INTELLIGENT ENERGY MANAGEMENT SYSTEM OF SERIES HYBRID ELECTRIC VEHICLE (HEV)

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Faculty of Electrical & Electronics Engineering

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DECLARATION

I hereby declare that I have checked this Final Report and in my opinion, this Final Report is adequate in terms of scope and quality for the closure of research grant RDU160388.

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STUDENT'S DECLARATION

I hereby declare that the work in this Final Report is based on my original work except for quotations and citations which have been duly acknowledged.

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Date : 16th DECEMBER 2018

DEDICATIONS

To my family, who have always supported me in all of my endeavours.

ACKNOWLEDGEMENT

Apart from the efforts of me, the success of any project depends largely on the encouragement and guidelines of many others. I take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this project. I would like to show my greatest appreciation to Dr Mohd Rusllim Mohamed. I can't say thank you enough for his tremendous support and help. I feel motivated and encouraged every time I attend his meeting. Without his encouragement and guidance this project would not have materialized. For the useful comments, remarks and engagement through the learning process of this Final Report, I am so grateful to have him as my supervisor. The guidance and support received from all the members who contributed and who are contributing to this project, was vital for the success of the project. I am grateful for their constant support and help.

ABSTRACT

Regardless of chosen/preferred configurations, energy management system has become a vital functionality for hybrid electric vehicles (HEVs) to operate at an optimum or quasi-optimum to conserve energy with no impact on system performance. This study presents a design and testing through software and hardware simulation of a fuzzy logic energy management system for series hybrid electric vehicle. Fuzzy logic rule-based controller is used to manage the propulsion and power split between the engine, generator and energy storage depending on the vehicle energy demand. The system is capable to demonstrate the performance of a series hybrid electric vehicle under difference condition of operation with respect to speed and state of charge (SOC) for the battery pack.

ABSTRAK

Tanpa mengira konfigurasi dipilih / pilihan, sistem pengurusan tenaga telah menjadi satu fungsi penting untuk kenderaan elektrik hibrid (HEVs) untuk beroperasi pada optimum atau separa-optimum untuk menjimatkan tenaga dengan tidak memberi kesan kepada prestasi sistem. Kajian ini membentangkan reka bentuk dan ujian melalui perisian simulasi dan perkakasan logik sistem pengurusan tenaga kabur untuk siri hibrid kenderaan elektrik. Fuzzy logic controller berasaskan peraturan digunakan untuk mengurus dan kuasa pendorongan perpecahan antara enjin, generator dan penyimpanan tenaga bergantung kepada permintaan tenaga kenderaan. Sistem ini mampu untuk menunjukkan prestasi siri hibrid kenderaan elektrik dalam keadaan perbezaan kuasa berkenaan dengan kelajuan dan keadaan caj (SOC) bagi pek bateri.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HEV	Hybrid electric vehicle
FLC	Fuzzy logic controller
SOC	State of charge
ITS	Intelligent transport system
GPS	Global positioning system
PMSM	Permanent magnet synchronous motor
BLDC	Brushless dc motor
AC	Alternating current
DC	Direct current
ICE	Internal combustion system
EMS	Energy management system
DOD	Depth of discharge
RFB	Redox flow batteries
FC	Fuel cell
NiMH	Nickel metal hydride

LIST OF SYMBOL

P_o	demand power
n_T	Transmission efficiency
m_a	vehicle mass
g	Acceleration gravity
f_r	rolling coefficient
A	Frontal area
Δ	Rotating mass coefficient
A	slope angle

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF PROJECT

New millennium brings changes to the world transportation. Pollution, oil shortage, world global warming issue brings to the emerging of electric vehicles and hybrid electric vehicles. The hybrid had been sought as the most comprising solution to the energy crisis and urban pollution [16, 17].A hybrid electric vehicle is the combination of convention vehicle with electric propulsion system. The internal combustion engine attached with the electric power train to perform a better fuel consumption performance. There are many types of HEVs in the market currently. Series hybrid, parallel, series parallel, plug in hybrid and also fully electrify vehicles. Different hybrid model presented different driveway and operation system.

The first battery powered electric vehicle (EV) was actually a tricycle. The inventor of this EV was Thomas davenport in 1834. The vehicle running over the 100km/h was namely ‘Jamais Contente' (Never Satisfied), which was driven by Camille Jenatzy in 1899. But, the first electric vehicle that had commercially launched electric vehicle was in 1897 by Electric Carriage and Wagon Company of Philadelphia. They built it as New York City taxi, the first taxi to be fuel by electricity. But still it was not much impressive with the speed limitation at 32km/h due to the lacking of transistor based technology and limitation in research and development. Compare to nowadays, the technologies has been tremendously developed Tesla Model S from Tesla motor this June 2012 with the speed up to 210 km/h.

Parallel electric vehicle has an internal combustion engine that works in conjunction with electric motor range from 5kW to 25kW, to provide sufficient torque to the power train system in the vehicles. The engine also uses to charge back the battery pack during slow driving such as zero acceleration.For plug-in function, any types of hybrid car can be charge by external supply for example usually a normal electric wall socket outlet.

Mechanically, series HEV use the engine to create electricity for running the car. Then fuel use up to recharge back the battery, there is no direct contact between the generators to the engine. Series HEV has generator and parallel don't. For parallel HEV, electric motor and the engine are set to be parallel to run the vehicle.

Recently, many researches had been done to improve the energy management for both parties. A few methods were proposed to manage the power split for the HEVs wisely. Rule- based control, pattern recognition control, dynamic programming and two scale dynamic programming are the four categorize that being used nowadays. Rule based control is the most basic controller to be use in this case, one of the examples is Fuzzy Logic management system. Sugeno and Mandani method are amongst of the famous FLC to be adapted to the system.

1.2 PROBLEM STATEMENT

The main issue for electric vehicle and hybrid type vehicle is the efficiency of battery while driving and charging mode. The power split for the driving and charging mode were the main problem to be tackle with in HEVs application.

Fuzzy logic controller had been used as the energy management system in order to deal with the inequality and complexities decision for the SHEV. Below are few problem statements listed for further investigation:

1. Electric vehicle major problem in less efficient battery usage while driving and charging mode.

2. The optimum solution to manage the power split for the driving and charging mode of HEV.

3. How does the Mandani fuzzy method in solving the inequality and complexities decision for a series hybrid electric vehicle?

4. Does the output of the experiment shows the positive outcome when the Mandani fuzzy logic controls is apply and are advisable to be applying in series hybrid electric vehicle.

1.3 OBJECTIVES

The aim of this project is to propose a suitable design simulation of energy management system for series hybrid electric vehicle.

The main objectives of this project are:

I. To develop an Energy Management System (EMS) in managing the power split between battery and engine under instantaneous vehicle power demand.

II. To analyses the performance of developed EMS in various set of membership function.

1.4 SCOPE AND LIMITATION

The project have theoretical design (i.e. perform the Fuzzy Logic Controller by using Matlab) in such that to support the simulation results. The result of the simulation was then discusses and supported by fact from literature review. The matter to be considered during design process is the variables to be choose. The two variables that will determine the FLC are acceleration, state of charge (SOC). The output will be the charging state for the battery and power split between it. The entire configuration was carrying on by using Matlab. The result has been further study.

1.5 PROJECT OUTLINE

This project consists of five chapters including this chapter. The content of each chapter are as below:

The Final Report starts with an introduction and overview of the application for energy management system in series hybrid vehicle and its necessity.

Chapter 2 provide a literature review from past research in the hybrid electrical vehicles control system done by mostly IEEE institution. The content of this literature review are focusing on series hybrid electric vehicle and control system for HEVs. From the past research, some of the design and control method had been analyze and further discuss in my application.

Chapter 3 describe the research methodology in this project. The chapter will start to discuss about the theoretical method of fuzzy logic toolbox in Mathlab. This chapter will emphasize the application of fuzzy logic into the energy management system for series hybrid vehicle. The modelling of fuzzy logic in Mathlab will be performed and analysis the primary result shown. There were three stages to perform the final drive system for stimulation which included the construction of vehicle role model in Mathlab, lithium battery modelling and lastly combination of all expect including the FLC into the vehicle modelling.

Chapter 4 presents the theoretical system for the application of the fuzzy logic controller in the energy management system for series hybrid electric vehicle.

