INVESTIGATION OF RULE-BASED CONTROL STRATEGY IN A SERIES-PARALLEL HYBRID ELECTRIC VEHICLE

By

MUHAMMAD WAFI BIN AKASHAH

FINAL YEAR PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

INVESTIGATION OF RULE-BASED CONTROL STRATEGY IN A SERIES-PARALLEL HYBRID ELECTRIC VEHICLE

by

Muhammad Wafi Bin Akashah

A project dissertation submitted to the
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

Approved:

____

AP DR Nordin Saad

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2012

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 acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Muhammad Wafi bin Akashah

ABSTRACT

Advance in technology has lead many bad effects especially to our nature. In automotive industry, vehicle that use internal combustion engine has being a major need to the people. Internal Combustion Engine has cause major air pollution because of dangerous gaseous such as carbon dioxide, sulphur monoxide, and sulphur dioxide that can cause a lot of disease. Hybrid technology has come as a solution to reduce the emission of this dangerous gas by reducing the usage of internal combustion engine. The idea of hybrid technology is combining the internal combustion engine with electric motor in order to achieve this target. The purpose of this project is to develop the best control strategy to minimize the usage of energy called energy management. Many method will be test to discover the best strategy to minimize the energy usage in hybrid electric vehicle. All type of control strategy will be demonstrated in the Simulink Matlab software. The types of electric motor use are permanent magnet synchronous motor.

ACKNOWLEDGEMENTS

The author would like to thank his supervisor, Associate Prof. Dr. Nordin for his priceless time and assistance in completion of this final year project. The author is also very thankful to his co-supervisor Mr Saiful Azrin in guiding throughout this final year project. This project is a requirement to get Bachelor of Engineering (Hons) in Electrical & Electronic Engineering.

Finally I would like to thank all of my collegue and friend who help me direct or indirectly towards completing this final year project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ICE	Internal Combustion Engine
DC	Direct Current
HEV	Hybrid Electric Vehicle
SOC	State of Charge
DOE	Department Of Environment

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Automobile has been one of the greatest achievements in the development of internal combustion engine.[1] This achievement leads to increment rapidly in automotive industry through a lot of demand from society. The automotive industry and other industry that support it has become society choice for working places. However the larger number usage of automobile has increase the emission of dangerous gaseous that cause air pollution. Hybrid Electric Vehicle is one of the solutions to the air pollution. Hybrid vehicle is a vehicle that uses more power sources such as combining internal combustion engine and electric motor. Both the motor and engine provide torque to drive the vehicle directly through controllable transfer unit. [2] Electric Motor can be DC Motor or AC motor. Induction motor is one of AC Motor type. The combination of both motor and the engine create a difference result. There are several combinations type such as parallel and series hybrid vehicle. In parallel type of vehicle, the torque from internal combustion engine is mechanically couple with electric motor. In other hand, the series type all the torque require to propel the vehicle provide by the electric motor.

1.2 Problem Statement

1.2.1 Problem Identification

Hybrid vehicle apply both internal combustion engine and the electric motor. The idea of hybrid vehicle is to reduce the usage of internal combustion engine to reduce air pollution. These two sources must have a good control strategy to minimize the usage of internal combustion engine without reducing the torque applies to vehicle. Therefore a study must be done to implement the best control strategy in order to create large torque from electric motor. Management of energy also must be taken care to minimize the usage of electric energy [3]

1.2.2 Significance of Project

Technology that can overcome pollution has become attraction. People nowadays are looking for the best solution to overcome pollution problem cause by internal combustion engine in vehicle. Hybrid Electric Vehicle has come as one solution that can minimize the usage of internal combustion engine.

1.3 Objective and Scope of the project

1.3.1 Main Objective

The main objective of this project is to simulate the control strategy on hybrid electric vehicle. The energy applies and the usage of internal combustion engine must be minimized without reducing the performance of the propulsion of the vehicle.

1.3.2 Scope of Project

This project will start with some literature review related to overview of hybrid electric vehicle and about the induction motor. Next will be the research on control strategy that needs to apply for the model designed using MATLAB software. The characteristic of every control strategy must be analyzed. The management of energy of the model must record.

1.4 Relevancy of Project

Nowadays the environmental impact has been taken serious by society. [3] Hybrid electric vehicle has become one of way to decrease the emission of dangerous gas cause by internal combustion engine. Due to limitation in performance of electric vehicle, the project on improvement of hybrid vehicle must be done. A good control strategy must be identify.

1.5 Feasibility of Project

The project will be done in two semesters which include three area which are research, development and also improvement of the model itself. The objective is to reduce the usage of combustion engine and to have a god management of energy.. Besides that, MATLAB will be used as the tools to develop all the control strategy. The implementation of full system will be using the same software. Therefore, this project is feasible and can be carried in time.

Chapter 2
LITERATURE REVIEW

2.1 Hybrid Electric Vehicle

Hybrid Electric Vehicle (HEV) can be defined as a vehicle that involves electric propulsion. [4] Hybrid Electric Vehicle is a root from Electric Vehicle (EV) displinary. EV is a multidisplinary course that cover broadly. The conventional vehicle are using internal combustion engine (IAE) [1] which cause air pollution by the emission of gas from exhaust. IAE have a very poor usage of fuel because of mismatch the real operation [5] , dissipation of kinetic energy during braking and low efficiency in hydraulic transmission in nowadays vehicle. [6]

Hybrid Vehicle usually uses two power sources. In HEV, high peak power combine with quick power response of electric traction will cause high performance in acceleration. [7] Hybrid Electric vehicle usually divide by two types which are series type and parallel type. Nowadays a lot of architecture of hybrid electric vehicle has been expanding. Below are the block diagrams showing the process in different architecture.

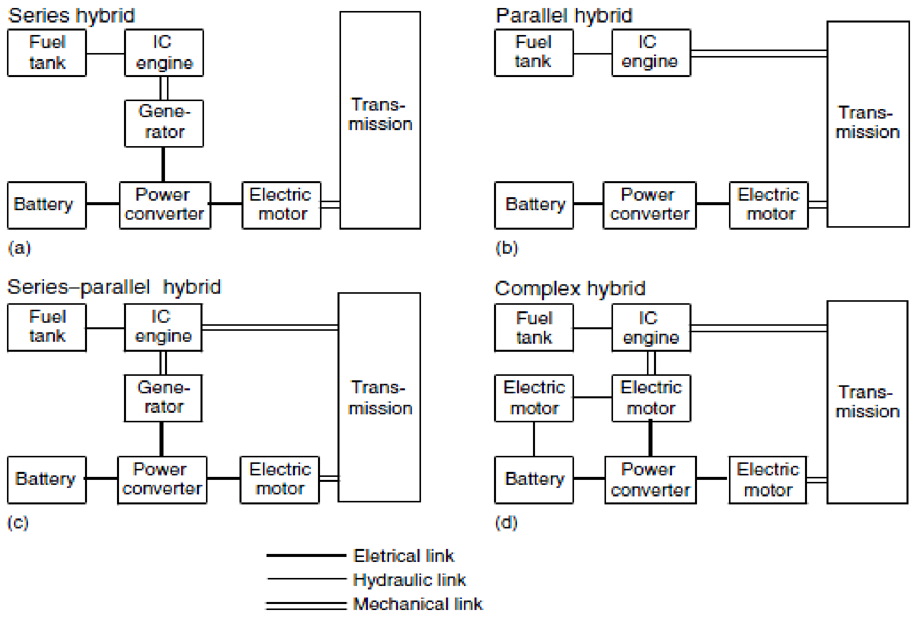


Figure 1 Classification of Hybrid Vehicle [1]

2.1.1 Series Hybrid Electric Vehicle

Series type of HEV has a battery built in the vehicle. The torque apply to the wheel is directly from electric motor. When the battery state of charge is at lowest state, then the ICE will be active to charge the battery. [8] The ICE usually will maintain the charge process until 65-75%. [9] The advantage of series configuration are ICE running in optimal combination of speed and torque and more applicable for city driving.

2.1.2 Parallel Hybrid Electric Vehicle

For parallel HEV, the torque apply to the wheel are the combination of torque apply by both engine. The advantages of this type are there will be no energy conversion like series. Therefore the space will be reduced because generator can be neglect. The size of will be more compact and the weight also can be minimize. [7] As recent studies demonstrated [10; 11], to prove the advantage topology and energy flow strategy in parallel HEV. In parallel configuration, power can be split between ICE and electrical path from electrical motor. The disadvantage is these splits are dependent on control itself. [12]

2.2 Energy Management System in HEV

In order to increase the efficiency of HEV, the energy use in the system must be manage. One of the technique can be apply are by using Ultracapacitor and Neural Network. By using Neural Network (NNS) that already developed and tested. This system will minimize the energy requirement of the vehicle. The battery uses are lead-acid type to built ultracapacitor bank (UCAP). [13]

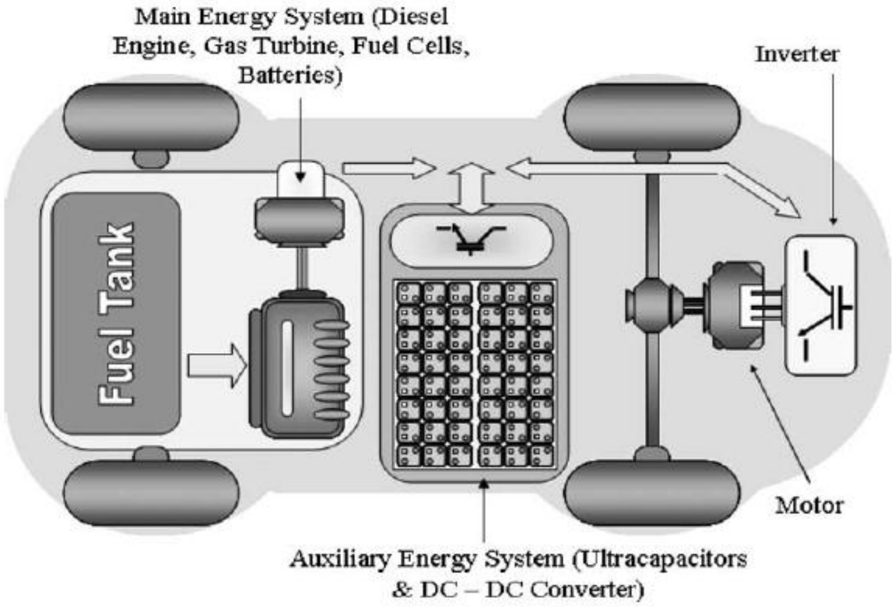


Figure 2 Power Circuit for typical serial hybrid vehicle [13]

2.2.1 Adaptive Equivalent Consumption Minimization Strategy

An Adaptive Algorithm for Hybrid Electric Vehicle was one type of energy management. This strategy was called ECMS. Real time energy management for HEV was obtained by adding to ECMS framework an on-the-fly algorithm for estimation of equivalence factor according driving condition. The main idea was periodically refresh the control performance according to speed of driving so state of charge maintain in boundaries and fuel usage can be minimize as possible. [14]

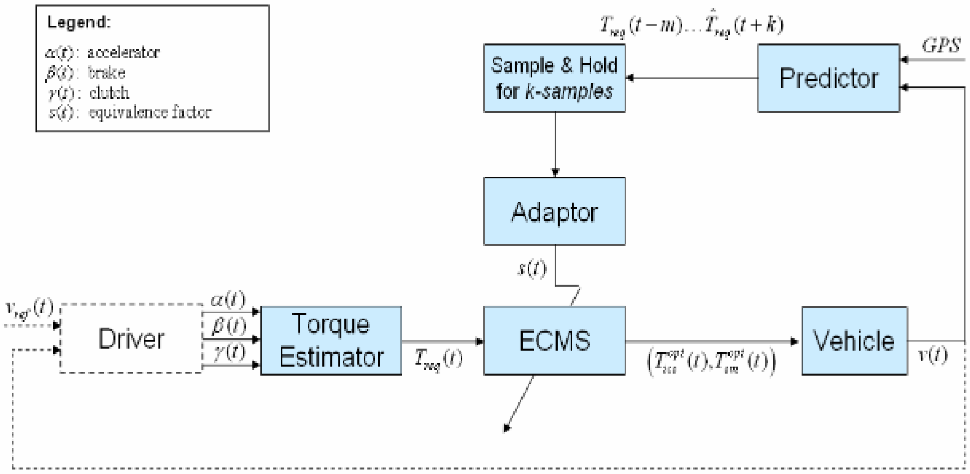


Figure 3   Control Block Diagram of ECMS [14]

2.2.2   Genetic Algorithm (GA)

Employment of Genetic Algorithm (GAs) can minimize a cost function descriptive of design objective in term of fuel consumption and emissions. The propose methodology start from design of vehicle in the road and identification of the value of energy flow management parameter. Genetic Algorithm seems to be suitable. Compared to other optimization methods such as calculus-based and enumerative strategies are global and can be apply without resource to domain-specific heuristics. The parameters are determined to identify which parameter can be control. Parameter such as battery state of charge, vehicle speed below engine shut off, torque below engine shut off and load torque applied to the engine to recharge the battery. [3]

2.3 Preliminary Rule-Based Control Strategy

There are five possible operating modes for parallel hybrid vehicle. The operating modes are motor only, engine only, power assist (engine and motor), recharging (engines charge the battery) and regenerative braking. To get the best power management, the controller must decide in which time the useful operating modes only operate. The power management design process starts by interpreting the driver pedal as power request. Through this power request will determine which operating modes needed. [15]

Power split control is apply to control the efficiency of the usage of operating modes. [16] Figure 4 showing the configuration of the power split control.

