UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ELECTRIC VEHICLE SYSTEM MODELLING USING MATLAB

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE TECHNOLOGY) WITH HONOURS

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A thesis submitted
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DEDICATION

I am dedicating this thesis to my beloved parents, Mr Ismail Bin Mahmud and Mrs Zaiton Binti Hamali who has always been a positive role model in my life and continually provided their moral, spiritual emotional and financial support. Thank you for being my source of inspiration and gives me strength when I am on my weakest point.

ABSTRACT

Industry roadmaps state that electric vehicles (EVs) will play a key role in automotive power systems technology going forward. Major global manufacturers are currently putting a lot of concentration on EVs because they are predicted to drastically change the road transport sector. As of mid-March, Malaysia had sold up to 192,474 electric vehicles this year. Selecting a motor and battery size appropriate for the e-buggy's usage is crucial to the project. The objective of this project is to create a mathematical model of an electric vehicle using MATLAB-Simulink. Therefore, MATLAB simulation may be used to evaluate the e-buggy's performance based on the battery and motor configuration. There are differences in the performance and range of different battery types. MATLAB-Simulink will be used in this project to design an electric vehicle system with three subsystems. There are three subsystems: battery, inverter, and motor mechanical. The controller and the measurement, which are external components, are the other two subsystems in the electric vehicle system. The controller's responsibility is to control each subsystem, whereas the measurement's is to collect data and present a graph. The vehicle parameter will be set as closely as is practical based on the actual vehicle parameter. As a result, it is feasible to measure an electric car's voltage and current. In this project, parameters from the verification model and the new e-buggy model will be used to compare the voltage and current data from MATLAB-Simulink. Parameter fine tuning will be done until a correlation of more than 80% is obtained with the verification model. To sum up, the project's objective was to suggest and create a MATLAB-Simulink model for an electric vehicle system, then compare the new e-buggy's mathematical model with the verification. In the process, important car characteristics that have a bigger influence on the e-buggy's performance were also identified.

ABSTRAK

Pelan hala tuju industri menyatakan bahawa kenderaan elektrik (EV) akan memainkan peranan penting dalam teknologi sistem kuasa automotif pada masa hadapan. Pengeluar global utama pada masa ini meletakkan banyak tumpuan pada EV kerana mereka diramalkan akan mengubah secara drastik sektor pengangkutan jalan raya. Sehingga pertengahan Mac, Malaysia telah menjual sehingga 192,474 kenderaan elektrik tahun ini. Memilih saiz motor dan bateri yang sesuai untuk penggunaan e-buggy adalah penting untuk projek itu. Objektif projek ini adalah untuk mencipta model matematik kenderaan elektrik menggunakan MATLAB-Simulink. Oleh itu, simulasi MATLAB boleh digunakan untuk menilai prestasi e-buggy berdasarkan konfigurasi bateri dan motor. Terdapat perbezaan dalam prestasi dan julat jenis bateri yang berbeza. MATLAB-Simulink akan digunakan dalam projek ini untuk mereka bentuk sistem kenderaan elektrik dengan tiga subsistem. Terdapat tiga subsistem: bateri, penyongsang, dan mekanikal motor. Pengawal dan ukuran, yang merupakan komponen luaran, adalah dua lagi subsistem dalam sistem kenderaan elektrik. Tanggungjawab pengawal adalah untuk mengawal setiap subsistem, manakala pengukuran adalah untuk mengumpul data dan membentangkan graf. Parameter kenderaan akan ditetapkan sehampir praktikal berdasarkan parameter kenderaan sebenar. Akibatnya, ia boleh dilakukan untuk mengukur voltan dan arus kereta elektrik. Dalam projek ini, parameter daripada model pengesahan dan model e-buggy baharu akan digunakan untuk membandingkan data voltan dan arus daripada MATLAB-Simulink. Penalaan halus parameter akan dilakukan sehingga korelasi lebih daripada 80% diperoleh dengan model pengesahan. Kesimpulannya, objektif projek adalah untuk mencadangkan dan mencipta model MATLAB-Simulink untuk sistem kenderaan elektrik, kemudian membandingkan model matematik e-buggy baharu dengan pengesahan. Dalam proses itu, ciri-ciri kereta penting yang mempunyai pengaruh yang lebih besar terhadap prestasi e-buggy juga dikenal pasti.

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In the Name of Allah, the Most Gracious, the Most Merciful

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LIST OF SYMBOLS AND ABBREVIATIONS

EV - Electric Vehicle
CO_2 - Carbon Dioxide
NOx - Nitrogen Oxide
NiMH - Nickel-Metal Hydride
Li - Lithium
PM - Particulate Matter
BEV - Battery Electric Vehicle
FCV - Fuel Cell Vehicle
IGBTs - Insulated-Gate Bipolar Transistors
GHG - Greenhouse Gas
ASEAN - Association of South-East Asian Nations
ICE - Internal-Combustion Engine
BMEP - Brake Mean Effective Pressure
SOH - State Of Health
SOC - State Of Charge
RPM - Revolution Per Minute
DC - Direct Current
AC - Alternating Current
MCU - Motor Control Unit
PMSM - Permanent Magnet Synchronous Motor
SRM - Switched Reluctance Motor

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CHAPTER 1

INTRODUCTION

1.1 Background

The world's environmental problems include energy conservation as one of their biggest issues. A lot of challenges also exist in our global energy landscape. Even while no one can predict the exact state of the energy market, we remain confident that transportation will be crucial to preserving the energy of the upcoming years (IEEE Malaysia Section et al., 2017).