Chapter 5 provide a general conclusion and recommendation for current research and development of hybrid electric vehicles.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter describe the literature review on energy management system and hybrid electric vehicles done by other researchers. Understanding the operational for HEV and related sub core is one of the necessities in completing this project. Reference from previous study done by most researchers will be the beneficial step for me to explore more on the energy management system for HEV. Gasoline and diesel used for vehicle propulsion are refined from fossil oil[1]. The world most consumed oil sector goes to transportation used up around 60% from total oil consumption. As the world population continues to grow up, it will also bring to the increasing demand of transportation and oil consumption. Conventional vehicle is the highly oil consumption vehicle that guide to the incresing of oil needs. Rather than oil consumption, pollution also generated during the oil burning inside the internal combustion engine (ICE). The pollution issue and crude oil has brought to the emerging of hybrid electric vehicle. This is one of the alternative ways to replace internal combustion engine vehicle. HEVs offer the combination of the ICE and electric generator/motor. This combination has help in reducing significant oil amount for an on-road HEVs compare to ICEV.

2.2 STRUCTURE FOR HEV

As proposed by Technical Committee 69 (Electric Road Vehicles) of the International Electrotechnical Commission, HEV is a vehicle in which propulsion energy is available from two or more kinds or types of energy stores, sources or converters, and at least one of them can deliver electrical energy. Based on the general description, few types of HEVs such as the engine-battery, engine-fuel cell, battery-capacitor, battery-flywheel and battery and hybrid have been invented. Several types of hybrid electric vehicle are now in production, with rising sales and range of specification. Most of the current production vehicles are light hybrids, with most of the power supplied by engine or oil tank [21]. Hereby, HEVs are newly classified into four kinds:

a. Parallel hybrid
b. Series hybrid
c. Series-Parallel hybrid
d. Plug-in complex hybrid

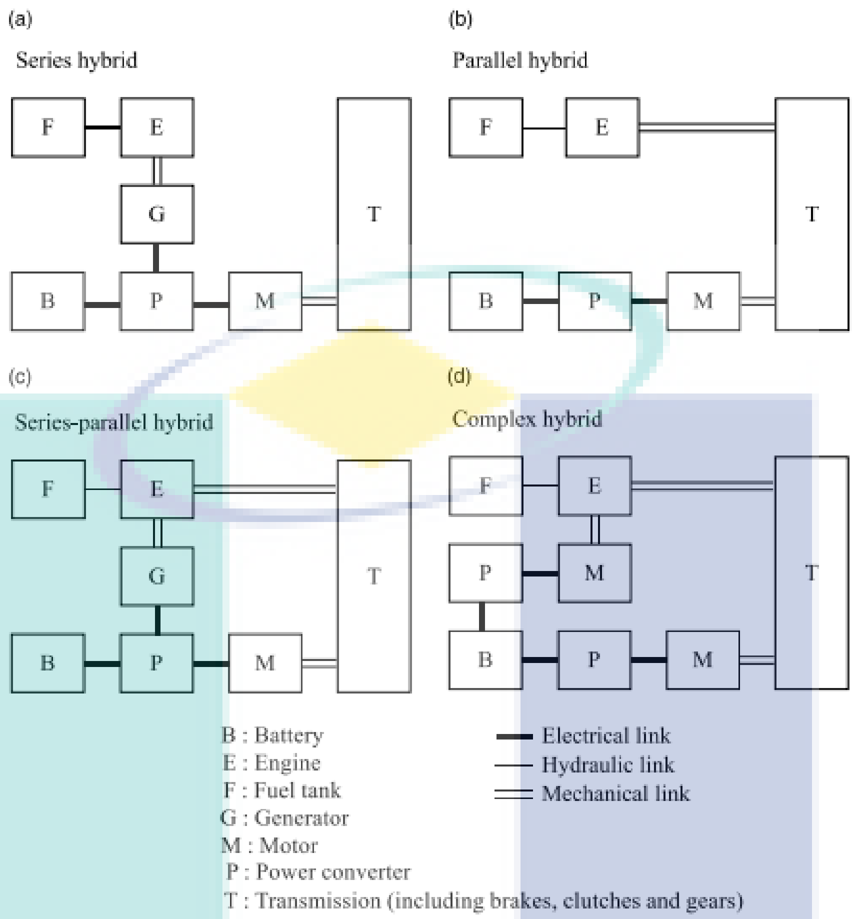

Figure 1: Classification of HEV [22].

2.2.1 PARALLEL HYBRID CONFIGURATION

The paper state that [11] Engine and electric motor both drive the wheel and in the same time the electric motor can act as the generator to recharge the battery. Differing from series hybrid, the parallel HEV allows both engine and electric motor to deliver the power in parallel to drive the vehicle. The motor that can act as generator also allow the regenerative braking to recharge back the battery. Compare to series hybrid, this type of hybrid has smaller engine and electric motor. But, these types of drive train also perform some difficulty especially when we need to perform driving and charging in the same time and it will cause the health of battery to deteriorate. As the temperature for the batteries rise, the health for the batteries goes bad.

2.2.2 SERIES HYBRID CONFIGURATION

The series hybrid is known as the simplest kind of HEV. The drive train for series hybrid is consisting of internal combustion engine, pack of batteries, control unit, fuel and generator. The fuels use to recharge back the batteries but does not directly power up the vehicle. It has no direct contact to the wheel [11]. Only engine drive the vehicle wheel. Compare to parallel hybrid, it has the definete advantage of flexibility for locating the engine-generator set due to the absence of clutches through the mechanical link. But it needs three propulsion devices- the engine, the generator and electric motor compare to the parallel only needs two.

2.2.3 SERIES-PARALLEL HYBRID CONFIGURATION

This is a complex model which combines series and parallel drive train together in same vehicle. In paper [17], it states that series-parallel hybrid electric vehicles (SP-HEV) have excellent advantages to other types of HEV. However, the construction for SP-HEV is more complex and costly compare to series or parallel type. For series-parallel type, it can operated as a series, parallel or series-parallel HEV. With the advances in control and manufacturing technologies recently, most of the HEVs manufacturer prefer to adopt this system to their's car.

2.2.4 COMPLEX HYBRID CONFIGURATION

The battery is directly charged when plugged in the electric source, it share the characteristic of hybrid and electric vehicle. This type of configuration shows a more advance and applicable compare to the conventional vehicle. Recently, the development of complex hybrid has been focused on the dual axle propulsion system for HEVs. In this system, the front wheel axle and rear wheel axle are separately driven. There is no propeller shaft or transfer to connect the front and rear wheels, so it enables a more lightweight propulsion system and increases the vehicle packaging flexibility. One of the typical examples is a four wheel drive system (4WD). This complex configuration involving multiple electric motor and planetary gear system according to M.Chris [1,2].

2.3 HEV ENERGY MANAGEMENT SYSTEM

The drive train of HEV is controlled by the energy management system and the propulsion of the driving model will be elected by the EMS. From [3], the author conclude that EMS work as the central to command the system. For further study, there were many types of control method that will associate in the EMS and act as the supportive tool for decision making necessary.

For a better driving performance, energy management system is one of the vital causes in this case. The more accurate road data and the precision of decision making procedure will be the factor for a better driving experience. From the relevant research on this particular topic, Maghsoodlou.F, Masiello.R and Ray.T [3] has found out the major objective for the energy control system. They state that EMS as a control system, EMS acts as central control unit to provide a reliability operation for any system. For better driving performance, several methods have been introduced by the most researchers which are rule based, pattern recognition control, dynamic programming and two scale dynamic programming.

Rule base controller is the most basic controller which is fuzzy set theory and reasoning. Fuzzy logic can adopted for realising a real time and suboptimal power split. It is the extension of the conventional rule based controller. It is easier to be implemented in any case of driving system. In the paper [5], the fuzzy management with predictive control and durability extension of battery was introduced. This is an application of fuzzy logic in series HEVs with two embedded-predictive control and durability. It said that fuzzy logic is a tool that can adopted for realizing a real time and suboptimal power split. The control system can tolerance to imprecise measurement and it is easily to bet set up. Other than that, there was also application of fuzzy logic controller with neural network. In this application, super capacitor is use to ensure appropriate amounts of energy are stored in the super-capacitor to ensure that the super capacitor always working under appropriate state of charge status.

