing had been analyzed; battery sizing and IWM sizing. These calculated results will lead to a better understanding on the limit output by each of the components in HEV. For the FYP 2, the aim was to develop a base vehicle model before modifying it to become HEV model. The base vehicle model created in MATLAB Simulink was compared with ADVISOR and the result showed reasonable output which will then became the benchmark to evaluate the performance of HEV model. Based on the results obtained from HEV model, the EMS simulation shows that the HEV model consumed less fuel to 23% in comparison to the base model.

6.2 Recommendation

To improve study for future work, more research study on HEV modelling by using MATLAB/Simulink can be done in detail manner. For example, there are some collections of research paper done which are related to each other. More intensive study about the topic should be done to acquire as much knowledge as can in order to have better understanding especially on HEV modelling. It is believed that the base model could produce a better results of the modelling of the vehicle in MATLAB/Simulink if more parameters were included. For instance, the modelling of ICE in this project was simplified with several assumptions due to time constraint. The temperature of fuel in fuel converter was set to be constant instead of becoming variable as in ADVISOR. This would lead to error in terms of fuel used. Detail modelling of the vehicle would perhaps overcome the problem and reduce the percentage error in terms of performance. Other than that, the gearbox model should be modelled as details as what can be found in ADVISOR. This is to ensure results obtained had taken into accounts all the parameters (effect of inertia, torque loss etc) in the models that would influence the result of final torque.

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APPENDIX A

PERODUA MYVI TECHNICAL SPECIFICATIONS

10/29/2014 Myvi - Specifications | Perodua

PERODUA

Myvi XT Specifications

Introduction Exterior Interior Practicality Performance Safety Colour Other variant

Everything you need to know about the specifications.

Dimension & Weight Engine Chassis Exterior Interior Comfort Safety & Security Accessories View All

Technical Specifications

Myvi		GX1	EZ1
Dimension & Weight			
Overall length / width / height	mm	3690 / 1665 / 1545	
Interior length / width / height	mm	1850 / 1380 / 1265	
Wheelbase	mm	2440	
Track front / rear	mm	1455 / 1465	
Minimum road clearance	mm	160	
Kerb weight	kg	950	960
Seating capacity		5	
Min. turning radius	m	4.7	
Engine			
Transmission	Manual - MT, Automatic AT	5MT	4AT
Engine type		K3-VE	
Valve mechanism		DOHC, 16V with DVVT	
Total displacement	cc	1298	
Bore x stroke	mm	72.0 x 79.7	
No. of cylinders		4	

Compression ratio		10.0 : 1	
Max. output (DIN)	kW/rpm	67 / 6000	
Max. torque (DIN)	Nm/rpm	117 /4400	
Fuel System		Electronic fuel injection (EFI)	
Fuel tank capacity	litres	40	
Chassis			
Steering type		Rack and pinion	
Main brakes			
Front		Disc brake with booster	
Rear		Drums (leading & trailing)	
Parking brake		Mechanically operating on rear wheels	
Suspension			
Front		MacPherson strut with coil spring	
Rear		Torsion beam with coil spring	
Tyres		175 / 65 R14	
Spare tyres		Temp. tyre T115 / 70 D14	
Exterior			
Headlamps		Projector type	
Front fog lamps		⊖	⊖
Electric side mirrors		With side turn signals	With side turn signals
Windshield		Green (laminated)	
Outside door handles		Body colour	
Disc wheels		5-spoke 14" alloy rims	
Rear spoiler		⊖	⊖
Rear combination lamps		LED type	
Rear reflector		✓	
Interior			
Instrument panel		Two-tone	
Optitron meter combination		Amber illumination	Amber illumination
Centre cluster		Material colour	Material colour
Shift lever & parking brake			
Floor shift with centre lever		✓	⊖
Instrument panel shift with centre lever		⊖	✓
Shift lock release button		⊖	✓
Seat cover material		Fabric	Fabric
Rear seats		60:40 split flat fold	
Door trims		Full trim, two-tone fabric	