An electric vehicle (EV) is a type of vehicle that is powered by one or more electric motors, using electrical energy stored in rechargeable batteries or other energy storage devices. Electric vehicles can be either fully electric or hybrid, meaning they have both an electric motor and an internal combustion engine. The growth of electric vehicles (EVs) has made a contribution and will keep on contributing to the ease and safety of our daily lives. This is due to electric vehicles do not only lower at operating costs, but they also reduced emissions which means electric vehicles do not have tailpipes, so they do not emit any harmful pollutants or greenhouse gases during operation. This means that they can significantly reduce emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), particulate matter, and other pollutants that contribute to air pollution and climate change. Moreover, electric vehicles are generally more environmentally friendly than conventional cars that run on gasoline or diesel fuel, which means they require less energy to travel the same distance. This results in lower fuel consumption and cleaner electricity, even when taking into account as more renewable energy sources like solar and wind power are integrated into the electricity grid, the emissions associated with charging an electric vehicle are becoming lower. Therefore, electric vehicles can be part of a broader strategy to reduce greenhouse gas emissions by supporting the transition to clean energy sources.

In the Malaysia, today's market, a statement from Datuk Aishah Ahmad, head of the Malaysian Automotive Association (MAA), 2,631 EVs have been sold in Malaysia during the past year. The BMW iX was sold in Malaysia with the higher price that is RM 528,430.00, meanwhile the Mercedes Benz EQB was sold with RM 333,888.00. The electric vehicles only rely on batteries technology, which that cost is very expensive. There are many types of battery for electric vehicles such as Lithium-Ion Battery and Nickel-Metal Hydride Battery. Therefore, the performance of EV system can be evaluated and estimated based on different types of battery.

1.2 Problem Statement

One of the major challenges with electric vehicles (EVs) is their limited driving range compared to conventional internal combustion engine vehicles. The range anxiety, or the fear of running out of battery power, is a significant concern for potential electric vehicle buyers. The need for frequent recharging restricts long-distance travel and requires a robust charging infrastructure to support widespread adoption.

Next, electric vehicles rely on battery technology, which represents a significant portion of their overall cost. The cost of manufacturing and sourcing high-capacity batteries remains relatively expensive, impacting the affordability of electric vehicles for many consumers. Research and development efforts to improve battery efficiency and reduce costs are necessary to make electric vehicles more accessible to a broader population.

Moreover, the availability and accessibility of charging stations remain a critical barrier to the widespread adoption of electric vehicles. Many regions lack on adequate network of charging stations, making it inconvenient for electric vehicle owners to recharge their vehicles, especially in urban areas or during long journeys. Expanding the charging infrastructure to meet the growing demand is essential. Therefore, the selection of battery types and its capacity should meet the vehicle based specification in term of budget, performance and distance.

This project is focusing on to create a mathematical model of an electric vehicle system that can precisely anticipate how the system would perform under various operating circumstances. The battery, motor, power electronics, and other important EV system parts should all be represented in the model. The model should account for elements like the battery's thermal behaviour, the motor's effectiveness, and the power losses in the power electronics. The model should be utilised to optimise the system's architecture after being validated with actual data from an EV. The model should be used in particular to examine the effects of various battery chemistries and configurations on the performance of the EV system and to find ways to boost the system's effectiveness and range. The final deliverable should comprise a thorough report outlining the modelling approach, the outcomes of the simulations, and design suggestions, as well as a MATLAB script for putting the model and simulations into practise.

1.3 Research Objective

The main aim of this research is to propose and design an electric vehicle system modelling using MATLAB-Simulink. Specifically, the objectives are as follows:

a) To implement the benchmark model to validate the newly developed e-buggy model.

b) To evaluate different design options and identify strategies for boosting efficiency and range

1.4 Scope of Research

The scope of this research are as follows:

- This study focuses on the design of mathematical model in electric vehicle using MATLAB-Simulink with simulation and analysis of the EV system based on WLTP driving cycle and analyzing the results to evaluate performance and identify opportunities for improvement.
- The main priority of this project is to design the NiMH battery performance simulation and validate the result with benchmark model.
- Moreover, batteries for electric vehicles should have a balance of high energy and power density, long cycle life, fast charging and lastly have high safety standards.