The second control method is pattern recognition control .This is more Optimized method compare to rule based, it need historical data or pattern to perform the simulation [11]. It needs data such as acceleration data, parking pattern, stop time and regenerative brake data management system for HEVs. Example of the implementation is [11] Real time validity with advancement in ITS system and global positioning systems (GPS). Real time traffic data will has more accurate drawback for the control system. But for this case we are dealing with the high computational loads of data. Lastly it would be the advance dynamic programming which computes more speed and is very helpful in sophisticate traffic data.

2.4 ELECTRIC MACHINE

Advances in the development of power electronics and electric machine are the key of success for electric, hybrid or even hybrid plug-in vehicles nowadays. Electrical machines are devices that transform electrical power to mechanical power which the mechanical power are usable to turn the wheel on the road.

There are few types of electric motor being considered to be used in the configuration which are induction motor, brushless dc motor, permanent magnet synchronous motor (PMSM) and brushed DC motor. Primary requirement for electric machines are low cost, high efficiency, small size, high reliability, low noise and high stability. [1]

2.4.1 INDUCTION MOTOR

This type of motor also calls as asynchronous AC motor. It supplies the power to the rotating device by electromagnetic induction. [1]

2.4.2 PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM)

PMSM is synchronous machines implementing excitation on rotor with permanent magnet. PMSM usually chosen for modern traction drives. The advantages including high efficiency, compact size, high torque at low speed, ease of control for regenerative braking. This motor can operate as motor during normal driving, acting as a generator during braking or power splitting[1].

2.4.3 BRUSHLESS DC MOTOR (BLDC)

This type of motor is developing from conventional brushed DC motor. BLDC is a motor with electronic controlled commutation system.

2.4.4 BRUSHED DC MOTOR

There are five existing types of this DC motor such as separately excited, shunt, permanent magnet, series and compounded types. [1] This type of motor is seldom being used in Hevs due to many disadvantages such as reliability concern, bulky size, and low efficiency.

2.5 POWER DEMAND FOR HEV

To calculate power demand, we can apply the formulae stated below:

$$P_o = \frac{1}{n_T}\left(\frac{m_a g f_r}{3600}V + \frac{C_0 A}{76140}V^2 + \frac{\delta . m_a . V}{3600}\frac{dv}{dt} + \frac{m_a . g . sin \propto . V}{3600}\right) \ldots \ldots \ldots (2.5)$$

P_o=demand power, kW

n_T =Transmission efficiency

m_a = vehicle mass, kg

g= acceleration gravity, m/s^2

f_r= rolling coeffiecient

A=frontal area, m^2

δ= rotating mass coefficient

α= slope angle,rad

2.6 ENERGY STORAGE

The characteristic of the batteries had been study to allocate the most suitable batteries for the need of series hybrid electric vehicles for this study. There are many types of batteries in the market [10] which are lithium ion, lead acid, NiMH, NiCd, Nickel metal hydride and molten salt battery. Suitable batteries type has to be choosing in term to supply a long time driving time and safety for driving purpose. Therefore high energy density and power capability are the factor to be considered in this matter. The temperature of charging and discharging also one of the big issues in hybrid vehicles, too high or too low will affect the health of the batteries and cause the lifespan of the batteries reduced. Self-discharge rate and the durability for the batteries are the main two factors that cause the price of usage to either increase or decrease. As below, it shows the summarized batteries characteristics for lead-acid, lithium ion and NiMH.

Table 1: varies types of batteries and the relevant data

Characteristics/type	Lead- acid	Lithium ion	NiMH
Specific energy, Wh kg^{-1}	85	180	70
Energy density, Wh L^{-1}	70	180	140
Energy/consumer price, wh/usd	7	2.8	2.75
Electrical efficiency, %	90%	85	66%
Self discharge rate, %/month	20%	5	30%
Durability, cycles	800	1200	1000

2.6.1 LEAD ACID

Lead acid [2] is the oldest types of battery that being used in electric vehicle and all types of hybrid electric vehicles.

The chemical reaction are given by

Cathode: $PbO_2 + 3H_3O^+ + HSO_4^- + 2e^- \rightarrow PbSO_4 + 5H_2O$

Anode: $Pb + HSO_4^- + H_2O \rightarrow PbSO_4 + H_3O^+ + 2e^-$

However, lead acid not the favour for HEV due to heavy limitation on lead acid operation, since the water need to be replacing regularly. Others disadvantages including low life cycle and low energy density.

2.6.2 NICKEL METAL HYDRIDE (NIMH)

These are the advantages for NIMH batteries large energy density, high specific power density, long cycle life and moderate price. With those advantages had made NIMH to be selected by Honda and Toyota for their HEVs production line.

The chemical reaction equations are given by

Cathode: $NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$

Anode: $OH^- + MH \rightarrow H_2O + M + e^-$

However, the application of NIMH in HEVs has few drawbacks in heat generation problem during charging, its poor performance at low temperature and the requirement for overcharge prevention.

2.6.3 LITHIUM ION

The concept of lithium ion was proposed by Whittingham from Binghamton University in the 1970s. Li-on have an advantage on weight compare with other equivalent secondary batteries. The lithium-ion battery is one of the rechargeable type batteries.

The cell reaction for lithium ion batteries,

Negative Electrode Reaction: $Li_xC \Leftrightarrow xLi^+ + xe^- + C$

Positive Electrode Reaction: $MO_2 + xLi^+ + xe^- \Leftrightarrow Li_xMO_2$

Overall reaction: $Li_xC + MO_2 \Leftrightarrow C + Li_xMO_2$

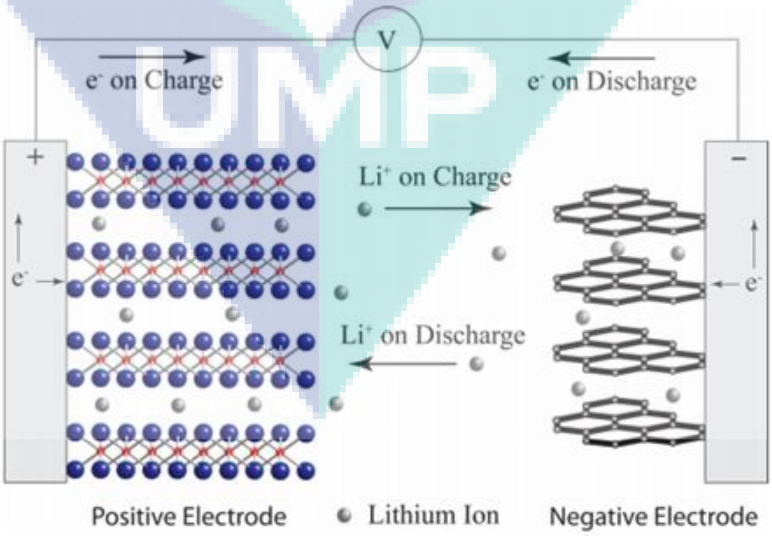

Figure 2: This is a reaction for lithium-ion batteries.

2.6.4 REDOX FLOW BATTERIES (RFBs)

Redox flow batteries which use flowing liquid electrolytes have potential to replace the fuel cell.RFBs and FC has very similar characteristic and only differ in flowing electrolyte for RFBs while the electrolyte for FC remain within the cell stack. Many different types of RFBs have been considered this few years including bromine-polysulfide, vanadium-vanadium, vanadium-bromine, iron-chromium, zinc-bromine, zinc-cerium, and soluble lead RFBs [22]. RFBs can match the lead acid energy density but still significantly low compare to lithium ion batteries.

2.6.5 FUEL CELL

There are plenty types of fuel cell such as proton exchange membrane fuel cell (PEMFC), alkaline fuel cell, phosphoric acid fuel cell,molten carbonate fuel cell, solid oxide fuel cell, adn direct methanol fuel cell. High cost, unsatisfactory durability, poor transient performance and subzero temperature startup issue are the main obstacles for the commercialization of clean fuel cell vehicles. The current fuel cell does not allow bidirectional energy flow and having difficulty in recovering braking energy. For current technologies, fuel cell vehicle need secondary energy provider such as NIMH and lithium ion to achieve powerful and responsive driving.

2.6 BATTERY POWER

The battery power depend on few factors which are capacity (C) of battery pack, energy stored (E), state of charge (SOC),depth of discharge (DOD), specific energy, energy density, specific power and power density.

2.8 FUZZY LOGIC THEORY STUDIES

According to Bathaee and Hajizadeh [18], fuzzy logic controller satisfies the split work between battery and electric motor, battery charge balance and also reduction of emissions. Fuzzy Logic controller is useful for complex, nonlinear and uncertain system such as Hevs application. However, to get a more accurate decision user for fuzzy logic controller need to identify variables that is necessary for the system.