Door armrests with door pull handles	Silver painted	Silver painted
Inside door handles	Material colour	Material colour
Seat back pockets	✓ (driver & passenger)	✓ (driver & passenger)
Cup/bottle holders	4 front, 2 rear	
Sun visors	With holder (driver's side) and vanity mirror (driver's & passenger's side)	
Comfort		
Audio (flush type) with 4 speakers	Radio CD Player with MP3/WMA, USB & Bluetooth	Radio CD Player with MP3/WMA, USB & Bluetooth
Multi-info display	✓	
Power steering	✓ (electric power steering)	
Tilt steering wheel	✓	
Power windows	✓	
Adjustable seat belt anchors	✓	
Seat height adjuster	–	–
Stabiliser bar	✓ (FR only)	
Shift position indicator	–	✓
Meter illumination control	✓	
Reverse sensor	✓	
Safety & Security		
Dual SRS airbags	Driver & passenger	
ABS with EBD & BA	–	–
Anti-theft device	Alarm & immobiliser	
Driver seat belt pre-tensioner	✓	
Rear seat belts	3-point ELR	
ISOFIX child restraint system	✓	
Accessories		
Carpet mats	✓	
Luggage tray	✓	
Tool kit bag	✓	
Safety triangle	✓	
Registration plate holders	✓	

Notes :

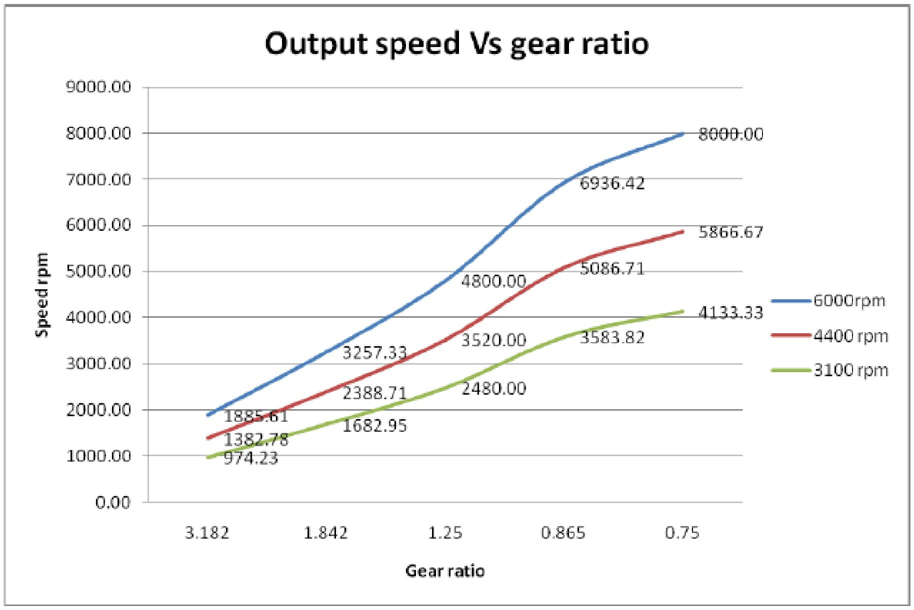
✓ With, – Without

Specifications are subject to change without prior notice.

For further details, visit your nearest Perodua Showroom.

APPENDIX B

PERODUA MYVI GEAR RATIO DETAILS



APPENDIX C

ENGINE EFFICIENCY CALCULATION

```
for i = 1:8
for j = 1:11
DD(i,j) = fc_map_spd(j).*fc_map_trq(i);
j=j+1;
end
i = i+1;
end

CC=DD./(fc_fuel_map');
Thermal_eff2=CC./(44.4*1000);

fc_map_spd2 = [0 fc_map_spd];
fc_max_trq2 = [0 fc_max_trq];

figure;
hold on;
contour(fc_map_spd,fc_map_trq,Thermal_eff2,10);
colorbar;
plot(fc_map_spd2,fc_max_trq2);
xlabel('speed (rad/s)');
ylabel('Torque (N.m)');
figure;
surf(fc_map_spd,fc_map_trq,Thermal_eff2);
shading interp;
```