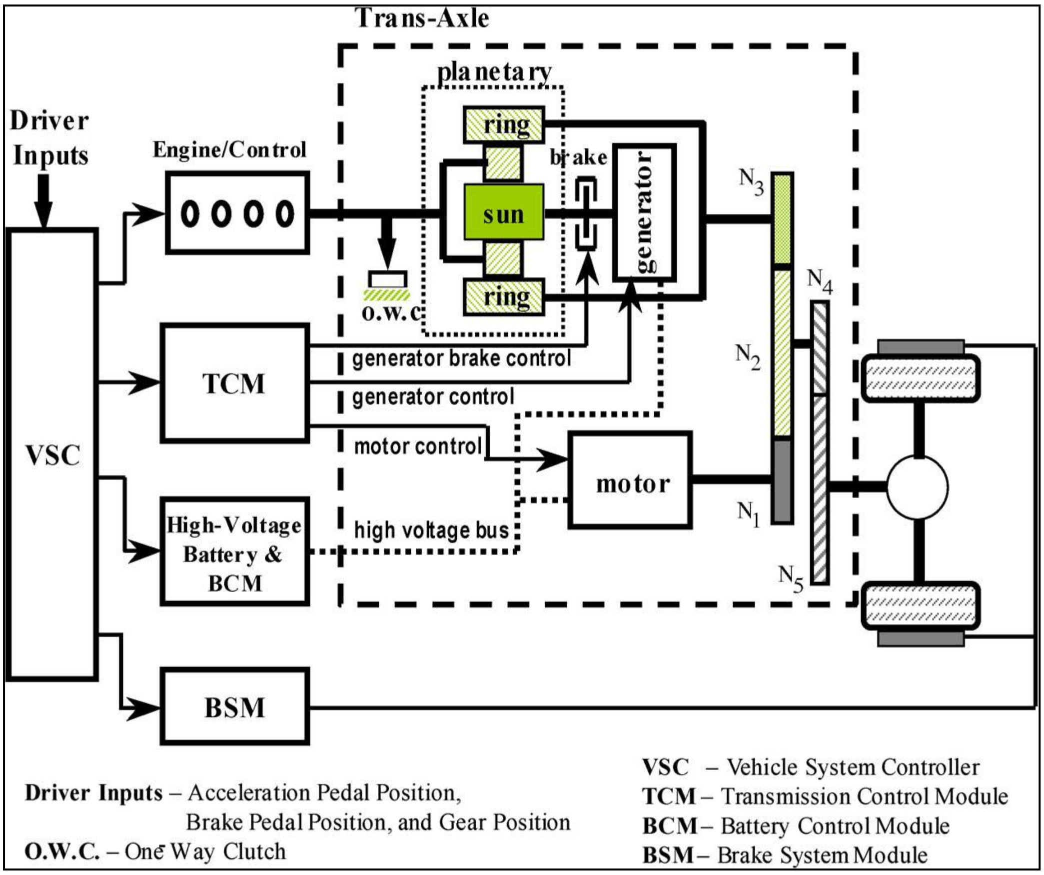


Figure 4 Power-split type HEV configuration [16]

2.4 Fuel Cell Based Propulsion System

Fuel Cell is one type of system use that beneficial in overall efficiency and quieter operation. There are many types of fuel cell that can be differentiated according to their electrolyte material used. There are proton exchange membrane (PEM) fuel cell and the solid oxide fuel (SOFC) that use for normal automotive application. [8]

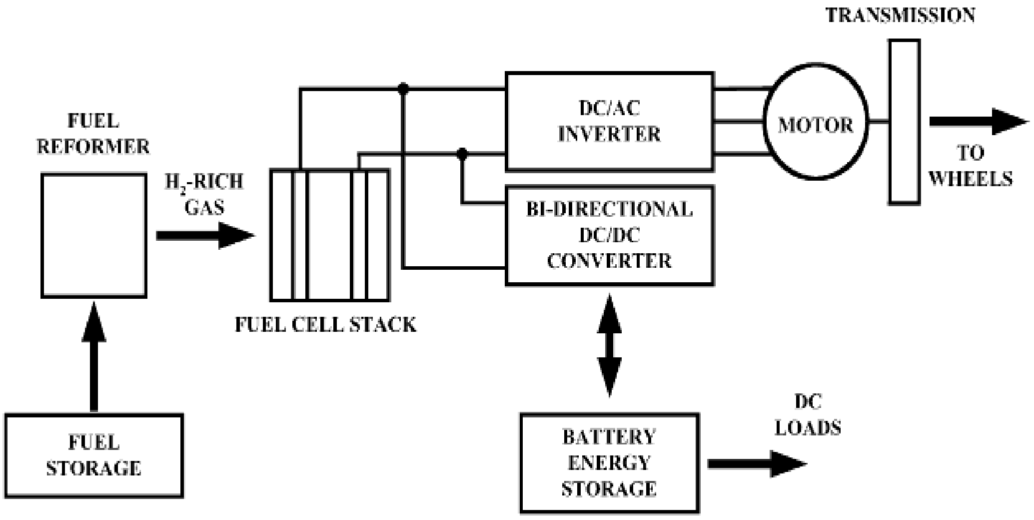


Figure 5 Schematic Layout of a fuel cell system with a fuel processor [8]

As shown in figure 5, the hydrocarbon fuel will reform to obtain the hydrogen using reformer (fuel processor). The hydrogen then will be link to anode cell. The hydrogen also can be store using pressurize cylinder. The oxygen gas will be link to the cathode cell. The flow of hydrogen and oxygen will produce dc output voltage. [17] The output of fuel cell stack is fed to the power conditioner to get the require output voltage and current. Theoretically the power conditioner must have minimal loss. Power conditioning efficiency can goes to 90%. [18] Fuel cell can replace batteries in pure battery electric vehicles. The main power sources use for HEV can be replaced by the fuel cell stack. [19]

2.5 Induction electric motor

Basically induction motor use an AC supply. Power is supplied to the rotor by means of electromagnetic induction. The DC supply must be converted to AC first to get AC supply to the induction motor. Induction motor gives large torque to the wheel. [20] Figure 6 showing the configuration of the hybrid vehicle using induction motor. The configuration is much complex because the supply need to be converter to AC sources.

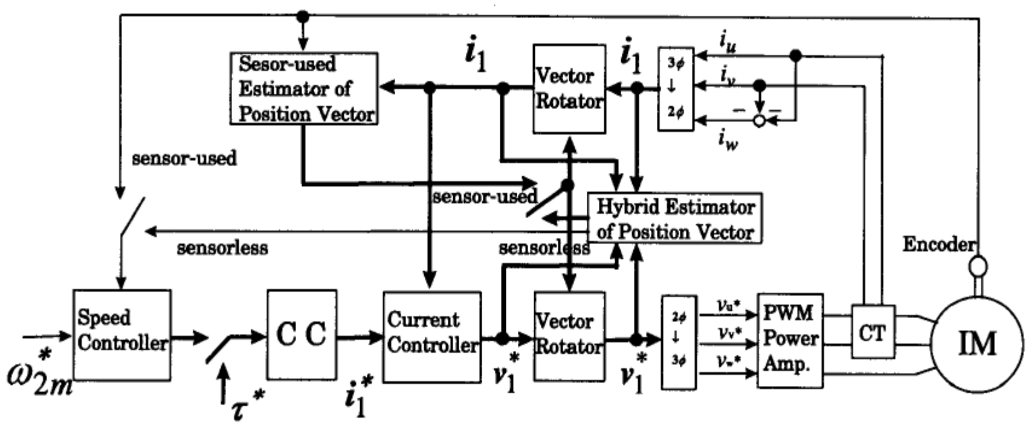


Figure 6 Drive Control System for EV [21]

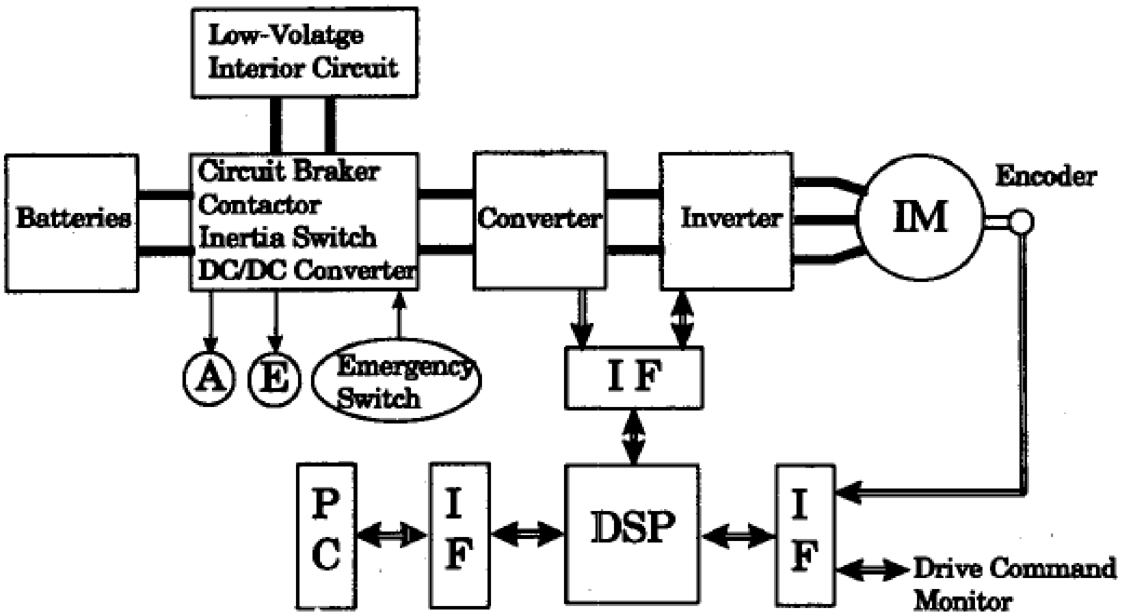


Figure 7 Configuration of Electric Power & Signal Transmission system for EV [2]

The operation of all the operation is being control by single Digital Signal Processing (DSP) board. Main parts of the drive in figure 6 are just a piece of board in figure 7.The batteries uses are lead-acid battery DC supply. The signal from the rotation of induction motor will be sent to the board.

2.6 FPGA Based Powertrain Control for Electric Vehicle

Some method using Field-Programmable Gate Array (FPGA) platform to address the powertrain control is being present. This platform uses the electric motor and the power converters control, of multi-motor EVs. This FGPA is better than using DSP control because it can reduce the cost. [22] The advantages of FPGA are high processing speed, modularity and parallel capabilities, and hardware reconfigurability.