Generally, [19] fuzzy controller consists of four conceptual blocks: fuzzification interface, a set of rule base, fuzzy inference engine and defuzzification interface. The behaviour of the system tend to be translated into the fuzzy set and by using the rule based as linguistic representation of data to process the fuzzy data. In my project, the fuzzy controller scheme consists of two inputs (the battery SOC and speed of vehicle) and one output (battery charging mode).

2.8.1 MANDANI METHOD

In the design of fuzzy logic, Mandani model seem to be more close to the zadeh's method.Mandani method is widely accepted for capturing expert knowledge,it is more intuitive more human-like manner according to A.Kaur[23]. The mandani type is widely used in decision making. For mandani, fuzzy knowledge base are acquired fro human expertise to design the required set of rules. The most difference between mandani and sugeno is the crisp output generated from fuzzy input. Mamdani use the technique of defuzzificztion of a fuzzy output and sugeno weighted average to compute the crisp output.

2.8.2 SUGENO METHOD

Sugeno type FL was introduced in 1985 by sugeno.The main difference between Mamdani and sugeno is the sugeno output membership functions are either linear or constant. Table 2 shown the advantages for both FL.

Table 2: Advantages for Sugeno and Mamdani method.

Sugeno method	**Mamdani method**
It is computationally efficient.	It is intuitive.
Work well with linear techniques (e.g. PID control).	Widespread acceptance.
Work well with optimization and adaptive techniques.	Well suited t human input.
Guaranteed continuity of the output surface.	Can be used for multiple input single output (MISO) and multiple input multiple output (MIMO).
Well suited to mathematical analysis.	
More robust and better sensitivity.	
Can be used only in MISO system.	

2.9 MEMBERSHIP FUNCTIONS

The membership functions for charging mode are presented in figure above. There are two considerable inputs which are state of charge and speed of vehicle. The specification of SOC is set to be in between of 20 as lower limit to 100 as higher limit in percentage. There are 5 membership functions which are low, medium low, medium, medium high and high. Speed of vehicle will be the second input for the system, the same specification is set. There are also 5 membership functions which are slow, medium slow, medium, medium high and high.

2.10 SUMMARY AND DISCUSSION

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In this project, the suitable energy management tool was selected after consideration. Fuzzy logic controller was employed to quantify the energy management for SHEV. The conceptual of proposed fuzzy controller had been implemented by using Matlab/Fuzzy Logic toolbox. Mamdani type fuzzification method was chosen in this case. According to A.Kaur [23], Mamdani method is suitable for knowledge based case compare to Sugeno method.

For early stage of the investigation, without the driving profile for SHEV human experience was employed. By using basic configuration and knowledge, design was made to suite the investigation. In the first stage, a fuzzy EMS controller that maps the velocity of SHEV and state of charge (SOC) of lithium ion for the vehicle was developed. The design process will be made according to the flow chart shown as below:

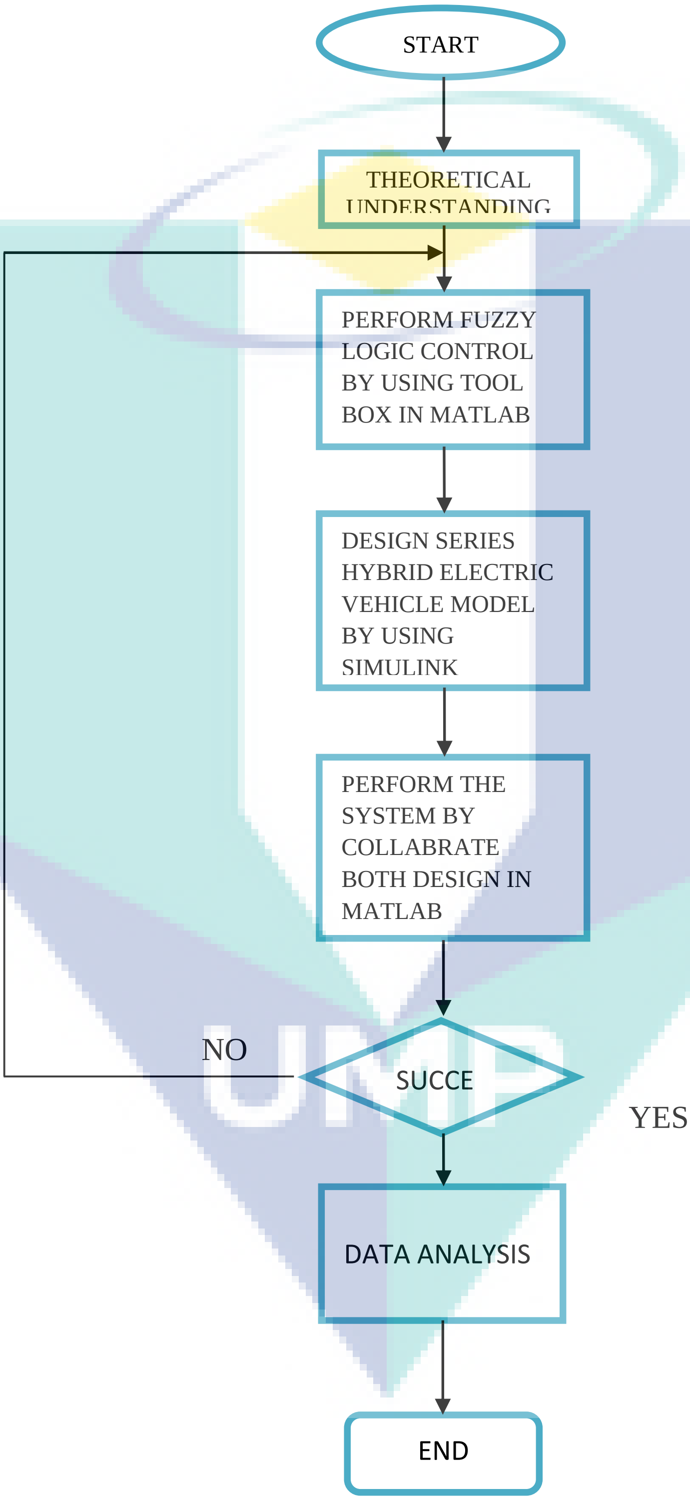

Figure 3: Flow chart for FLC design process

3.1 SERIES HYBRID SYSTEM CONFIGURATION

Figure below presents a power-assist series hybrid electric vehicle schematic diagram. The power of the vehicle is offered by electric motor. Internal combustion engine is used to charge the battery.

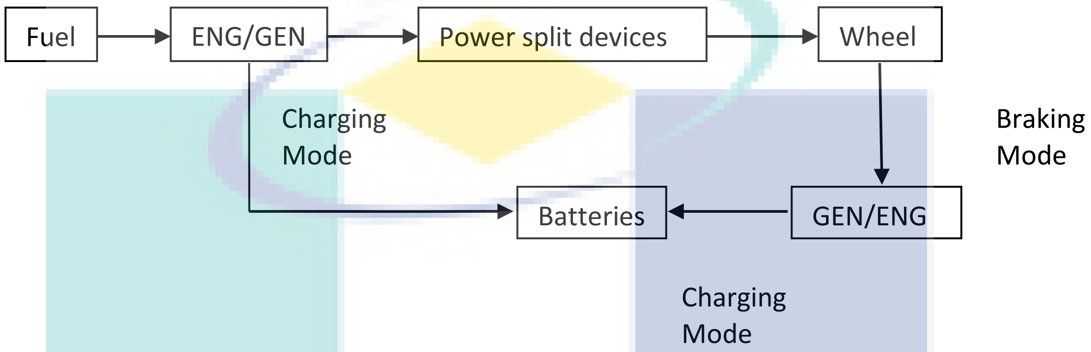

Figure 4: Series hybrid electric vehicle schematic.