CHAPTER 2

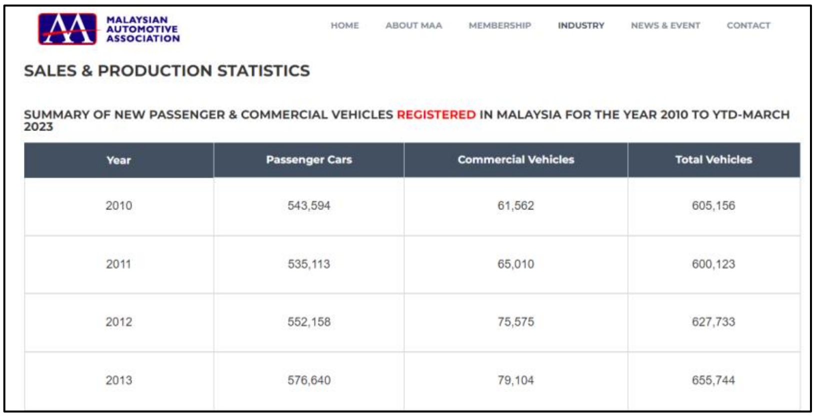
LITERATURE REVIEW

2.1 Introduction

In order to clarify and get a deeper grasp of the research issue, research was conducted in this chapter using a variety of resources, including articles, journals, research papers, and reviews. The energy storage system and car emissions will be the main topics of this chapter. Zero-emission vehicles, energy-efficient vehicles, and electric vehicle battery technologies are a few examples of the topic that will be covered. The research's findings were also intended to facilitate learning the system in electric automobiles.

2.2 Emission from Vehicle

Research on emission from vehicle in the world has captured more attention in the automotive industry nowadays since there are a lot of vehicles on the road around the world, particularly in inhabited areas and urban areas. Based on statistics by Malaysian Automotive Association (MAA) (2023), it shows that the number of new passenger & commercial vehicles registered in Malaysia for the YTD-MARCH 2023 is approximately 192,474. Higher emissions and pollution levels are caused by an increase in the number of automobiles. Figures 2.1, 2.2 and 2.3 offer an insight to the number vehicles registered in Malaysia for the year 2010 to YTD-MARCH 2023 by MAA.

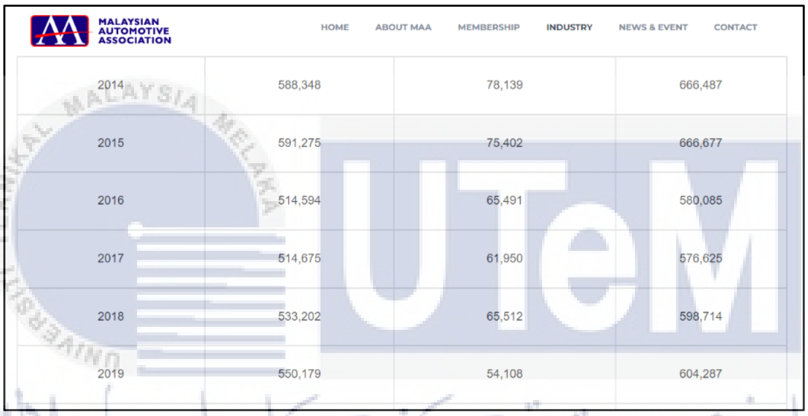


SALES & PRODUCTION STATISTICS

SUMMARY OF NEW PASSENGER & COMMERCIAL VEHICLES REGISTERED IN MALAYSIA FOR THE YEAR 2010 TO YTD-MARCH 2023

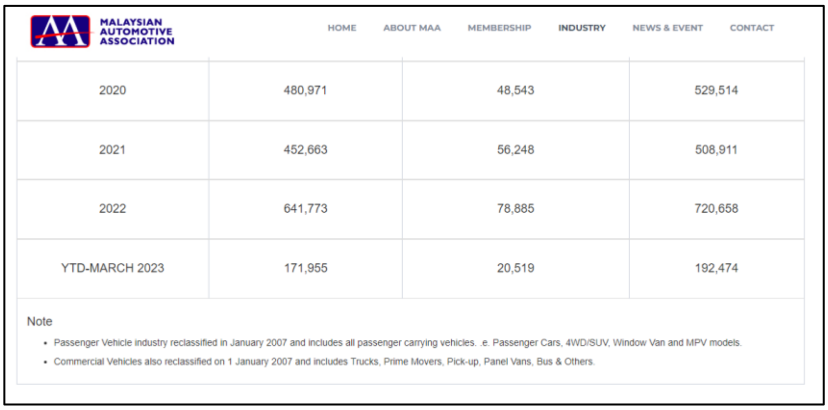
Year	Passenger Cars	Commercial Vehicles	Total Vehicles
2010	543,594	61,562	605,156
2011	535,113	65,010	600,123
2012	552,158	75,575	627,733
2013	576,640	79,104	655,744

Figure 2.1: Summary of new passenger & commercial vehicles registered in Malaysia for the year 2010 to YTD-MARCH 2023 (MAA. 2023)