2.6.1 Features of FPGA

The features of FPGA are to increase the torque control and decrease the discretization effects of some control and estimation techniques. [23] Other features are FPGA parallelism and modularity features open up new idea to incorporate multi-motor control in a single chip. This feature can be use for multi-axis robotic manipular arm. [24]

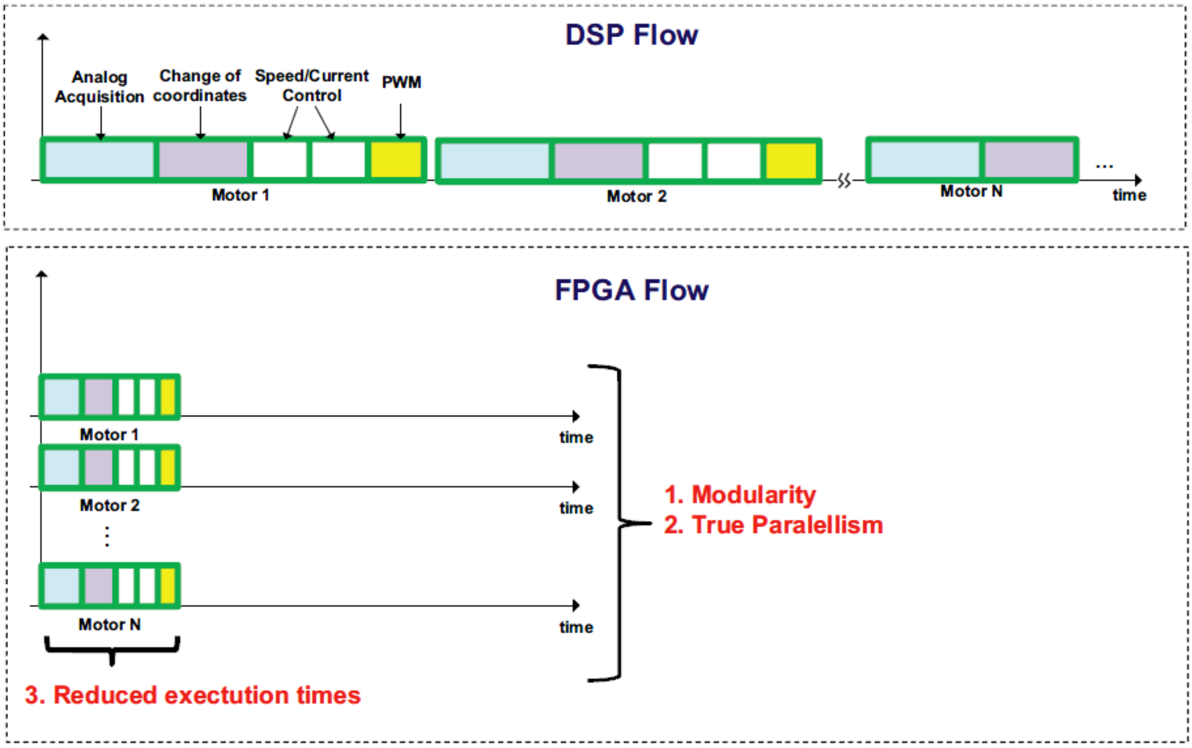


Figure 8 Advantage of FPGA when controlling multiple electric motor [25]

Some other features FPGA have a logic that allows the development a custom PWM in the logic. This solve one of problem of DSP architecture that multi-level modulation problem. [22] The challenge for this system is the designing time and the learning curve associate to the tools regarding FPGA. The lack in FPGA's is the absence of analog peripherals like analog to digital converter. This will cause additional external component on the control board.

2.6.2 Powertrain IP core library

This is inspired by the vector control signal processing blockset for use with Matlab-Simulink. Firstly at low level controller such as Proportional and Integral Controller, modulators, mathematical transformation were appllied. For next level, the motor control incorprote with block of estimation to regulate the electric motor torque and flux. The energy will be minimize once this process. [26]

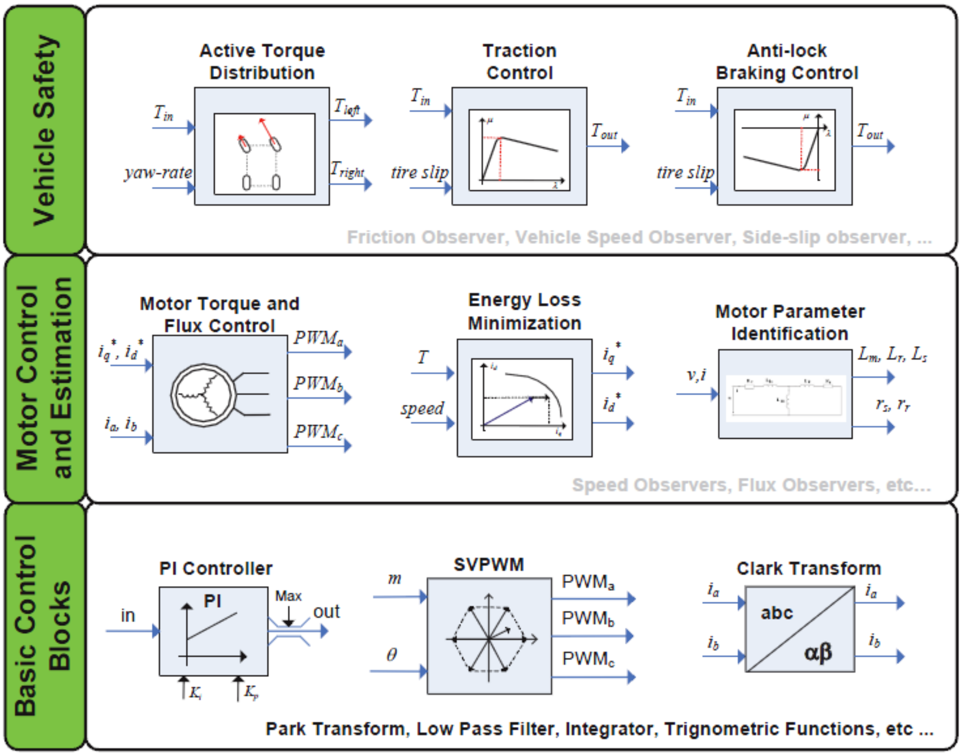


Figure 9 Powertrain IP Core Library for control of EV [25]

The library advantages are the designer has flexibility to specify controller architechure that fit the design objectives. It applies from basic powertrain controllers untul advances solutions with minimum of energy usage and driving aid system. To conclude, IP Core Block represent out of box solution to specific powertrain control problem.

Chapter 3
METHODOLOGY

3.1 Procedure and Identification

In order to achieve the objective of the project, research and investigation will be done. The research will be done on the method of control strategy in hybrid vehicle in books, journal and any technical paper to obtain information that related to the project. The issues relevancy between the selected papers and our project's objective need to be taken into account to ensure the credibility of this project. This project will be divided into two parts which is first part is final year project 1 and the other part is final year project 2. In final year project 1 a study on the methods and control strategy that going to be simulates and experimented.

In final year project 2, implementation of the method in software will be done and data collection will be done. The analysis will be done to investigate the rule-based strategy and to analyse the energy balance in the system. All the result be analyse in different part of the MATLAB Simulink model.

3.2 Flow Chart

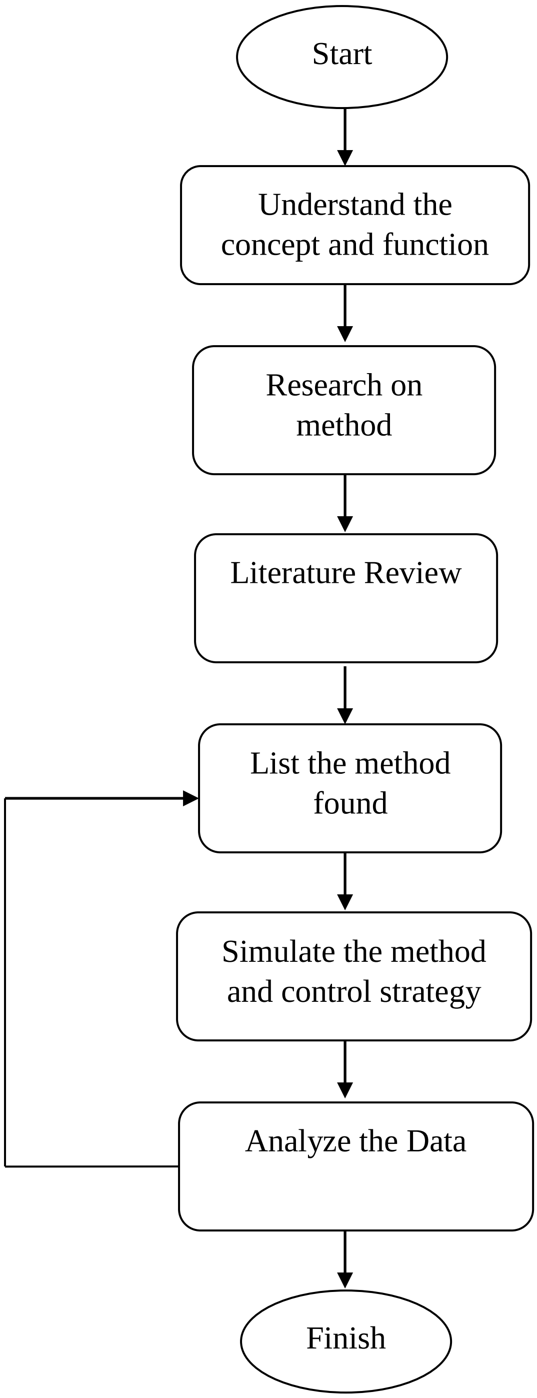


Figure 10 Flow of the project

3.3 Duration of Project

Activities	FINAL YEAR PROJECT 1													
	NO OF WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Choose Topic														
Study Topic														
Literature Review														
Research on the method														
Analyze the method														
List the method to simulate														
Run first stage simulation														

Table 1 Gantt Chart for Final Year Project I

Activities	FINAL YEAR PROJECT 2													
	NO OF WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Analyze the model														
Run the simulation														
Data Gathering														
Report Writing														

Table 2 Gantt Chart for Final Year Project II

3.4 Proposed Model

For experimental purpose, a dynamic model for Toyota Prius 2004 hybrid electric vehicle will be use. The model will base on Matlab Simulink HEV model which will be use to get the result and modification will be made. Below is a block diagram showing how the model will be structure in Matlab Simulink.

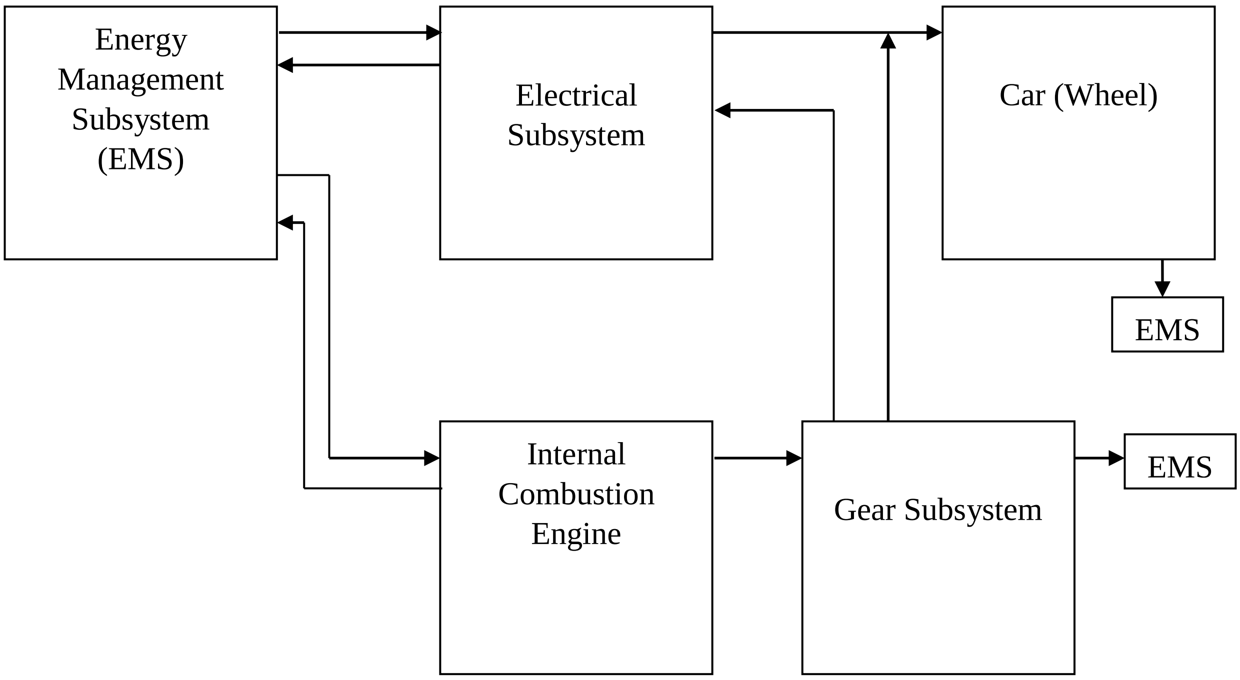


Figure 11 Block diagram of the system

3.4.1 Energy Management System

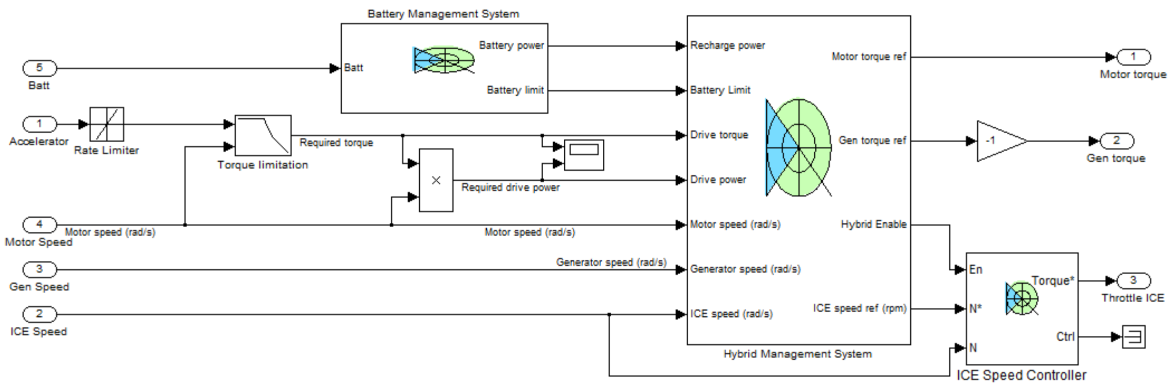


Figure 12 Energy Management System

Energy Management Subsystem is based on vehicle speed, subsystem that contain engine, motor and generator, input accelaration (drive cycle) and battery’s variable and also state of charge (SOC). This subsystem contains a main controller that define the amount of torque that each torque source like internal combustion engine and electrical motor should produce and divided by three parts that is battery management, hybrid management and ICE speed controller. Battery management system receive battery’s data values from energy storage subsystem to limit the range of SOC wanted and to specify the amount of receiving or sending power for battery

As figure 12 for hybrid management system there are subsystem itself as figure 13, the amount or required torque for engine, traction motor and generator can be determine by the help of subsystem;s rotatating speed and demand power as well as torque defined by the amount of accelaration and brake pedal from drive cycle.