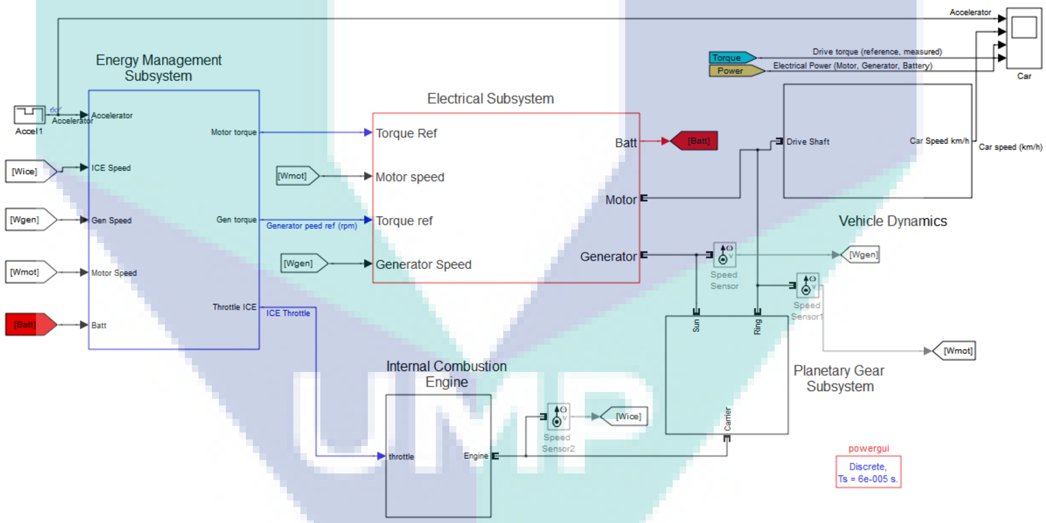

Figure 5: the constructed SPHEV system.

Figure 3.3.1b presented a fuzzy logic controller designed to handle the power split in the series hybrid electric vehicle. The model being used for simulation of fuzzy logic controller was designed based on SimPowerSystem and SimDriveline. The power train is one of the series-parallel types. For series parallel types, the vehicle model to series, parallel or both traction modes. In this project, series hybrid electric vehicle was choosing.

Table 3: Types of modes

Mode	Region Of Operation	Remark
1 (0<t<4)	accelerating	
2 (4<t<8)	cruising	
3 (8<t<13)	Recharging the battery while accelerating	
4 (13<t)	Recharging the battery while regenerative braking	

In this system, we have several systems for the construction of the SHEV which are electrical management system, electrical subsystem, vehicle, internal combustion system and planetary gear system.

The HEV Electrical Subsystem is composed of four parts: electrical motor, battery, generator and DC/DC converter. The planetary gear subsystem models the power split device by transmitting mechanical motive force from the internal combustion system to the motor and generator.

The internal combustion system (ICE) subsystem will burn the gasoline to supply the mechanical force to the generator. The generator will use up the power to recharge back the battery. The vehicle consists of the drive environment, tires and vehicle profile as the model for the simulation take part in.

The electrical management system manages the power split and controls the hybrid mode with charging mode in the simulation. The Fuzzy logic controller is located in here to apply it functional toward the subsystem.

For this experiment, a series hybrid vehicle role model had been used for further implementation of the controller. Below are vehicle data and characteristics:

Table 4: Vehicle specification.

Description	Requirement
Vehicle mass	975kg
Rolling resistance coefficient, C_o	0.015
Wheel radius, r_{wh}	0.3305m
Aerodynamic drag coefficient,C_{AD}	0.41
Frontal area,A_f	2.88m^2
Wheel base	2.6m

To calculate the power demand for the HEV, the manipulate variable would be the velocity,V and the slope angle, rad. The transmission efficiency is 0.90 for automated manual transmission.

c

Velocity, V(m s^{-1})	**Slope angle,rad**	**Demand power, P_o**
25.00	0.175	27.78
27.78	0.175	34.57

3.3 ENERGY MANAGEMENT STRATEGIE

This paper investigates the use of fuzzy logic controller in the energy management system for SERIES hybrid electric vehicle. The fuzzy logic controller control the charging mode of the battery during wheel rolling based on the state of charge of the batteries and the velocity of the vehicle.

From [10], it also agrees that vehicle speed is to critical factor in control strategy. Table 6 shows the rules used to relate the velocity of the vehicle and state of charge for the batteries. By using this table, Fuzzy Logic Controller tends to define the state for each variable and make a discrete decision for the EMS.

Table 6: Fuzzy logic rule based table.

CHARGING_MODE		STATE_OF_CHARGE FOR BATTERIES (%)				
		Low SOC<20	Medium low 20<SOC<40	Medium 40<SOC<60	Medium high 60<SOC<80	High SOC>80
VELOCITY,km/h	Low 0-20	HC	MC	MC	LC	LC
	Medium low 20- 40	HC	MC	MC	MC	LC
	Medium 40-60	HC	HC	MC	MC	MC
	Medium high 60-80	HC	HC	HC	MC	MC
	High 80-100	HC	HC	HC	HC	MC

Three examples of Fuzzy statement:

1. When V is low and SOC is low, the battery will be in high charging mode.
2. When V is medium and SOC is medium, the battery will be in medium charge mode.
3. When V is high and SOC is high, the battery will be in low charging mode.

In fuzzy logic toolbox

Define rule to be

Table 7 And operation

A	B	Min(A,B)
0	0	0
0	1	0
1	0	0
1	1	1

Table 8 Not operation

A	B	Max(A,B)
0	0	0
0	1	1
1	0	1
1	1	1

To select the suitable waveform for the membership function, the proper reference has been done on paper [8]. The writer had conclude the twele consideration while choosing the right choice. Table 7 and 8 presents the operation in the stage of defuzzification. In between of this applicable operation, the setting have to be made either using both or one of them. For this project, and operation is chosen.

The observation and analysis for this project of EMS controller has shown in figure 6. In this module, the input variable are the battery SOC and speed of the vehicle. The output variable is battery charging mode command from the controller. In early stage, the input will be sent to FLC and the output will be sent to define the mode of charging for the battery. For example, when the SOC is detected to be low and the speed of vehicle is high, the fuzzy logic controller will assign the highly charging mode for the battery. This is a continuosly system for the SHEV.

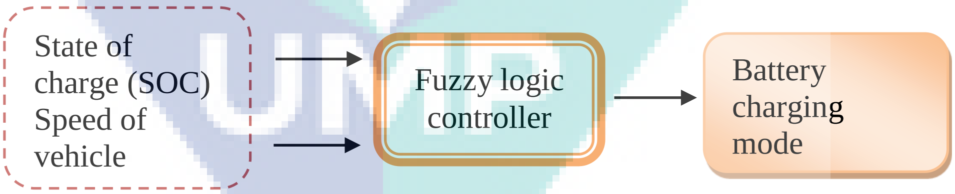

Figure 6: EMS interface of series hybrid electric vehicle.

The membership functions for SOC are presented in figure 7. A general controller consists of the four conceptual blocks: a fuzzification interface, a rule bases, fuzzy inference mechanism, and defuzzififcation interface as shown in figure 7. The specification of universal of SOC is derived from the system constraint from 0 to 100. The universal of discourse of SOC in partitioned into several domains. The input SOC consists of five membership function and are named low, medium low, medium, medium high, high. The shape of the membership can be trapezoidal or bell. Figure 8 present the fuzzy logic controller for this project.

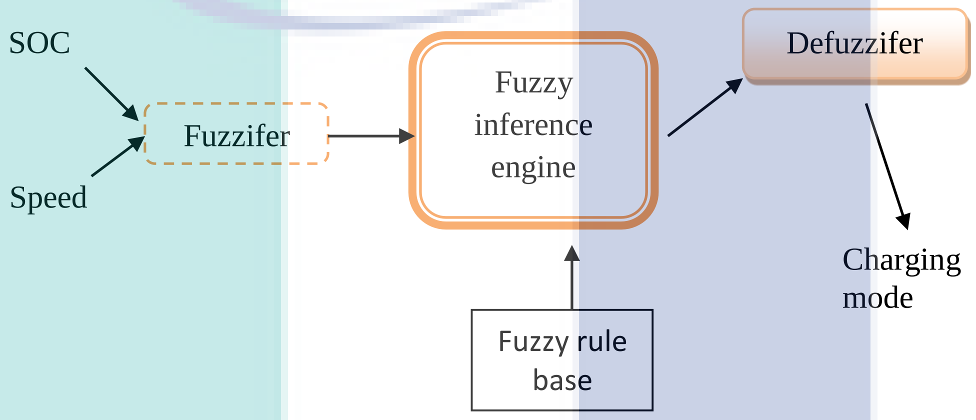

Figure 7: Fuzzy logic controller scheme.