2014	588,348	78,139	666,487
2015	591,275	75,402	666,677
2016	514,594	65,491	580,085
2017	514,675	61,950	576,625
2018	533,202	65,512	598,714
2019	550,179	54,108	604,287

Figure 2.2: Summary of new passenger & commercial vehicles registered in Malaysia for the year 2010 to YTD-MARCH 2023 (MAA, 2023)



2020	480,971	48,543	529,514
2021	452,663	56,248	508,911
2022	641,773	78,885	720,658
YTD-MARCH 2023	171,955	20,519	192,474

Note

- Passenger Vehicle industry reclassified in January 2007 and includes all passenger carrying vehicles. .e. Passenger Cars, 4WD/SUV, Window Van and MPV models.
- Commercial Vehicles also reclassified on 1 January 2007 and includes Trucks, Prime Movers, Pick-up, Panel Vans, Bus & Others.

Figure 2.3: Summary of new passenger & commercial vehicles registered in Malaysia for the year 2010 to YTD-MARCH 2023 (MAA, 2023)

After the Covid-19 limits were lifted, the world's transport sector began to rebound, which resulted in an 8% increase in CO2 emissions in 2021 over the previous year. From 1990 through 2021, the yearly average growth rate of transport emissions was roughly 1.7%, higher than that of any other end-use industry (Teter, 2022).

Around three billion metric tonnes of carbon dioxide emissions from passenger cars were produced globally in 2020. Since 2000, there has been a steady increase in the number of emissions produced by passenger cars, from 2.2 billion metric tonnes in 2000 to a peak of 3.2 million metric tonnes. In 2020, emissions decreased by about 6% as a result of the COVID-19 epidemic, which significantly disrupted transportation (Tiseo, 2023). Figure 2.4 shows that global passenger vehicle carbon dioxide emissions from 2000 to 2020 (in billion metric tonnes).

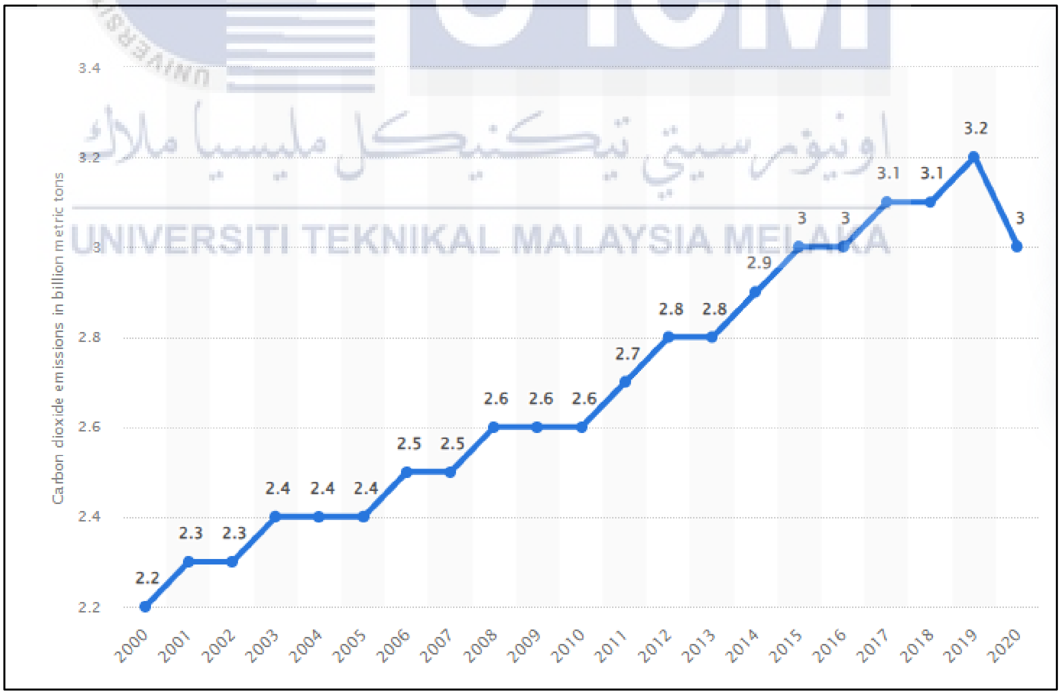


Figure 2.4: Global Passenger Vehicle Carbon Dioxide Emissions from 2000 to 2020 (in Billion Metric Tonnes).

Exhaust gases emitted by vehicles can have various negative effects on human health. Vehicle emission contribute to the release of fine particulate matter, such as PM2.5 (particulates with a diameter of 2.5 micrometres or smaller) and PM10 (particulates with a diameter of 10 micrometres or smaller). These particles can penetrate deep into the respiratory system, leading to respiratory and cardiovascular problems, including asthma, bronchitis, reduced lung function, and increased risk of heart attacks and strokes.