At first, state of hybridization is determined by demanded power, vehicle speed ,and battery’s SOC. In elementary model the instant of hybridization is not specified by vehicle speed, but according to DOE report, any increase in speed more than 24 km/h should activate ICE , therefore speed condition is added to this function

Another improvement in Simulink model is about motor reference torque during the brake time when the brake power exceeds the power capacity limit of battery. In our model, additional power is sent to a mechanical brake instead of motor and battery pack. In addition A DC link voltage controller has been added to the original model that provides the ability of dc link voltage controlling in different vehicle cycling modes. This has not been considered in MATLAB original model.ICE speed controller produces reference torque for ICE from its speed that achieved from efficiency map. Note that the efficiency map in MATLAB Simulink model doesn’t match with original map that this problem has been corrected in new model

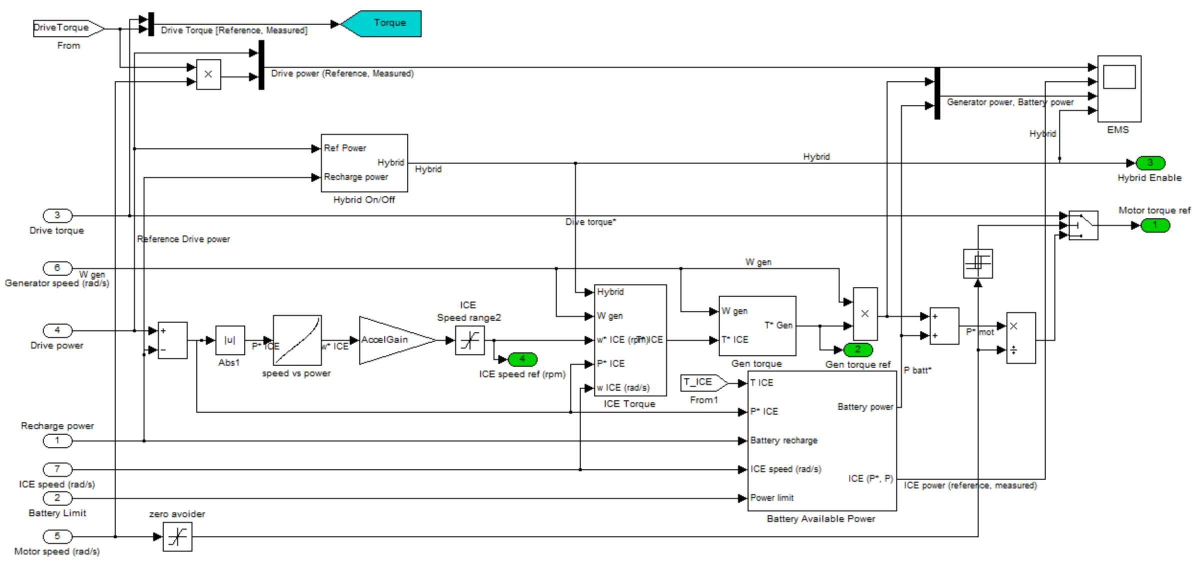


Figure 13 Hybrid Management System

3.4.2 Electrical Subsystem

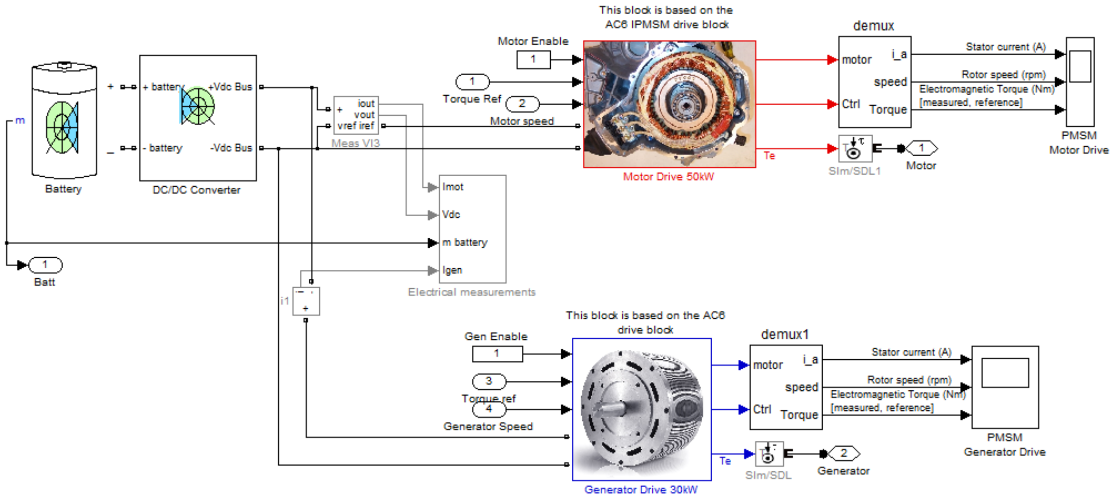


Figure 14   Electrical Subsystem

This subsystem contains motor and generator and planetary gear (Fig. 4). Motor has field weakening controller and its characteristics are like torque-speed data provided by DOE report.

3.5 Preliminary Rule-Base Strategy

The method use to implement in the simulation design was rule base strategy. Rule base strategy will have five possible modes. These modes will be determined by energy management system (EMS) according to driver's input. Driver's input will be the percentage of throttle being pressed. For this model the percentage of the throttle will be set by the author.

The modes that will be chosen by EMS in this strategy will give best performance to HEV. For example: if the drivers press 10% of the throttle, the EMS will determine which mode is better to reduce the usage of ICE but in the same time satisfy the need of the driver. The motor mode only will be applies when the speed demand by the driver is at minimum. If the drivers press the throttle more than 80%, the EMS will determine the best mode that will increase the speed using both electric motor and ICE.

The other modes are ICE mode only. In this mode only ICE will be running. This mode can be applied for the stage if the driver want the speed is to be intermediate speed. Only the ICE will be running in optimal rate. If the drivers want to speed further, the hybrid mode will be activated. In hybrid mode, ICE and electric motor will be run together to give drives to the vehicles. If the state of charge of battery reaches the lowest state, the ICE will be activated to transfer its energy to generator. Through the generator, ICE mechanical movement converted to electrical energy will charge the battery. If the modes are in hybrid mode, then the ICE needs to divide the power to drive the vehicle and charging the battery.

The brakes will be applied for conventional ICE vehicle if the driver wants to reduce speed. This braking process will cause the energy where that energy will be dissipated and wasted. For rule base strategy, the braking dissipated energy will be transferred to generator through planetary gear to charge the battery. Therefore the braking process will be beneficial to the system. This braking mode called regenerative braking.

Two phase of model will be run for this project. The first phase of model will be analyse on lowest SOC is 40% and the ICE will stop charging at 80%. For second phase of model will be analyse on lowest SOC is 30% and the ICE will stop charging the battery at 90%. The result will be analyse and discuss in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

Energy Management Subsystem is the important part in hybrid electric vehicle. One part in the simulation that must be controlled by energy management subsystem was electrical subsystem. Electrical subsystem contains battery, 30kW generator drive, 50kW Motor drive and DC to DC converter.

The model off hybrid electric vehicle series-parallel architecture of Toyota Prius is being used to demonstrate rule base strategy. These batteries are connected inside the electrical subsystem. The dc/dc converter acts as voltage regulator. It will be connected to the batteries to maintain constant value needed by the system. Electrical Management System (EMS) determines the reference signals for the electric motor drive, the electric generator drive and the internal combustion engine in order to distribute accurately the power from these three sources. In EMS the battery state of charge will be controlled accordingly to requirement.

The motor drive is 500Vdc, 500kW interior Permanent Magnet Synchronous with associated drive. The motor drive use to apply mechanical torque on system. The generator is 500 Vdc, 2 pole, 30kW PMSM with the associate drive. Generator drive is use to generate electricity to charge the batteries when it is needed. After individual verification of each component, the entire vehicle model was compared with published data for Toyota Prius performance ratings such as the acceleration time between 0 – 80 km/h.

4.1 Parameter analyse

Parameters that controlled inputs of the model are:

1. Throttle position (0-100%)
2. Initial Speed (km/h)
3. Initial Battery State of Charge
4. Applying Brake for Regenerative Braking

Each input aspect is controlled by the users. In the case of this model, every input aspect is being set accordingly to the model through the time of the model run. As the result of the input and the entire system in this model, the outputs which can be analysed are:

1. Vehicle Speed
2. Current battery State of Charge
3. Voltage Consumption

Most importantly, the behaviour of every part in the car can be analyse when the state was change from another state due to the preliminary rule base apply in this model. HEV speed starts from 0 km/h and reaches 73 km/h at 14 s, and finally decreases to 61 km/h at 16 s. This result is obtained by maintaining the accelerator pedal constant to 70% for the first 4 s, and to 10% for the next 4 s when the pedal is released, then to 85% when the pedal is pushed again for 5 s and finally sets to -70% for braking until the end of the simulation. This movement of from another state to another state can be view through scope in the car block.

The investigation are divided into two phase that is first phase to analyse the result if we set the state of charge lower than 40% and higher than 80%. For the first case, when SOC lower than 40% generator will be activated to charger the battery and when SOC higher than 80 % the generator will be off. The second phase is SOC lower than 30% and higher than 90%. Both phase will be analyse on their energy performance and car performance.

Subassembly	Specifications	
	Description	Value
Vehicle	Weight	1360kg
Maximum Vehicle Speed	Electric Mode	60km/h
	Hybrid Mode	80-160 km/h
Engine	Max Power	57kw/5000rpm
Planetary Gear	Ratio(ring/planet/sun)	2.6 (78/23/30)
Electric Motor	Maximum power	50kW
	Maximum Torque	400Nm (0-1200rpm)
	Maximum Speed	6000rpm
Electric Generator	Maximum power	30kW
	Maximum Torque	160Nm
	Maximum Speed	10000rpm
Battery	Nickel Cadmium number	28
	Nominal Energy	1.3kWh
	Nominal Voltage	201.6V

Table 3 Toyota Prius Model Components

4.2 The first phase for SOC lower than 40% and higher than 80%.

The following explains what happens when the HEV is moving:

- At t = 0 s, the HEV is stopped and the driver pushes the accelerator pedal to 70%. As long as the required power is lower than 12 kW, the HEV moves using only the electric motor power fed by the battery. The generator and the ICE provide no power.
- At t = 1.4 s, the required power becomes greater than 12 kW triggering to initiate the hybrid mode. In this case, the HEV power comes from the ICE and the battery through the motor. The motor is fed by the battery and also by the generator. In the planetary gear, the ICE is connected to the carrier gear, the generator to the sun gear and the motor and transmission to the ring gear. The ICE power is split to the sun and the ring. This operating mode corresponds to acceleration.

- At t = 4 s, the accelerator pedal is released to 10%. It shows the driver want to use cruising mode. The ICE cannot decrease its power instantaneously; therefore the battery absorbs the generator power in order to reduce the required torque.
- At t = 4.4 s, the generator is completely stopped. The required electrical power is only provided by the battery.
- At t = 8 s, the accelerator pedal is pushed to 85%.When pedal pushed to 85% it shows the driver want the car to be faster. Therefore ICE is restarted to provide the extra required power. The total electrical power in generator and battery cannot reach the required power due to the combination generator and ICE assembly response time. Hence the measured drive torque is not equal to the reference.
- At t = 8.7 s, the measured torque reaches the reference. The generator provides the maximum power.
- At t = 10 s, the battery SOC becomes lower than 40% because it was initialised to 41.53 % at the beginning of the simulation. Therefore the battery needs to be recharged. To charge the battery, the generators have to split its power by shares between the battery and the motor. It can be observe that the battery power becomes negative. It means that the battery receives power from the generator and recharges while the HEV is accelerating. At this moment, the required torque cannot be met anymore because the electric motor reduces its power demand to recharge the battery.
- At t = 13 s, the accelerator pedal is set to -70% and regenerative braking is simulated on this part. This is done by switching off the generator and the generator power takes 0.5 s to decrease to zero. This happens 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 is stored in the battery. For this pedal position, the required torque of -250 Nm cannot be reached because the battery can only absorb 21 kW of energy.

At t = 13.5 s, the generator power is completely stopped. The view of accelerator is shown in figure 15.