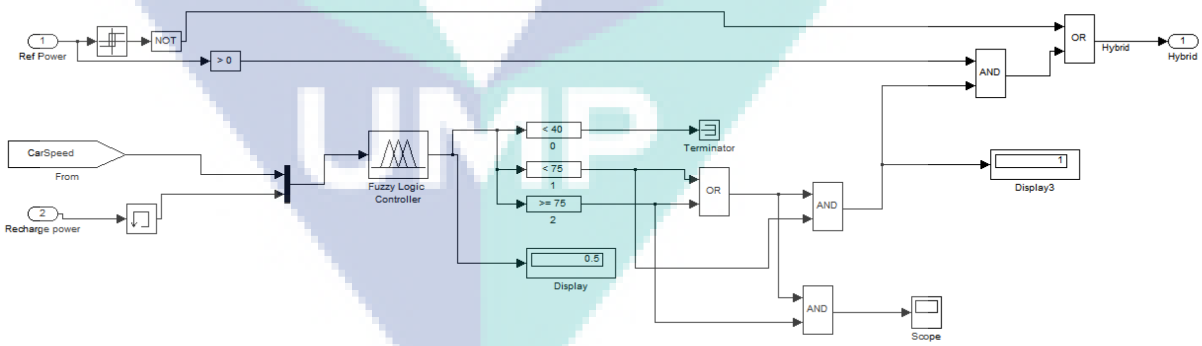

Figure 8: Fuzzy Logic Controller for this project.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter discusses on the result and analysis that involve the fuzzy logic controller in SHEV. The initially intention for the complement for this project was the implementation of fuzzy logic in SHEV. The analysis from the simulation has been discussed on the application of fuzzy logic control system in SHEV system. Further investigation was also being done to find out the most suitable shape for the membership function for car speed.

4.2 SOFTWARE CONFIGURATION

4.2.1 FUZZY LOGIC CONTROLLER TYPES 1 IN SHEV

i) For medium charging mode

For first investigation, bell shape membership function had been used. The result will thus compare with the second investigation. There were 5 memberships set for the first variable, velocity of SHEV. From the figure above, we can see that the shape of membership function for three graphs is in bell shape. The matter to investigate is the shape of membership function for the velocity of SHEV. For this case, bell shape has been chosen and the results are as below.

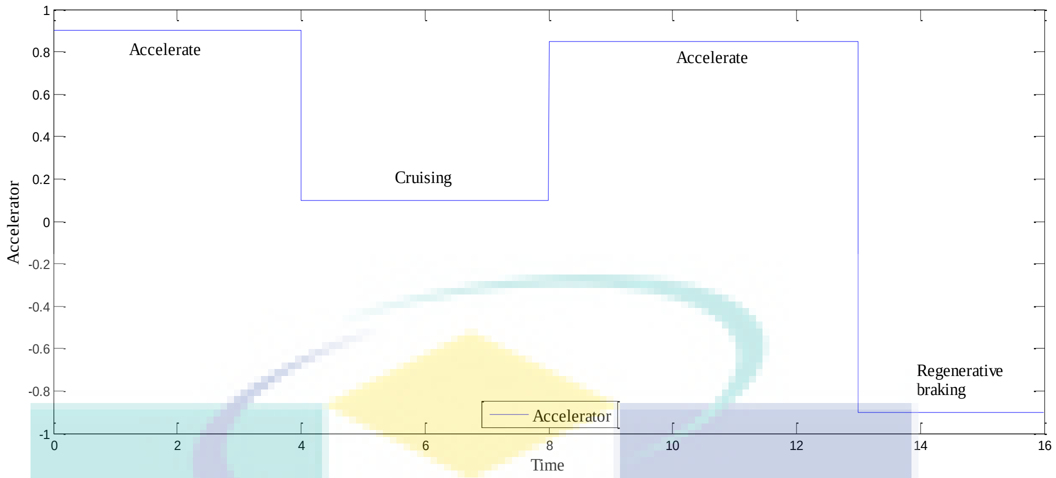

Figure 9: Graph show the accelerator profile for the SHEV simulation.

From 0s to 4s, the limit for accelerator set to be 90% out of 100%. This represent the accelerating mode for simulation take part. Starting from 4s until 8s, the vehicle will enter the cruising mode. The limit set to be 10%. Vehicle start to charge the battery while accelerating from 8s until 13s. lastly, it goes to braking mode from 13s and above. Those mode are set to perform a continuos cycle for a real time validation purpose.

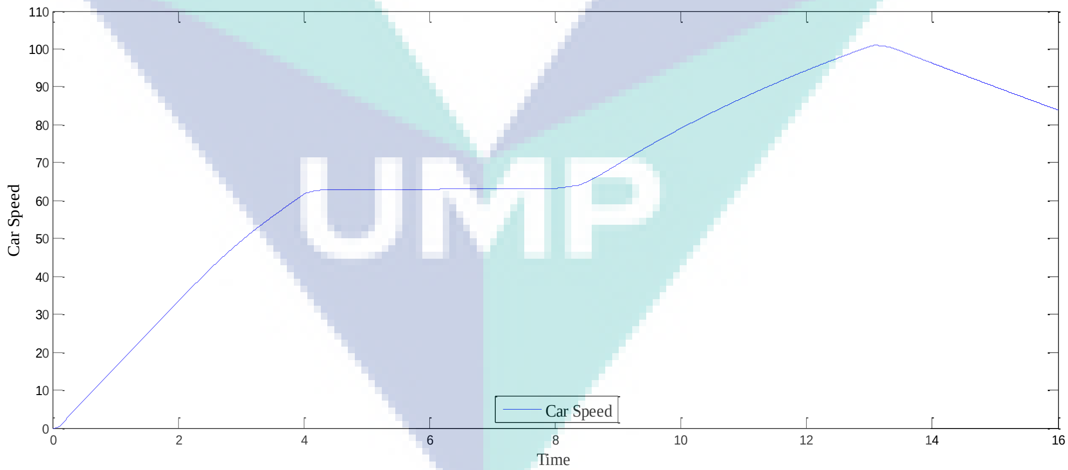

Figure 10: Graph show the car speed profile for the SHEV simulation.

From figure 14, we can conclude that car speed is directly proportional to accelerator. From 0 to 4s, it has showed the vehicle speeding up to 60km/h in 4s. When enter cruising mode, it has fixed the speed at 65km/h from 4.1s until 8s. The vehicle starts to speed up again when once again the accelerator showing the accelerating mode. Until the speed reached 105km/h at 13s, the vehicle undergoes a braking mode and the speed start to drop to 85km/h at 16s.

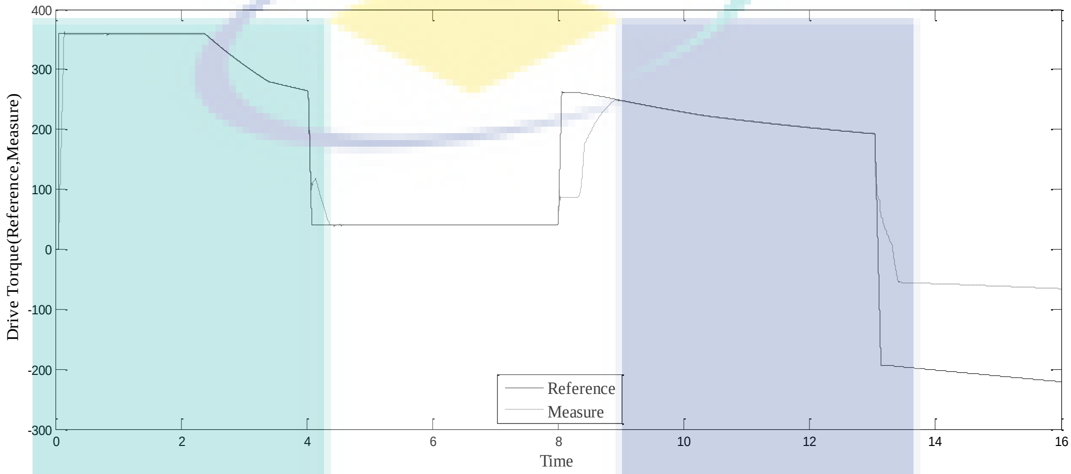

Figure 11: Graph show the drive torque profile for the SHEV simulation

This graph shows two types of drive torques which are reference and measure. Reference drive torque is what we want to achieve and for measure is what we get from the simulation.