Vehicles emit nitrogen oxides, including nitrogen dioxide (NO_2), which can irritate the respiratory system, cause inflammation of the airways, and worsen respiratory conditions such as asthma. NOx emission also contributes to the formation of ground-level ozone, which is a major component of smog and can cause respiratory problems and lung tissue damage (Germanova & Kernozhitskaya, 2017).

Vehicle exhaust contains carbon monoxide, a poisonous gas that can be harmful when inhaled. High levels of carbon monoxide can lead to headaches, dizziness, fatigue, and in severe cases can be fatal, particularly in enclosed spaces (Germanova & Kernozhitskaya, 2017).

2.3 Zero Emission Vehicle

A vehicle is referred to as a zero-emission vehicle (ZEV) if it has no hazardous tailpipe emissions during operation, such as greenhouse gases (GHGs) or other pollutants. These cars are made to reduce or completely stop the discharge of pollutants into the air, lowering air pollution and preventing climate change.

The phrase "zero-emission" primarily refers to the vehicle's operational direct emissions. It does not consider emissions produced during the generation of energy or, if appropriate, the extraction and refinement of fuels. However, when fueled by renewable energy sources, zero-emission vehicles can still have a large positive environmental impact.

Based on research from Department of Ecology State of Wahington (2023), there are two categories typical subsets of zero-emission vehicles which are Battery Electric Vehicles (BEVs) and Hydrogen Fuel Cell Vehicles (FCVs). Battery Electric Vehicles (BEVs) are referred to as "purely electric vehicles" because their powertrain only uses rechargeable batteries (Olabi et al., 2022). Meanwhile hydrogen as well as oxygen interact electrochemically to produce water, which is then used to power Hydrogen Fuel Cell Vehicles (FCVs) (Ambrose et al., 2017). When compared to toxic gases and particles created by the burning of fossil fuels, such as sulphur dioxide (SO_2) and the gas carbon dioxide (CO_2), water is a neutral consequence. Figure 2.5 and 2.6 shows that the Battery Electric Vehicles (BEVs) and Hydrogen Fuel Cell Vehicles (FCVs).

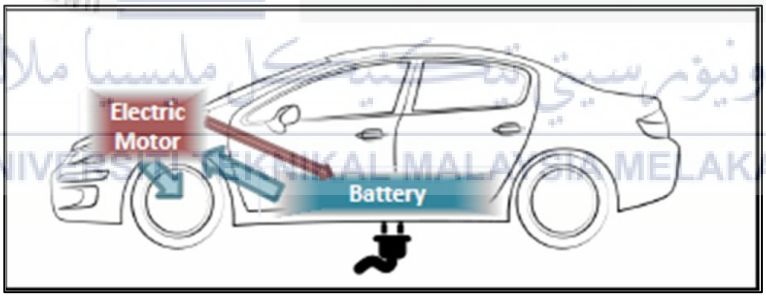


Figure 2.5: Battery Electric Vehicles (BEVs)

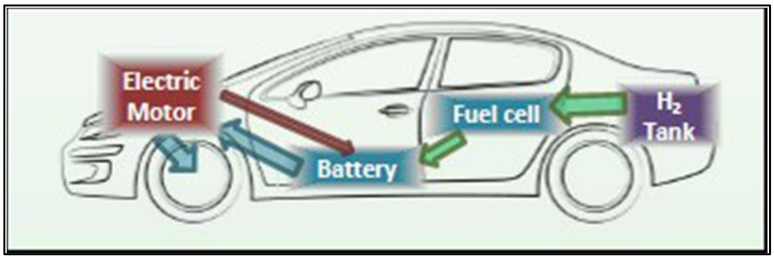


Figure 2.6: Fuel Cell Vehicles (FCVs)

Another two types of electric vehicles are Hybrid Electric Vehicles (HEV) and Plug-in Hybrid Electric Vehicles (PHEV). Hybrid Electric Vehicles (HEV) is a combination of electric power technology and IC engine technology. It can electrically power the vehicle with a load of up to 80 kW, necessitating the use of a high voltage battery. The amount of time the HEV is driven electrically as opposed to combustionally affects its fuel efficiency (Daisy Ranawat, 2018). The battery in a Plug-in Hybrid Electric Vehicles (PHEV) can be charged externally using an inductive pad or connected connection, which further lowers the fuel consumption. Fuel economy is increased by PHEV to the point where the battery can receive frequent recharges. After HEV, PHEV has the second-fastest rate of growth (IEEE Staff, 2018a). Figure 2.7 and 2.8 shows that the Hybrid Electric Vehicles (HEV) and Plug-in Hybrid Electric Vehicles (PHEV).