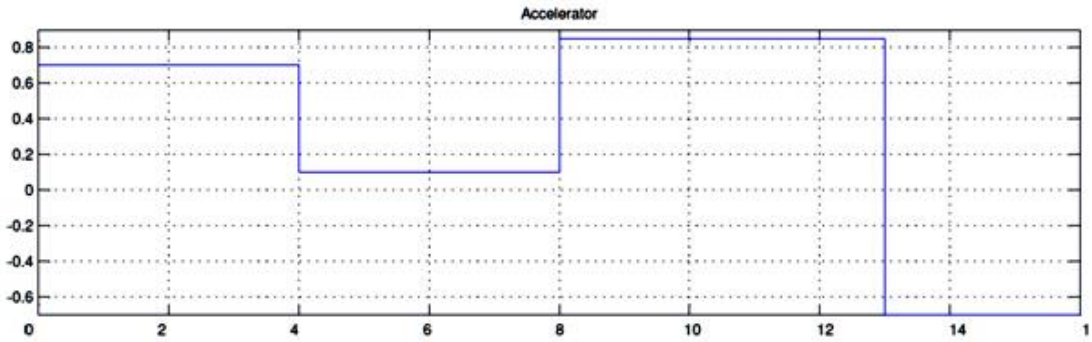


Figure 15 The accelerator of the car (first phase)

In figure 16, it showed the car speed in kilometre per hour. At first when the throttles are 70%, the speed is increasing slowly to 40km/h. Then accelerator decrease 10% but the speed does not decease instantaneously because ICE cannot be stop on the spot.

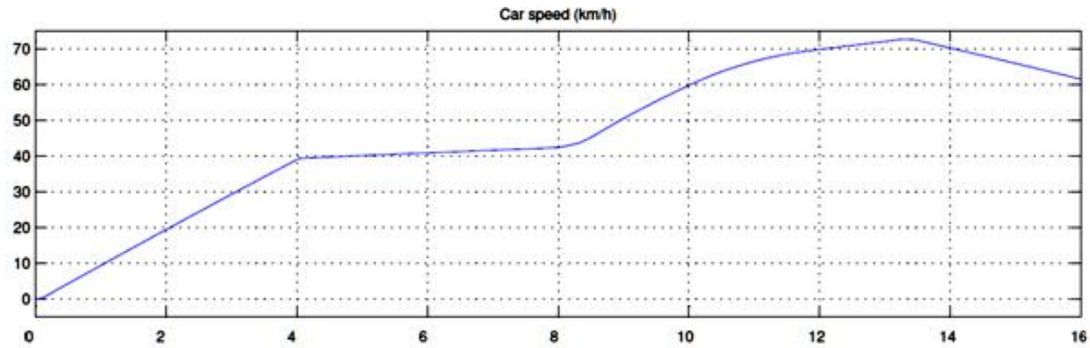


Figure 16 The car speed (first phase)

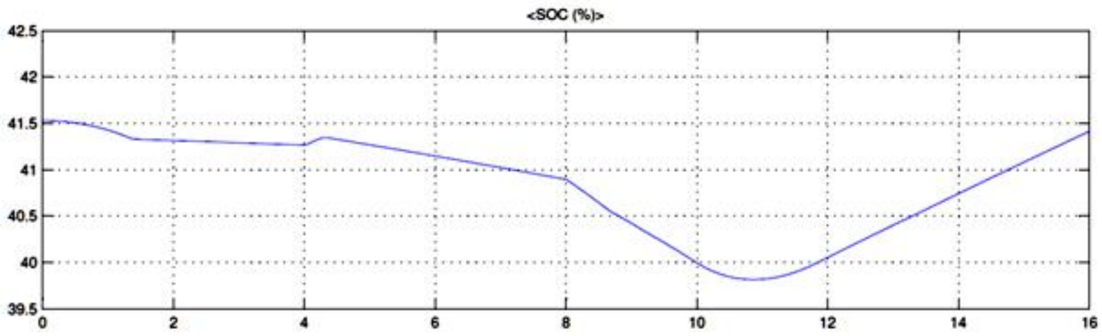


Figure 17 State of Charge (first phase)

In figure 17 shows the flow of state of charge of this model. Battery Management System will maintain the state of charge between 40%-80%. It also will prevent the voltage collapse by make sure the power require by the battery. Electrical power used by motor, electrical power produce by the battery and the electrical power that produce from generator shown in figure 18 below. At 4.4 s the generator stop due to increment of ICE.

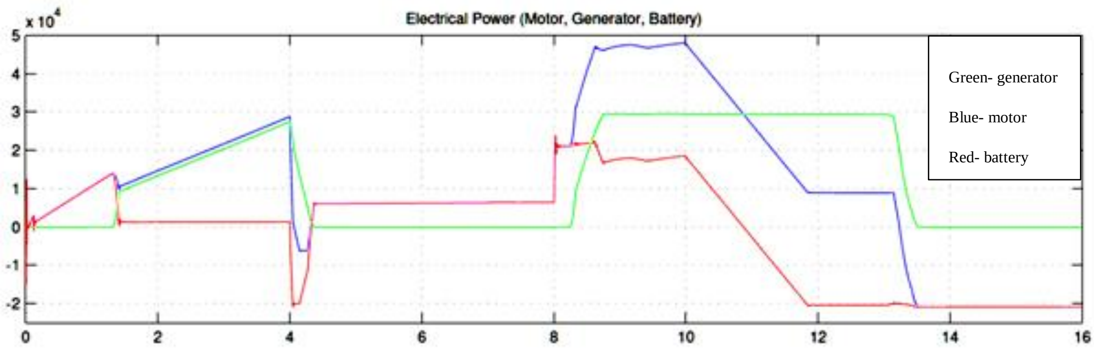


Figure 18 Electrical power (first phase)

4.2.1 Energy Management Subsytem Analysis

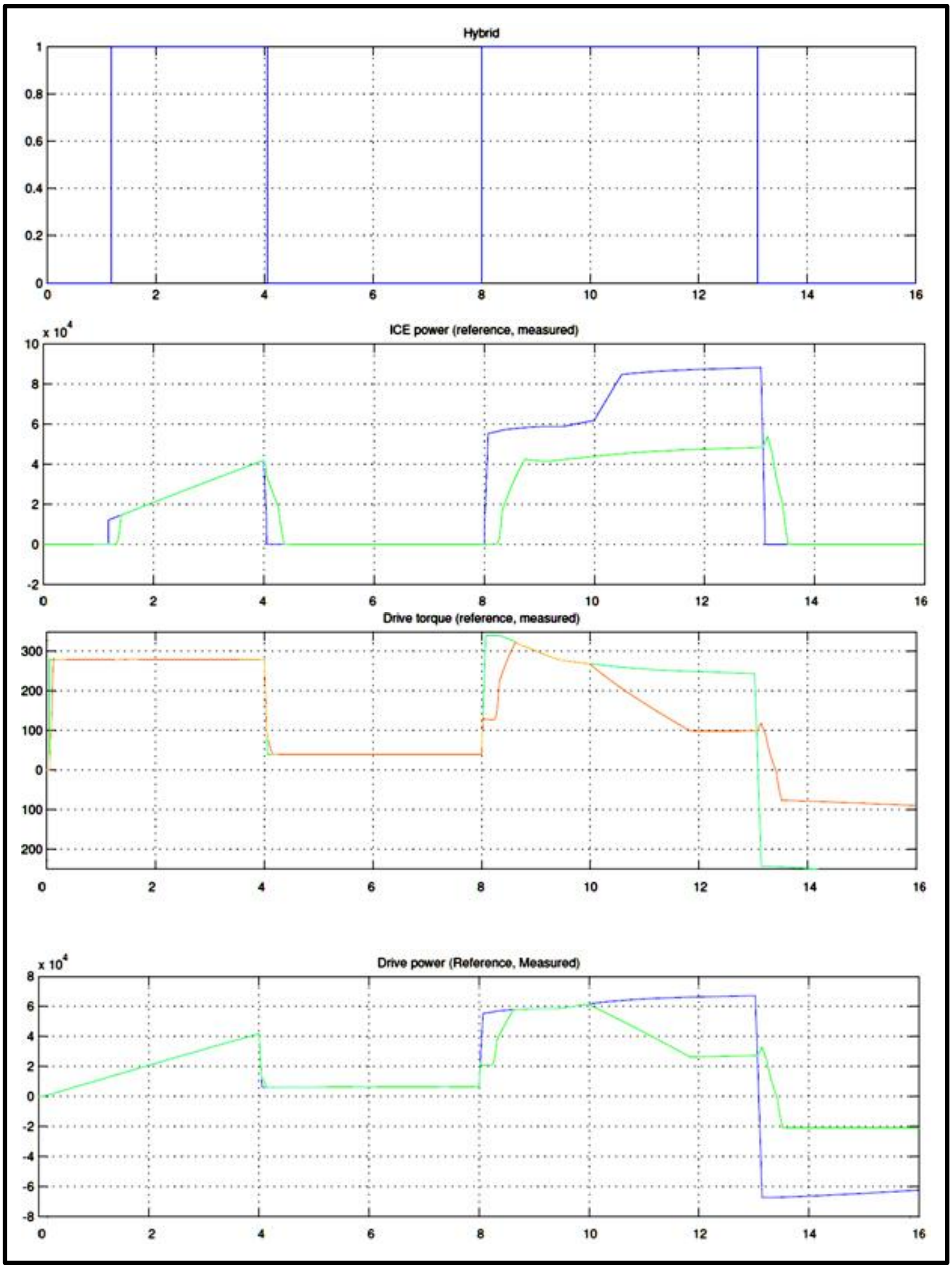


Figure 19 EMS Analysis (first phase)

4.2.2 Internal Combustion Engine

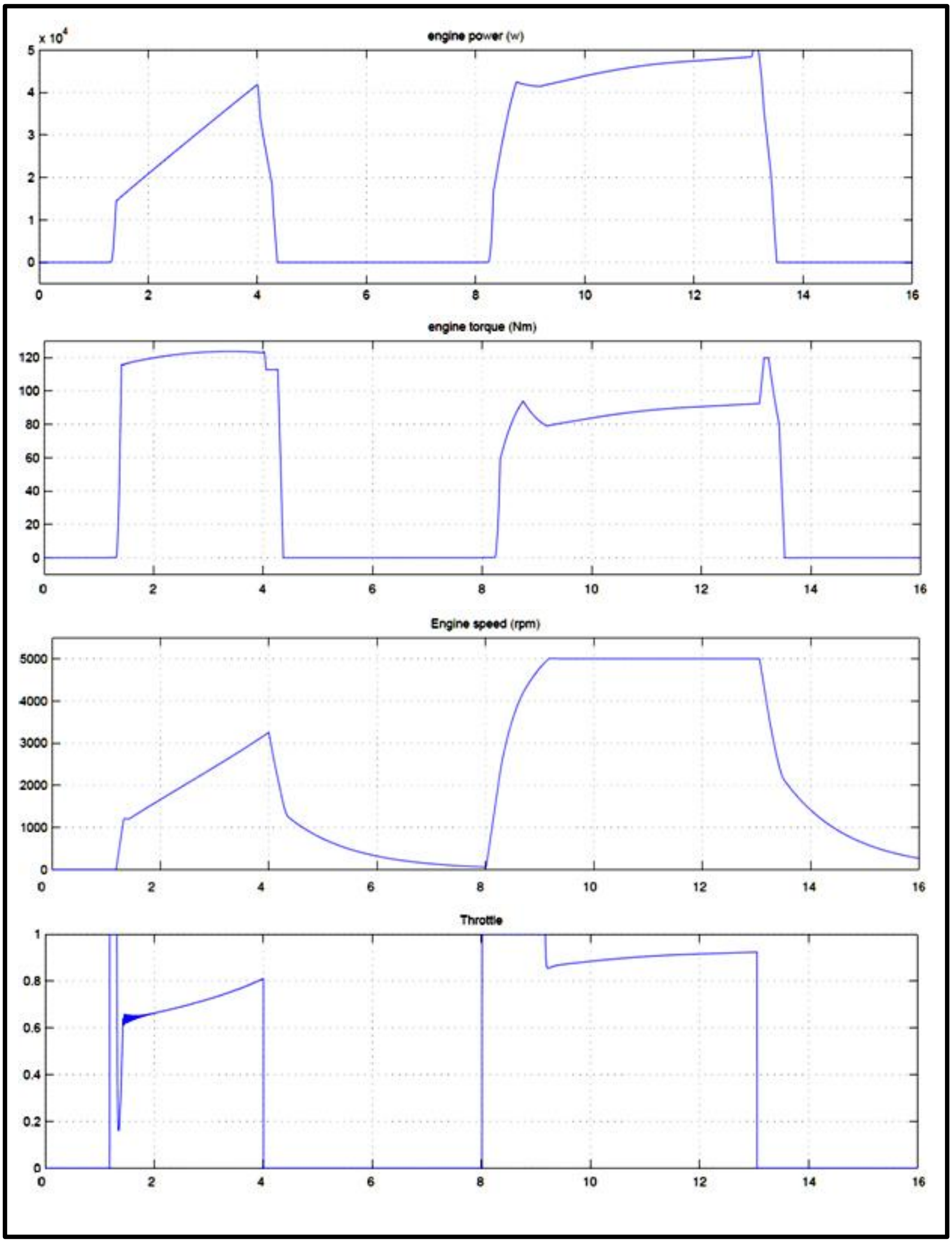


Figure 20 ICE Analysis (first phase)