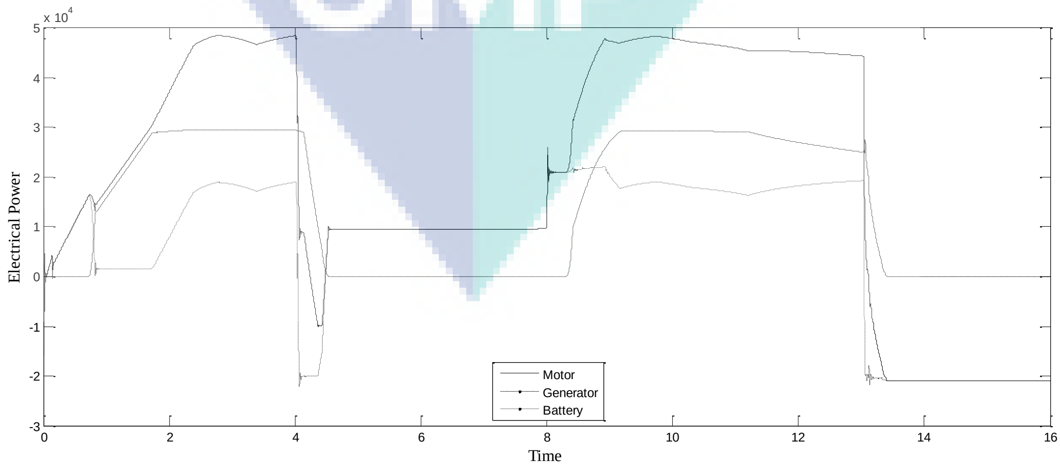

Figure 12: The electrical power profile for the SHEV simulation.

At the beginning, the electric motor absorbs the power from battery and generates the mechanical force for the vehicle to move. There will be huge power consumption at the beginning due to high motor torque. The battery continues to supply the motor until it reaches 13s. The motor has change to generator when regenerative braking is trigger. The power will be use to recharge the battery. The Internal combustion system will help to charge the battery while driving mode if receive command from the energy management system. It will turn the generator and apply the charging to the battery.

4.2.2 Fuzzy controller type 2 in SHEV

For second investigation, the bell shape had been change to trapezoidal shape for variable velocity. This is due to the definition that velocity may have discrete value. For discrete value, trapezoidal will be the best solution for this.

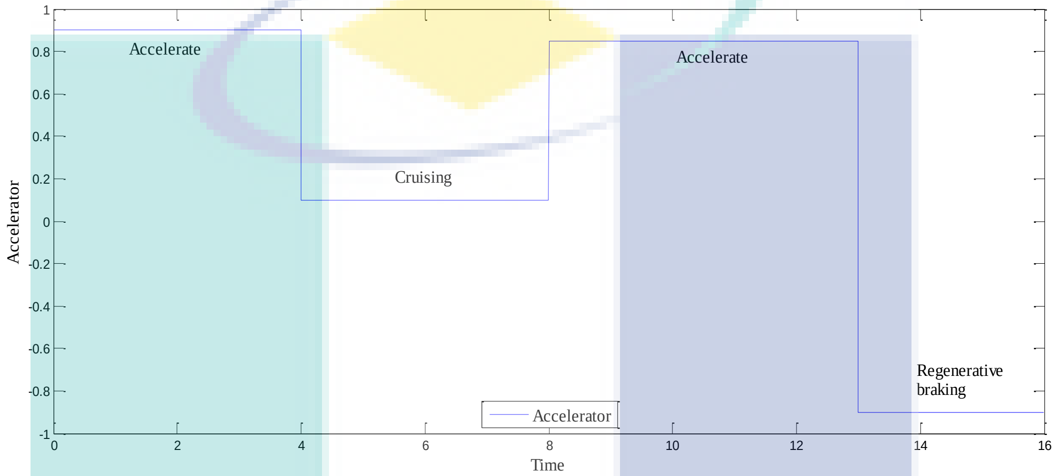

Figure 13: Graph shows the accelerator profile for the SHEV simulation.

From 0s to 4s, the limit for accelerator set to be 90% out of 100%. This represent the accelerating mode for simulation take part. Starting from 4s until 8s, the vehicle will enter the cruising mode. The limit set to be 10%. Vehicle start to charge the battery while accelerating from 8s until 13s. lastly, it goes to braking mode from 13s and above. Those mode are set to perform a continuos cycle for a real time validation purpose.

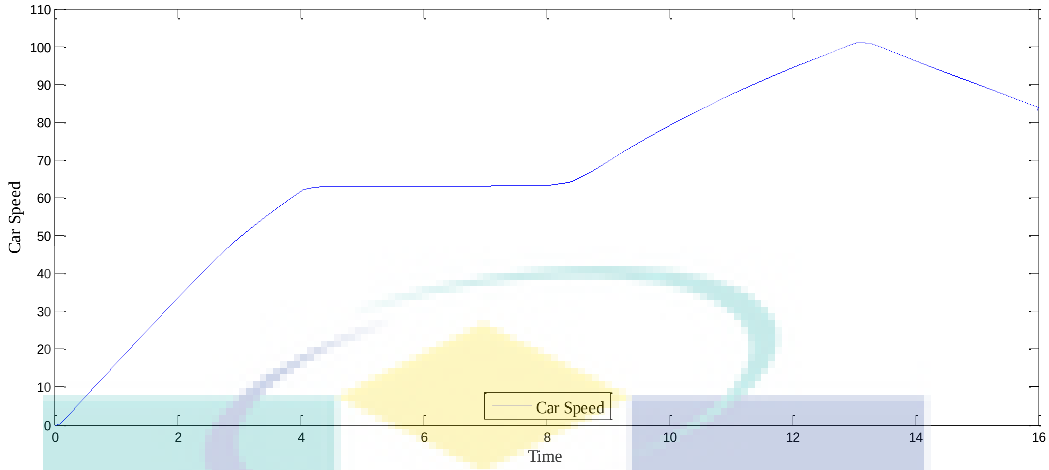

Figure 14: Graph show the car speed profile for the SHEV simulation.

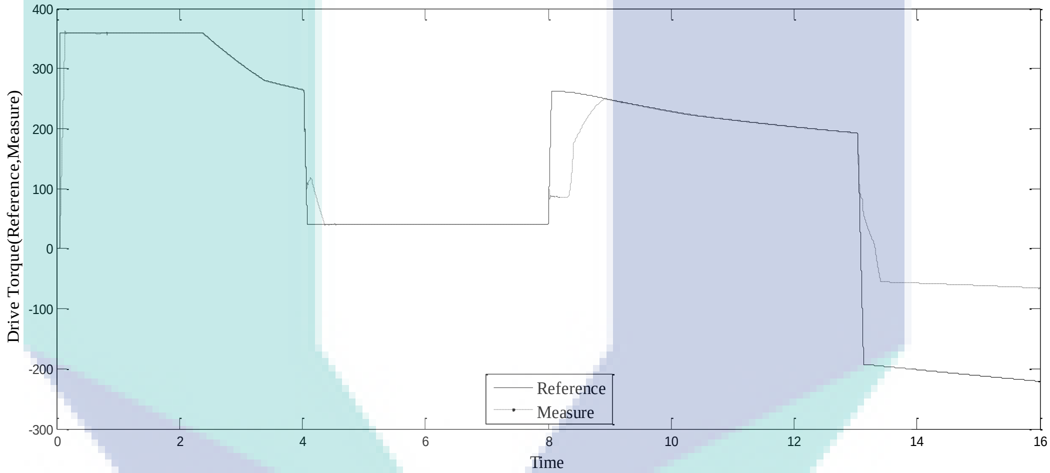

Figure 15: Graph show the drive torque profile for the SHEV simulation

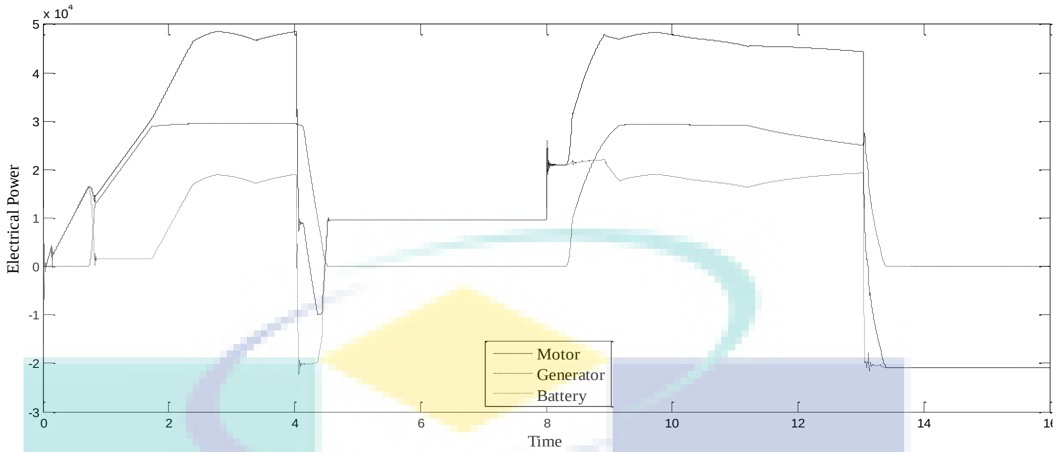

Figure 16: Graph show the electrical power profile for the SHEV simulation.