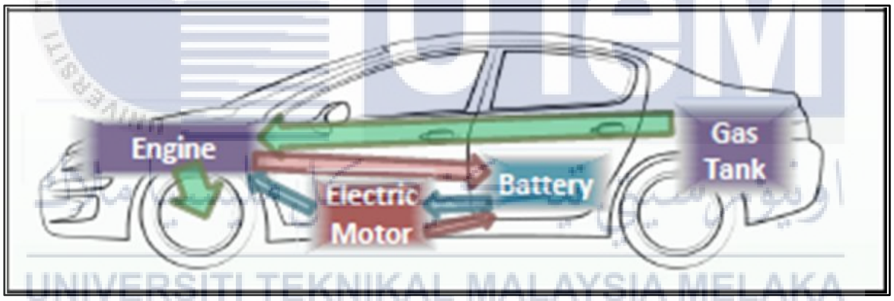


Figure 2.7: Hybrid Electric Vehicles (HEV)

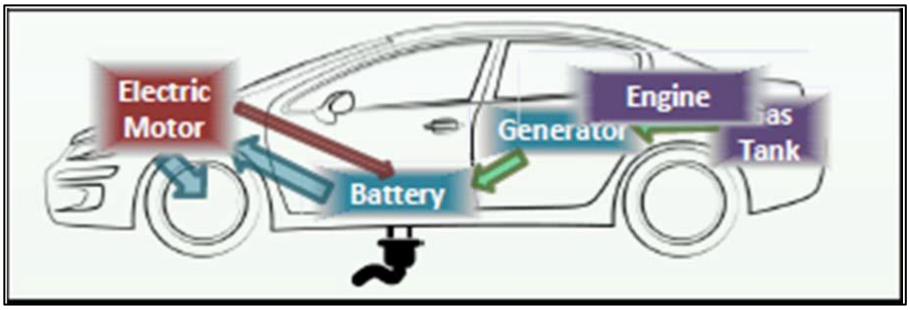


Figure 2.8: Plug-in Hybrid Electric Vehicles (PHEV)

2.3.1 Hydrogen Based Engine

Due to the current worldwide lack of petroleum and other fossil fuels, it is urgent for nations all over worldwide to produce new forms of energy. Every sphere of human existence prefer hydrogen since it is pure and constantly regenerable (Ambrose et al., 2017). Every sphere of human existence prefer hydrogen since it is pure and constantly regenerable. A hydrogen-powered engines operates on an identical concept to a traditional engine, primarily employing hydrogen as fuels. Hydrogen has the advantages of being easy to carry around and store, which lowers expenses. Hydrogen fuel burns more quickly than petrol under stoichiometric conditions, releases mass heat at a far higher rate, has a larger ignition range than diesel or petrol, and is capable of burning under lean situations. Since the physical and chemical characteristics of fuel made from hydrogen, engines that burn fuel using it are vulnerable to inappropriate burning issues like preignition and backfire, which can impair performance and even permanently harm the engine. The irregular combustion will significantly reduce the torque output of the hydrogen engine while it is operating and may possibly make it run in an unstable manner (Dang & Wang, 2022).

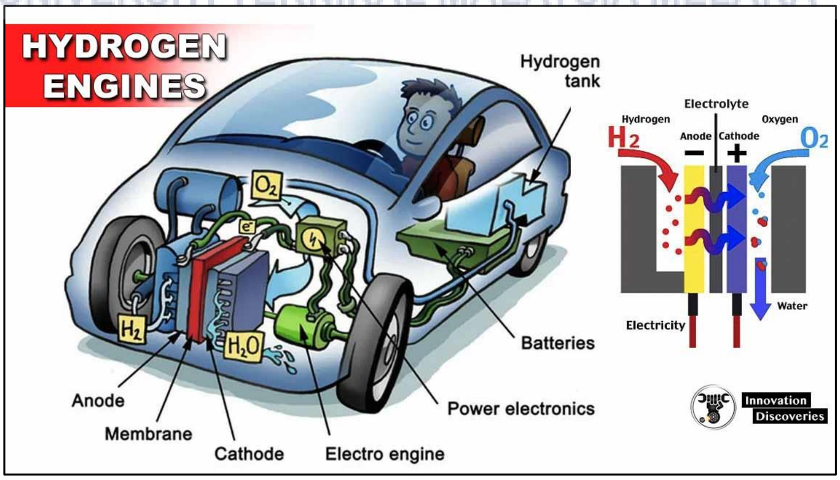


Figure 2.9: The working principle of hydrogen-based engine.

2.3.2 Energy-Efficient Vehicle

The most difficult environmental issue of recent times has evolved as a result of global warming and the rise in Greenhouse Gas (GHG) emissions. The release of carbon dioxide (CO_2) has risen dramatically as a result of the growth of energy use. In terms of carbon dioxide emissions from the automotive sector among the Association of South-East Asian Nations (ASEAN) countries, it has ranked Malaysia third behind Indonesia and the Philippines (Daud et al., 2021).

Energy-Efficient Vehicles (EEV) are a type of sustainable transportation that reduces carbon dioxide emissions and does away with the use of fossil fuels. An Energy-Efficient Vehicles (EEV) is a vehicle that meets a number of requirements for gasoline consumption (I/100km) and carbon emission limits (gram/kilometers, or g/km). The most powerful energy and least amount of fuel are used by Energy-Efficient Vehicles (EEV), which also has minimal to no negative effects on the environment (Daud et al., 2021). Models like the Mazda CX-5 2.0L, Perodua Axia 1.0L, Haval M4, Honda Civic, Volvo XC90, and Renault Zoe are a few examples of Energy-Efficient Vehicles (EEV) -certified vehicles that are on the market in Malaysia.