4.3 The second phase for SOC lower than 30% and higher than 90%.

The following explains what happens when the HEV is moving:

- At t = 0 s, the HEV is stopped and the driver pushes the accelerator pedal to 70%. As long as the required power is lower than 12 kW, the HEV moves using only the electric motor power fed by the battery. The generator and the ICE provide no power.
- At t = 1.4 s, the required power becomes greater than 12 kW triggering to initiate the hybrid mode. In this case, the HEV power comes from the ICE and the battery through the motor. The motor is fed by the battery and also by the generator. In the planetary gear, the ICE is connected to the carrier gear, the generator to the sun gear and the motor and transmission to the ring gear. The ICE power is split to the sun and the ring. This operating mode corresponds to acceleration.
- At t = 4 s, the accelerator pedal is released to 10%. It shows the driver want to use cruising mode. The ICE cannot decrease its power instantaneously; therefore the battery absorbs the generator power in order to reduce the required torque.
- At t = 4.4 s, the generator is completely stopped. The required electrical power is only provided by the battery.
- At t = 8 s, the accelerator pedal is pushed to 85%.When pedal pushed to 85% it shows the driver want the car to be faster. Therefore ICE is restarted to provide the extra required power. The total electrical power in generator and battery cannot reach the required power due to the combination generator and ICE assembly response time. Hence the measured drive torque is not equal to the reference.
- At t = 8.7 s, the measured torque reaches the reference. The generator provides the maximum power.
- At t = 10 s, the battery SOC becomes lower than 30% because it was initialised to 41.53 % at the beginning of the simulation. Therefore the battery needs to be recharged. To charge the battery, the generators have to split its power by shares between the battery and the motor. It can be observe that the battery power becomes negative. It means that the battery receives power from the generator and recharges while the HEV is accelerating. At this

moment, the required torque cannot be met anymore because the electric motor reduces its power demand to recharge the battery.

- At t = 13 s, the accelerator pedal is set to -70% and regenerative braking is simulated on this part. This is done by switching off the generator and the generator power takes 0.5 s to decrease to zero. This happens 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 is stored in the battery. For this pedal position, the required torque of -250 Nm cannot be reached because the battery can only absorb 21 kW of energy.

At t = 13.5 s, the generator power is completely stopped. The view of accelerator is the same as phase one (refer figure 15).

In figure 16, it showed the car speed in kilometre per hour. At first when the throttles are 70%, the speed is increasing slowly to 40km/h. Then accelerator decrease 10% but the speed does not decease instantaneously because ICE cannot be stop on the spot. For second phase it have to take longer time to decrease its speed.

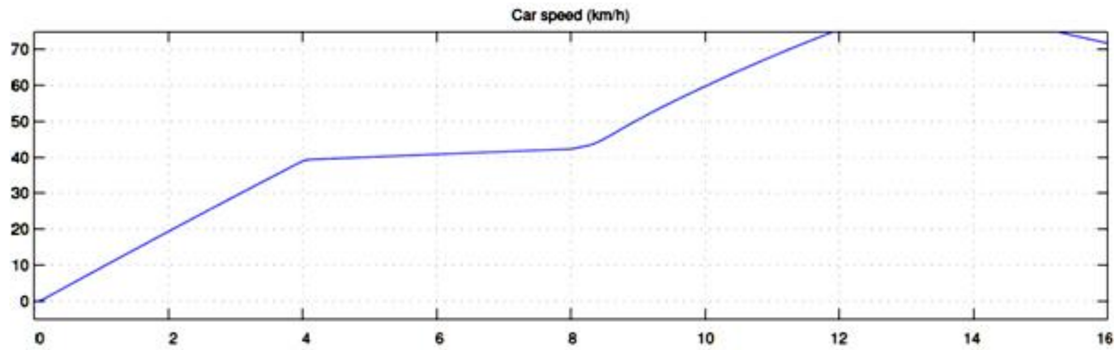


Figure 21 Car Speed (second phase)

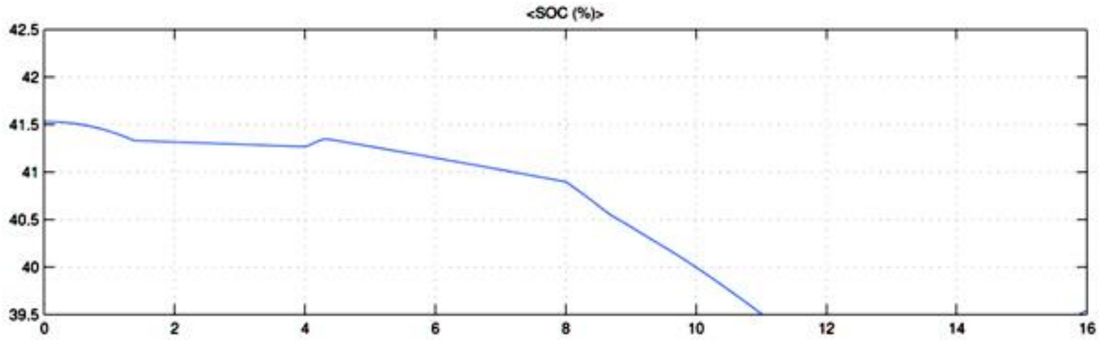


Figure 22 SOC (second phase)

In figure 22 shows the flow of state of charge of this model. Battery Management System will maintain the state of charge between 30%-90%. It also will prevent the voltage collapse by make sure the power require by the battery. For second phase, the state of charge tends to drop faster and takes longer time to recharge again. Electrical power used by motor, electrical power produce by the battery and the electrical power that produce from generator shown in figure 23 below. At 4.4 s the generator stop due to increment of ICE.

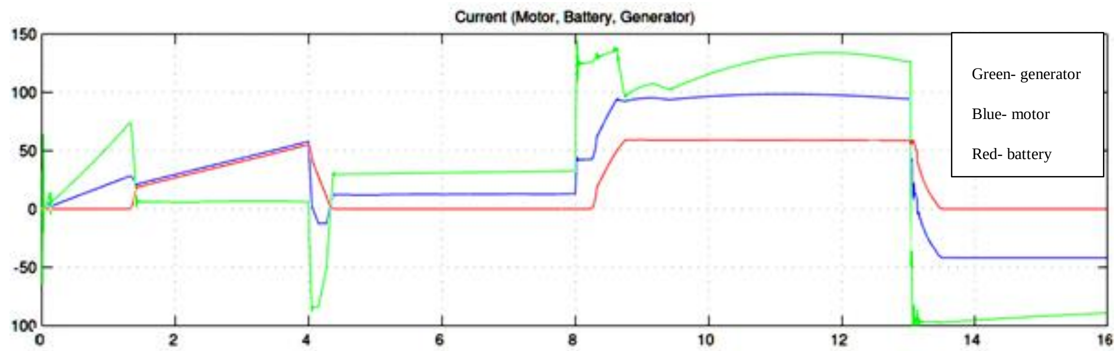


Figure 23 Electrical power (second phase)

4.3.1 Energy Management Analysis

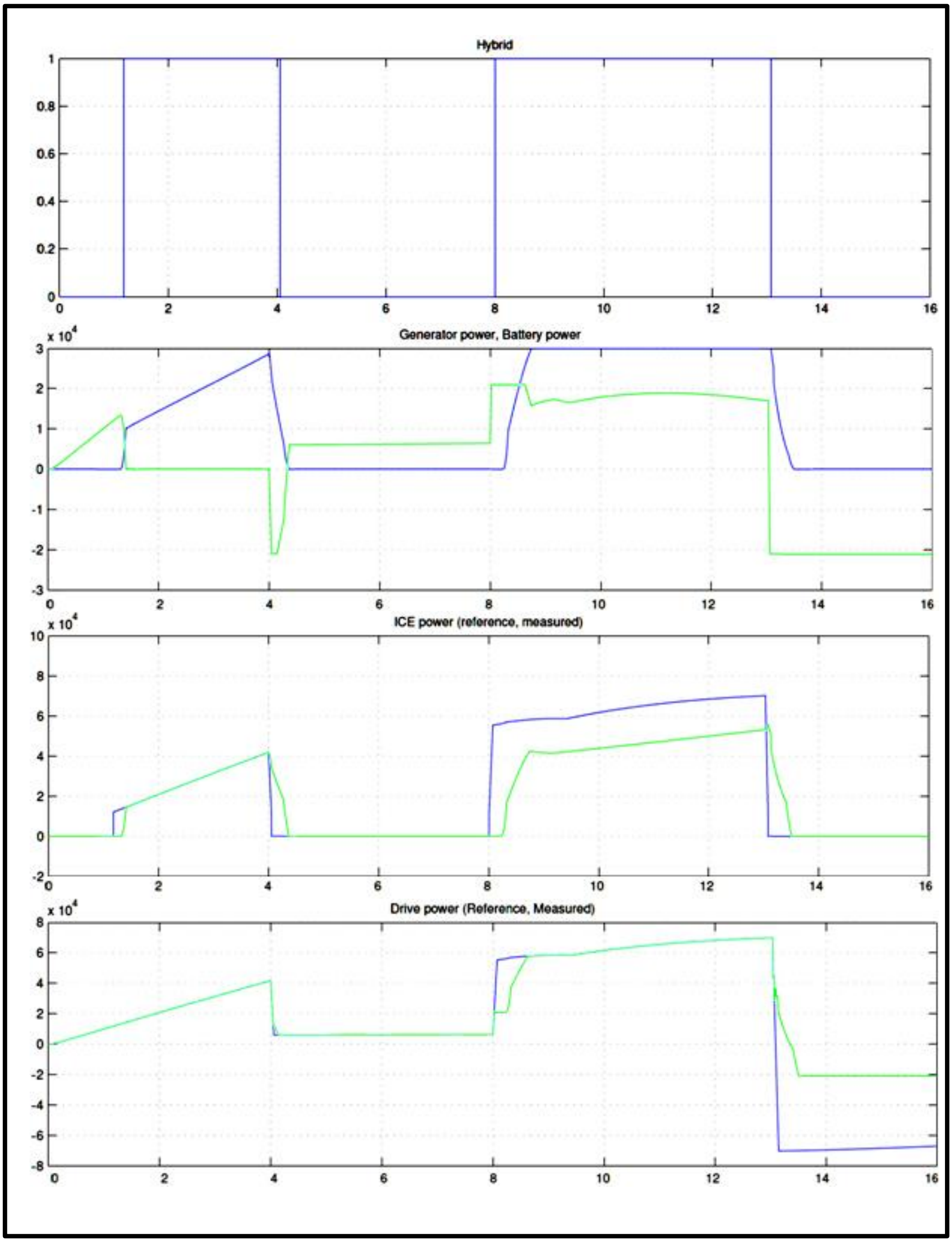


Figure 24 EMS Analysis (Second phase)