t=0s

- the accelerator is set to be 90%.
- We can see the speed has rise from 0 to 33km/h in 2s.

t=0.14s

- the measured torque reaches the reference. It has reaches the maximum torque. The generator provides the maximum power.

t=0.19s

- the hybrid mode on.

t=0.88s

- the hybrid mode off.

t=4s

- the car speed is approximately 62km/h. Then, change to the cruise mode.

t=4.4s

- the generator is completely stopped. The required electrical power is only provided by the battery.

t=13.1s

- the accelerator pedal is set to be -90% (this means the regenerative braking is stimulated).
- This is done by switching off the generator (the generator power takes 0.5s to decrease to zero) and by ordering the motor to act as a generator driven by the vehicle's wheels.
- The kinetic energy of the HEV is transformed as electrical energy which stored in the battery.
- The power will be fully absorb by the battery. Therefore, the battery is now charging by the braking mode.

t=13.25s

- the maximum speed has reach to 101km/h.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As a conclusion, fuzzy logic control system has showed it useful characteristic in SHEV system. It can be implementing with more improvement to perform a more reliable driving performance. It has also come to a conclusion that the shape of the membership either trapezoidal or bell shape doesn't bring much influence to the system.

5.2 PROBLEM ENCOUNTER

When undergoing the process of finishing this project, quite a number of problem had faced and relative action had been carry out well to solve the encounter problem. Among the problem faced and solution practice to solve it as below:

1. For the input of fuzzy logic controller, initially the problem stated that Input signal detected to be as non bus signal input. It has cause an error for fuzzy logic to detect the identical input. Solution taken was to change the signal selector to mux, and then it can read the signal from two sources and apply the fuzzy rule for the system.

2. When update the latest generator set and motor set to the system, it has shown that both drives can’t be set accordingly. Then, lastly the last design was consumed.
3. Two simple systems were developed for the validation before the final presentation. The system can run successfully but it fails to show the continuous system for a series hybrid vehicles. Further action taken was to find and design the appropriate system for the continuous driving system.

5.3 RECOMMENDATION

In this project, the focus is in the implementation of fuzzy logic controller for SHEV. Therefore, there are still developments that can be done for further investigation of EMS. Intelligence transport system and Global positioning system can be put into consider for this case, more actual data for fuzzy will guide to a better decision maker. Besides that, more variable also need to put in consideration in order to get discrete output from FLC. Since the software analysis has been done, then for the coming step will be the validation in hardware and improvement on the control system by adding the suggested idea such as ITS and GPS.

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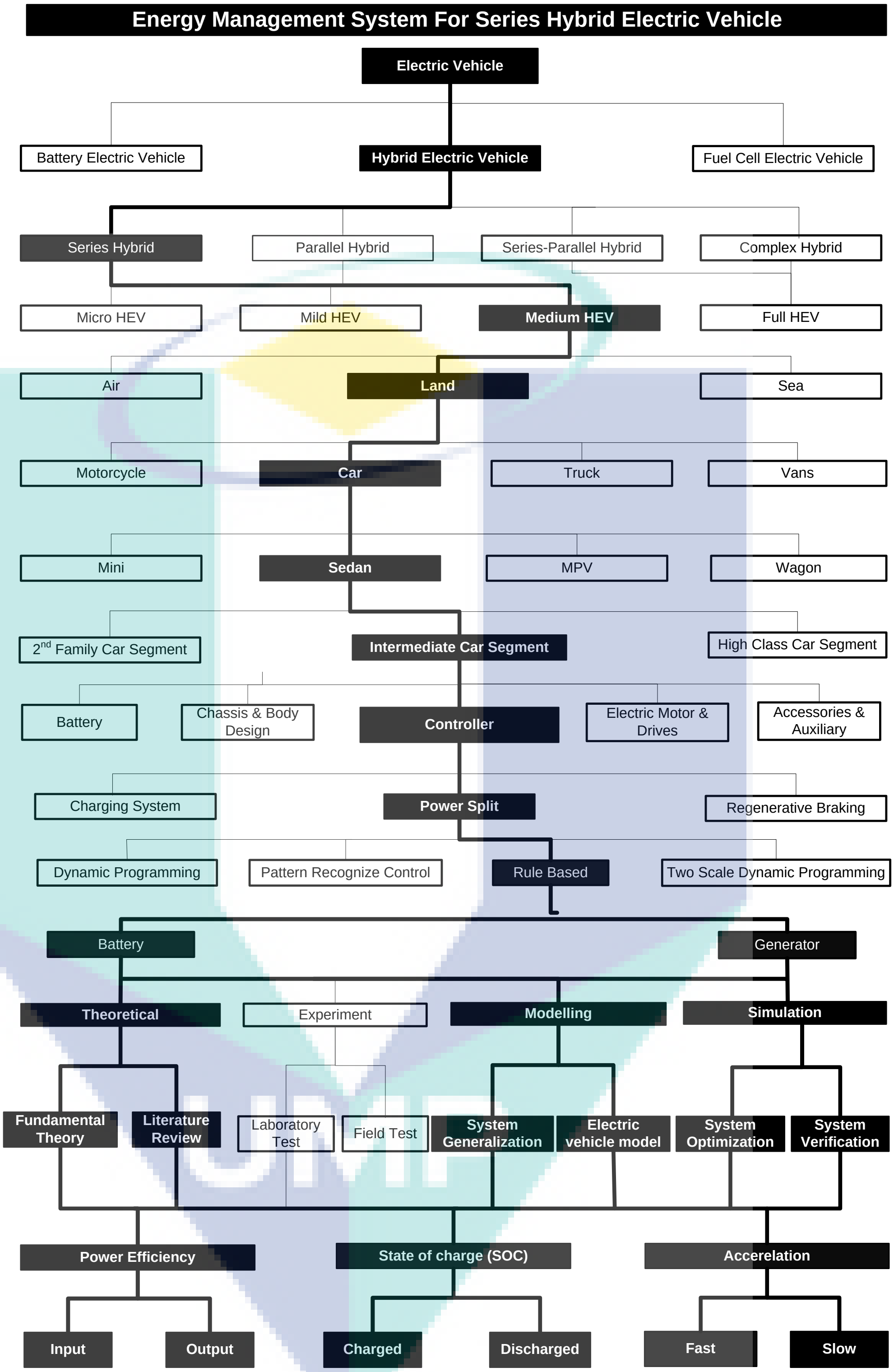
APPENDIX A


Energy Management System For Series Hybrid Electric Vehicle
Electric Vehicle
Battery Electric Vehicle
Hybrid Electric Vehicle
Fuel Cell Electric Vehicle
Series Hybrid
Parallel Hybrid
Series-Parallel Hybrid
Complex Hybrid
Micro HEV
Mild HEV
Medium HEV
Full HEV
Air
Land
Sea
Motorcycle
Car
Truck
Vans
Mini
Sedan
MPV
Wagon
2nd Family Car Segment
Intermediate Car Segment
High Class Car Segment
Battery
Chassis & Body Design
Controller
Electric Motor & Drives
Accessories & Auxiliary
Charging System
Power Split
Regenerative Braking
Dynamic Programming
Pattern Recognize Control
Rule Based
Two Scale Dynamic Programming
Battery
Generator
Theoretical
Experiment
Modelling
Simulation
Fundamental Theory
Literature Review
Laboratory Test
Field Test
System Generalization
Electric vehicle model
System Optimization
System Verification
Power Efficiency
State of charge (SOC)
Accerelation
Input
Output
Charged
Discharged
Fast
Slow