Internal-combustion engine (ICE) vehicles are anticipated to continue dominating fleet utilization for the next 20–25 years of existing vehicle technologies. Engine downsizing is a crucial tactic used in environmentally friendly vehicles to increase fuel economy and cut emissions. It entails swapping out a larger displacement engine for a smaller one while retaining or even improving performance by utilizing cutting-edge technology. The downsizing strategy tries to match engine output to the actual power needs of the car, improving efficiency under normal driving circumstances.

The use of smaller, lighter engines is made possible by downsizing, which lowers the vehicle's overall weight. The weight decrease helps to increase the fuel economy. Additionally, the internal friction of smaller engines is typically lower, resulting in improved energy conversion and fewer energy losses. Engine size reductions of up to 30% are possible (Martin et al., 2017). To compensate for the loss in engine displacement when employing a smaller engine, the brake mean effective pressure (BMEP) is increased to preserve vehicle performance. The configuration of the bore, stroke, and cylinders, modifications to the camshaft phasing, and direct injection can all boost BMEP.

Technology like turbocharging and direct fuel injection are frequently used in downsized engines to make up for the size decrease. An engine that has been downsized can now produce power that is comparable to or even exceeds that of bigger engines through the use of turbocharging, which harnesses the energy from exhaust gas compression. Direct injection increases the performance as well as effectiveness of combustion by delivering fuel directly into the combustion chamber.

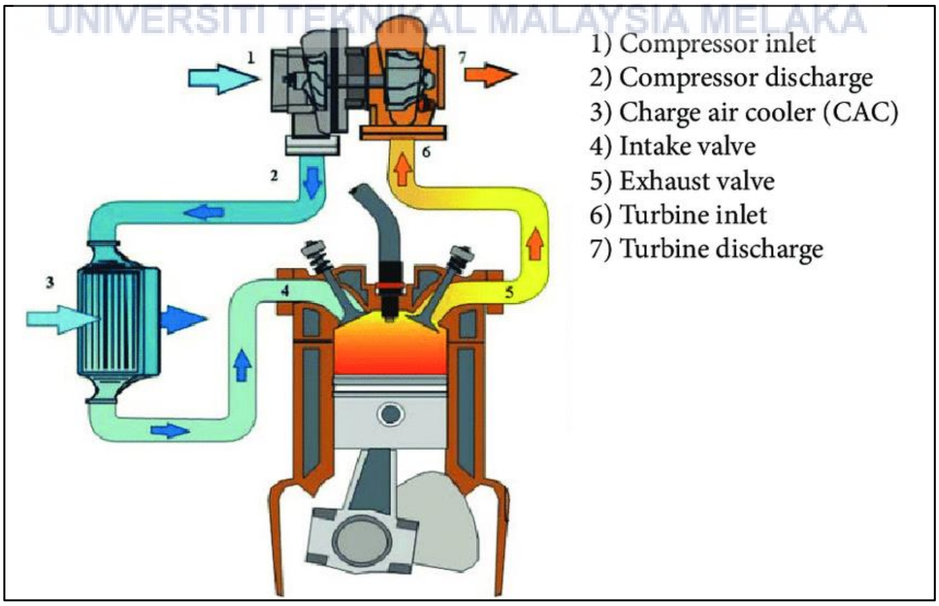


Figure 2.10: Schematic of a turbocharged engine.

Engine downsizing is the practice of employing smaller, lower-displacement engines, frequently in conjunction with turbocharging or supercharging, to increase fuel economy and lower emissions without compromising performance. The idea has been more well-known in recent years as a means of achieving ever-stricter fuel economy and emissions rules. With forced induction, performance is maintained or even improved when a larger engine is replaced with a smaller one that has fewer cylinders or a smaller displacement. By compressing the intake air to enhance the amount of oxygen available for combustion, forced induction techniques like turbocharging or supercharging provide more power.

The advantages of engine downsizing are smaller engines use less fuel because of their reduced displacement and reduced internal friction. Downsizing can result in significant fuel economy improvements when combined with other technologies like direct fuel injection and sophisticated engine control systems. Compared to larger engines, smaller engines produce fewer pollutants, especially when turbocharging is used. Reduced vehicle emissions of nitrogen oxides (NOx), particulate matter (PM), and carbon dioxide (CO_2) are all benefits of downsizing. Because smaller engines are typically lighter than their larger equivalents, the vehicle can gain weight. Weight loss can result in better handling, better overall performance, and more fuel-efficient driving. Even though they are smaller than bigger engines, downsizing engines frequently have an output of power and torque that is comparable to or even higher. The addition of forced induction makes up for the loss of displacement, enhancing acceleration and performance as a whole.