4.3.2 Internal Combustion Analysis

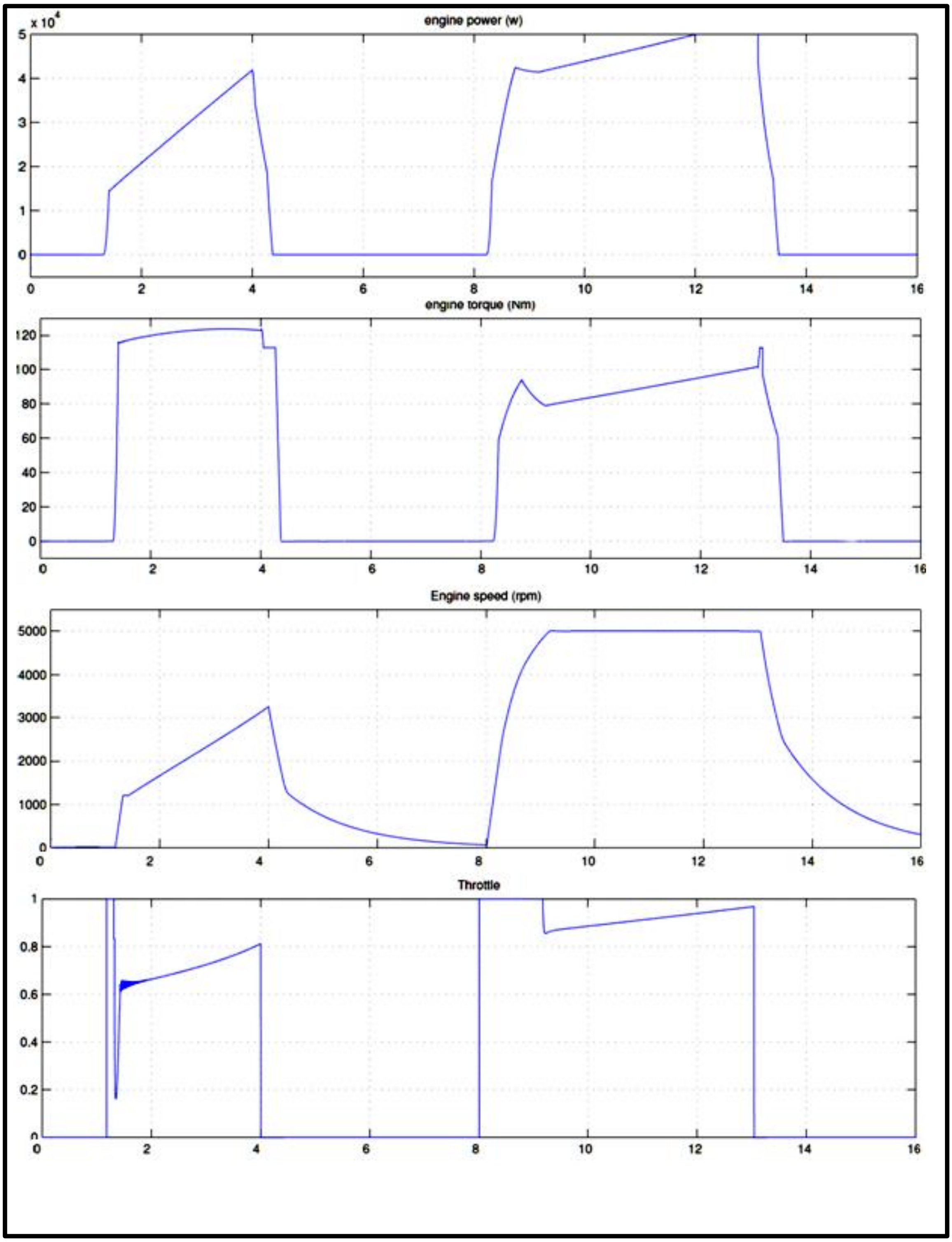


Figure 25 ICE Analysis (second phase)

CHAPTER 5
CONCLUSIONS & RECOMMENDATION

5.1 Conclusion

This report presents the work done by the author of the project simulation of hybrid electric vehicle using Matlab Simulink. Hybrid Electric Vehicle is a wide area of research project nowadays because of the importance of reducing usage of internal combustion engine. Due to inefficient of hybrid vehicle on early time of its approach, a lot of research has been done.

Most of main objective in this report are about to develop rule base control strategy for series parallel hybrid vehicle. Every part such as internal combustion engine, electric motor and electrical system will be control by the energy management system. Energy Management system is the very important part for hybrid electric vehicle. With energy management, the driver can know the status of the car and usage of every part can be maximized. Every system in the energy management system must be familiarize and understand in order to get the best result. Any improvement will be focus on energy management system. In this report shows the first phase of energy management are better than second phase. This is because the SOC for first phase can stay much longer than second phase.

The author also has to learned Matlab Simulink software. Mostly the library in the Matlab Simulink can be use to build a model of electric vehicle. The challenge is to understand all the model part and simulate. The model of Toyota Prius is a complex model to be understand.

5.2 Recommendation

A model need to well build and experiment must be done in order to examine energy management system through Simulink Matlab Model. Therefore an effort to research about the model must be performed so that perfect model can be built. In the future, the author suggests that there will be a specific library in Matlab for hybrid vehicle purpose. This will contribute to a lot of experimentation and will be beneficial to education purpose in the future. A research on usage of type of battery use also will be beneficial to improvement of hybrid electric vehicle.

REFERENCES

[1] Mehrdad Ehsani, Yimin Gao, Sebastien E. Gay, Ali Emadi. Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, CRC Press.

[2] A. J.Severinsky, "Hybrid Electric Vehicle," 1992.

[3] Antonio Piccolo, Lucio Ippolito "Optimisation of Energy Flow Management in Hybrid Electric Vehicle via Genetic Algorithm," IEEE, Como, 2001.

[4] C. C. Chan, "The State of the Art of Electric Vehicle," IEEE, Beijing, 2002.

[5] M.Ehsani, K.L. Buttler, Y. Gao, K.M Rahman "Next Generation passenger car with better range,performance and emission," 1998.

[6] M.Ehsani, K.L. Buttler, Y Gao,K.M Rahman, D Burke "Toward a sustainable transportation without sacrifice range, quality and performance," International Federation of Automotive Engineering Society, Paris, 1998.

[7] Mehrdad Ehsani, Yimin Gao,John M. Miller,"Hybrid Electric Vehicle:Electric Motor Drive," 2007.

[8] Ali Emadi, Kaushik Raja Shekara,Sheldon S. Williamson, Srdjan M Lukic "Topology Overview of hybrid Electric and Fuel Cell Vehicular Power System Architecture and Configuration," vol. 54, no. 3, May 2005.

[9] V. Wouk, "Hybrids: Then and Now," Jul 1995.

[10] V. Galdi. V. Ippolito, A. Vaccaro "Evaluation of Emission influence on Hybrod Electric Vehicle Sizing," 2000.

[11] Ehsani. M, Rahman K, M. Toliyat "Propulsion system design of electric adn hybrid vehicle," vol. 44, no. 1, 1997.

[12] Antonio Sciarreta, Micheal Back, Lino Guzzela "Optimal Control of Parallel Hybrid Vehicles," vol. 12, no. 3, May 2004.

[13] Jorge Moreno, Micah E. Ortuzar, Juan W. Dixon "Energy Management For Hybrid Electric Vehicle, Using Ultracapacitors and Neural network," vol. 53, no. 2, April 2006.

[14] Christian Musardo, Giorgio Rizzoni,benedetto Staccia "An Adaptive Algorithm For Hybrid Electric Vehicle Energy Management," 2005.

[15] Chan-Chiao Lin, Huei Peng, Jessy W.Grizzle, Jun Mo Kang "Power Management Strategy for a Parallel hybrid Electric Truck," vol. 11, no. 6, November 2003.

[16] Chan-Chiao Lin, jun-Mo Kang, J.W. Grizzle, Huei Peng"Energy Management Strategy for a Parallel hybrid Electric Truck," 2001.

[17] A. Emadi, S.S. Williamson "Status review of power electronic converter for fuel cell applications," vol. 1, no. 2, 2002.

[18] S.S. Williamson, A. Emadi "Fuel Cell application in the automotive industry," 2002.

[19] K. Rajashekara, "Power conversion and control strategies for fuel cell vehicles," vol. 3, 2003.

[20] Cristian Lascu, Ion Boldea, Frede Blaabjerg "A Modified Direct Torque Control For Induction Motor Sensorles Drive," vol. 36, no. 1, 2000.

[21] Shinji Shinnaka, Shigeru Takeuchi, Akira Kitajima, Fumio Eguchi, Hidemasa haruki "Frequency-Hybrid VEctor Control for Sensorles Induction motor and its Application to the Electric Vehicle Drive," 2001.

[22] Lopez, J. Alvarez, Doval-Gandoy, Freijedo, A. Nagueiras, A. Lago, C.M. Penalver "Comparison of the FGPA Implementation of Two multilevel Space Vector PWM Algoritm," vol. 4, no. 55, 2008.

[23] V. Delli Colli, R. Di Stefano & F. Marignetti "A System on Chip Sensorless Control for a Permanent-Magnet Synchronous Motor," vol. 11, no. 57, 2010.

[24] C. Jun Uk, L. Quy Ngoc & J. Jae Wook "An FPGA- Based Multiple-Axis Motion Control Chip," vol. 56, no. 3, 2009.

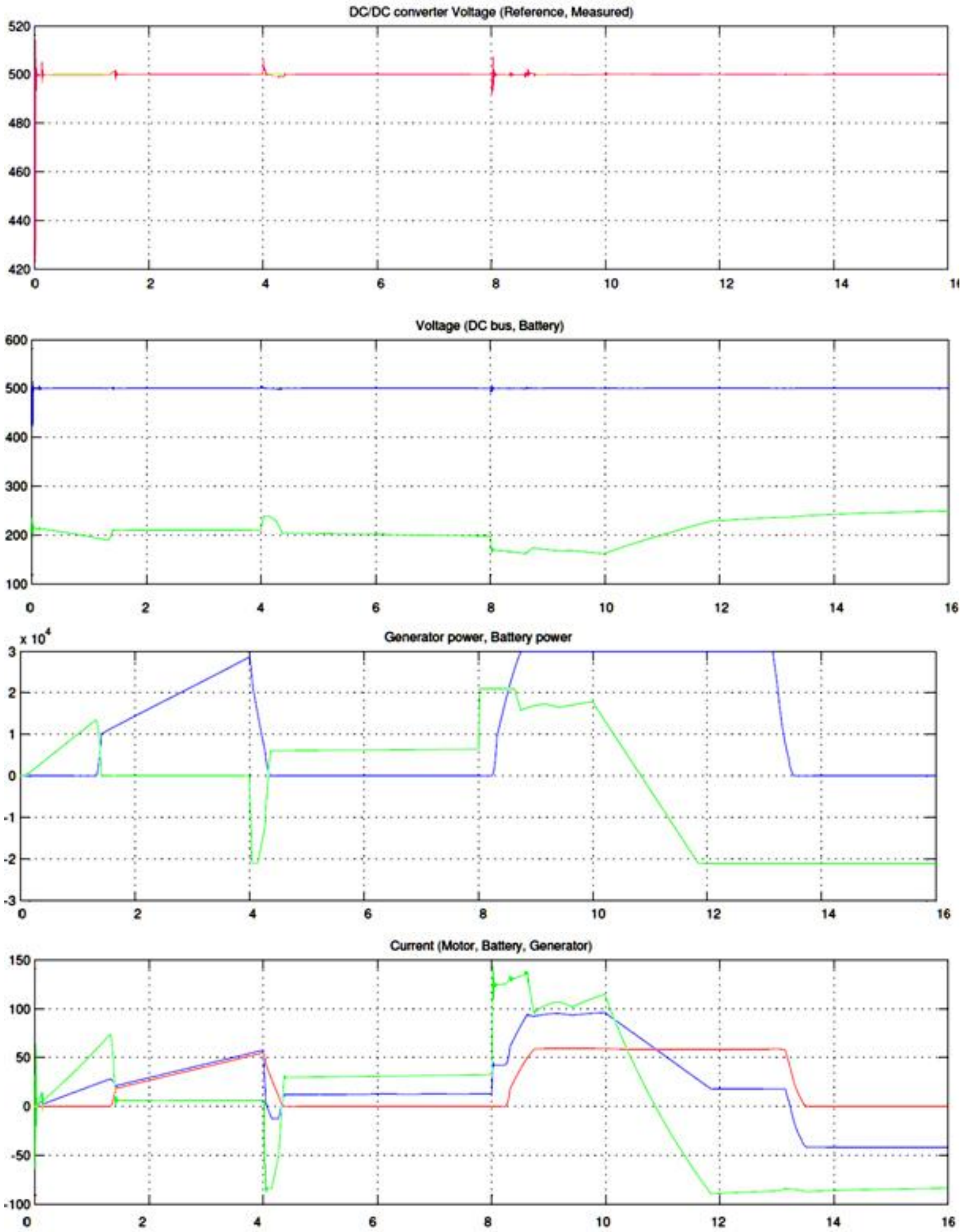
[25] Ricardo de Castro, Rui Esteves Araujo and Diamantino Freitas "FPGA Based Powertrain Control for Electric Vehicles".

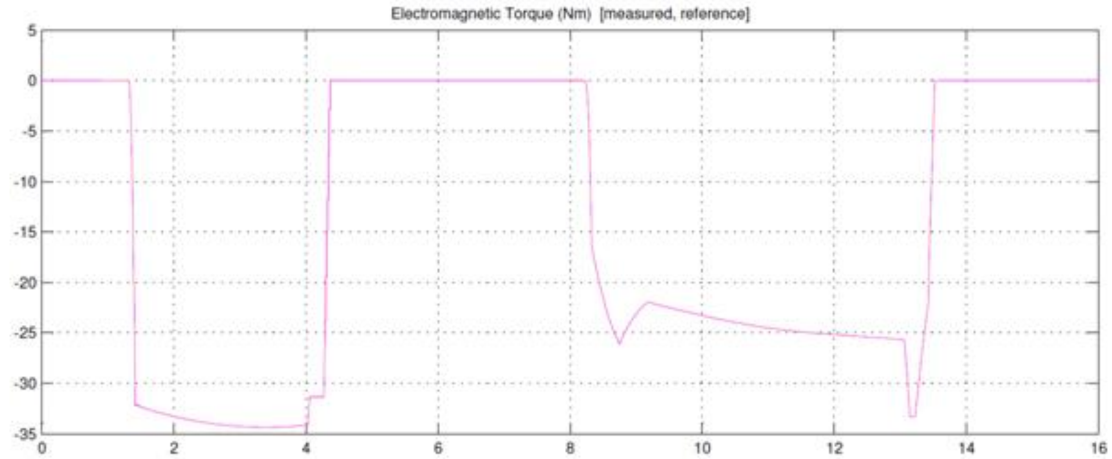
[26] R.E, Araujo, "Control System of Three Phase Induction Motor based on the Principle of Field Orientation," 1991.

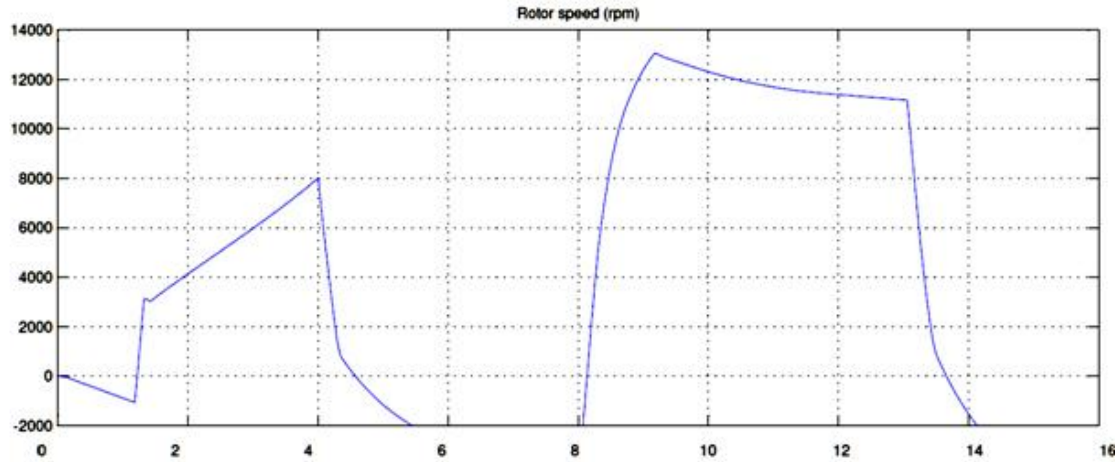
APPENDIX A

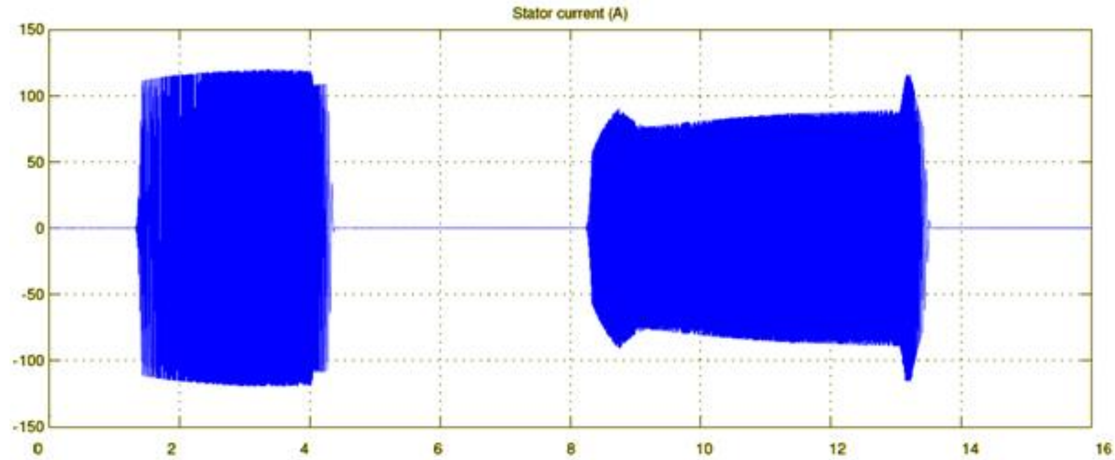
YOUR APPENDIX HEADING

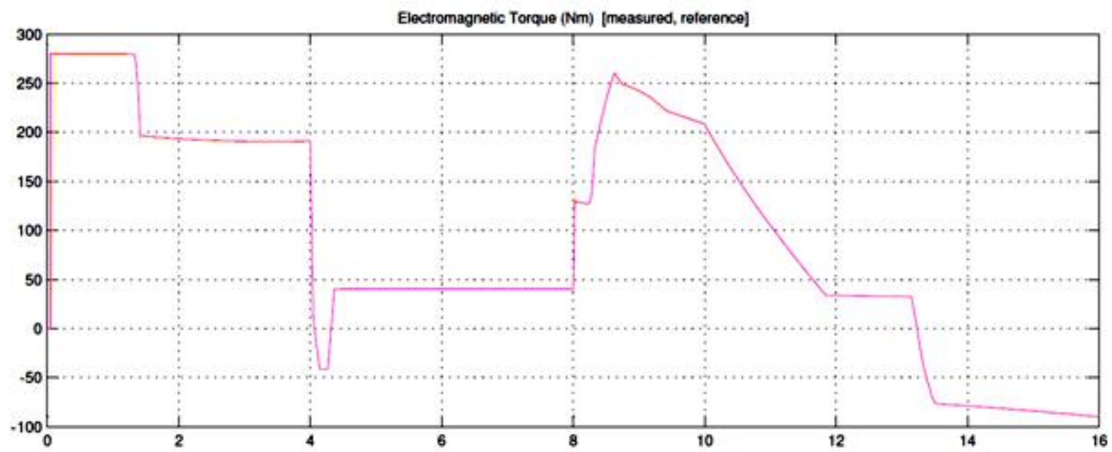
First phase result for other parameters.

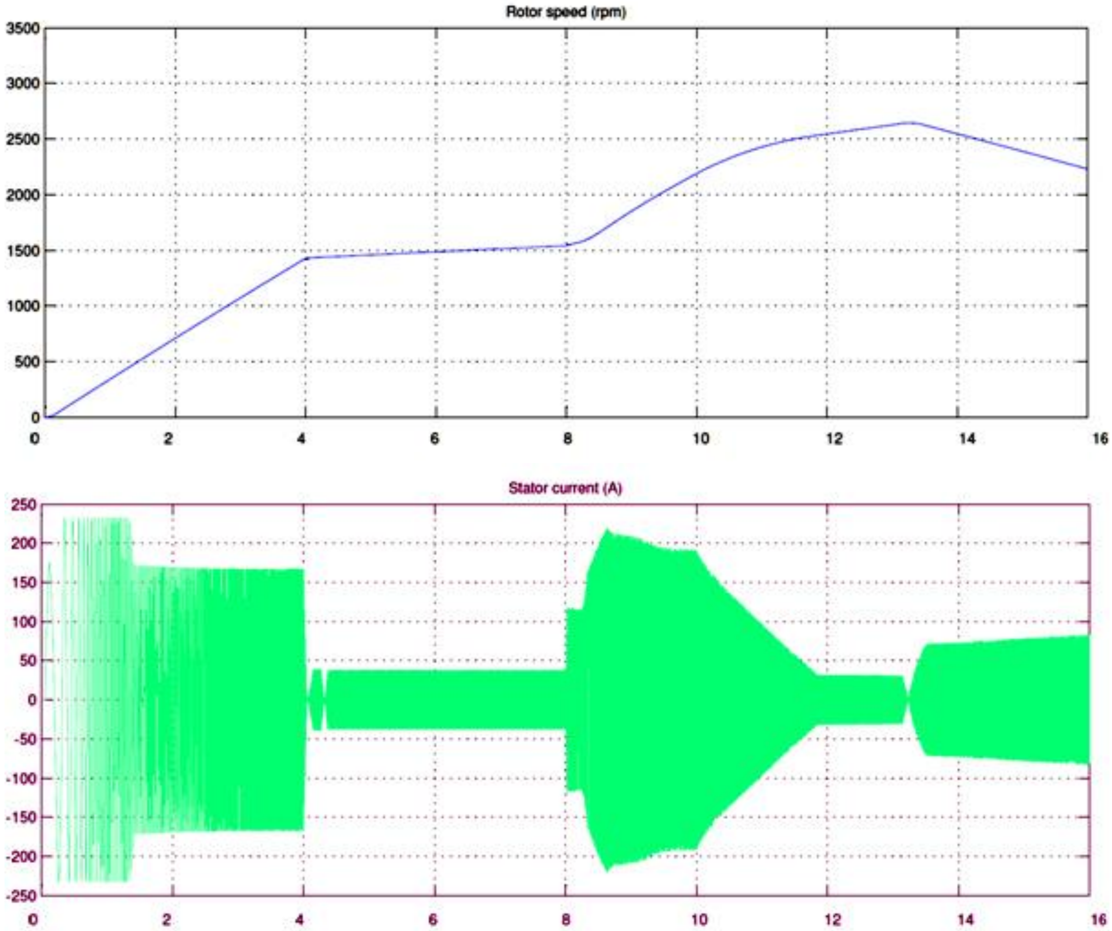



Electromagnetic Torque (Nm) [measured, reference]

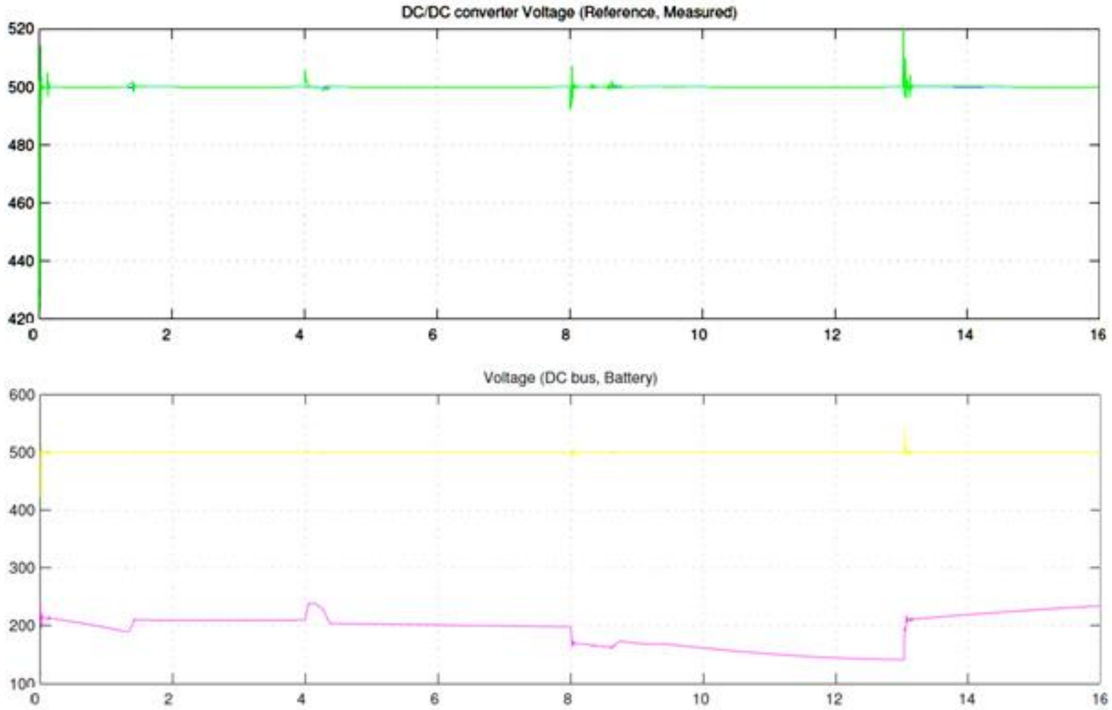

Rotor speed (rpm)

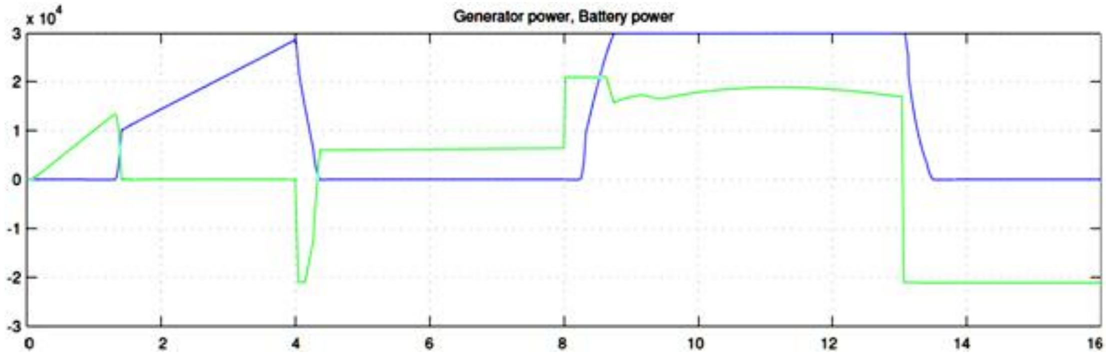

Stator current (A)


Electromagnetic Torque (Nm) [measured, reference]



Second phase result for other parameters




Generator power, Battery power
x 10^4
3
2
1
0
-1
-2
-3
0
2
4
6
8
10
12
14
16