2.4 Energy Storage System

Electric drivetrains in electric cars (EVs) are powered in large part by energy storage devices. These systems serve to power numerous vehicle operations, supply auxiliary power, and store electrical energy utilised to push the vehicle. A high-voltage battery pack, which is frequently based on lithium-ion battery technology, serves as the main energy storage device in the majority of EVs.

The primary source of energy storage in an EV is the battery pack. It is made up of numerous separate battery cells joined together to create a pack with a higher voltage. Due to their high energy density, long cycle life, and capacity to supply enough power for vehicle propulsion, lithium-ion batteries are frequently utilised. The EV's driving range is determined by the battery pack capacity, which is expressed in kWh (Kumar, 2023).

The battery pack's performance, health, and safety are monitored and managed by the Battery Management System (BMS). Cell voltage, temperature, state of charge (SOC), and state of health (SOH) are just a few of the data it monitors. The BMS guards against overcharging, overheating, and other potentially harmful circumstances while ensuring optimal charging, draining, and balancing of the battery cells.

Heat generated by battery packs during charging and discharging may compromise their functionality and shorten their longevity. The thermal management system controls the battery pack's internal temperature to provide ideal working conditions. To dissipate heat and keep battery temperature within a suitable range, it could contain cooling devices like liquid or air cooling (Kumar, 2023).

2.4.1 Battery Technology in Electric Vehicle

Due to how the gears, differential, axles, and drive shafts are configured, the majority of battery electric vehicles have an electric motor that is positioned in the centre and powers either the front or rear wheels through a differential gear. However, this layout leaves very little room for installation.

Electric vehicles have motors that provide all of their torque at very low speeds. Power rises and torque decreases proportionally as revolution per minute (rpm) rises. Although they are not required, gears could nevertheless be present in electric vehicles. Based on the paper by (Anseán et al., 2013), the different chemical properties of each different battery cells are highlighted as follows.

Table 2.1 Comparison of Different Chemistry of Battery Cells.

	Lead Acid	NiMH	Li-Ion	LiFePO4
Nominal cell voltage	2V	1.2V	2.5V/3.3V/3.6-3.7V	3.2V
Specific Energy	30-45 Wh/kg	30-80 Wh/kg	90-220 Wh/kg	80-100Wh/kg
Energy Density	60-75 Wh/L	140-300 Wh/L	280-400 Wh/L	220Wh/L
Specific power	180 W/kg	250-1000W/kg	600-3400 W/kg	400 W/kg
Cycle life	500-800	500-1000	1000-8000	5000
Self-discharge	2-45% /month	20-30% /month	2-5% /month	5% /month
Optimum working temperature range	-40-55°C	-20-45°C	15-35°C	-20-60°C

2.4.1.1 Lithium-Ion Battery

Lead acid, NiNH, Li-ion, and Na-NiCl are among the batteries that have been put into use in electric vehicles. In comparison to conventional batteries, Li-ion batteries have higher specific energy, greater energy density, and faster charging times.

Despite being more expensive than other options, they have all the requirements for a vehicle energy source (Samuel, 2017). Lithium-nickel-cobalt-aluminium (NCA), lithium-nickel manganese cobalt (NMC), lithium-manganese spinel (LMO), lithium titanate (LTO), and lithium-iron phosphate (LFP) are a few examples of well-known technology used for automotive purposes (Daisy Ranawat, 2018). Figure 2.11 provides a comparison of these technologies based on several factors.

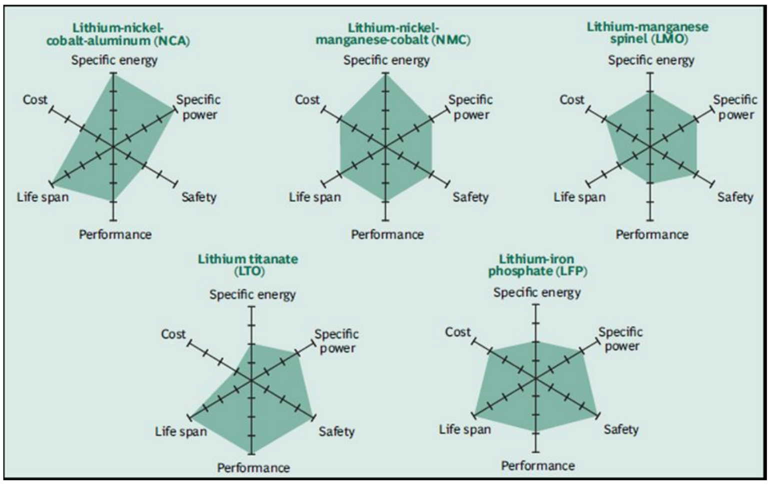


Figure 2.11: Trade-offs among five principal lithium-ion technologies.

In many different medical equipment as well as portable electronic devices, Li-ion rechargeable batteries have demonstrated great performance. Due to the fact that these batteries offer high specific energy and power densities, the auto industry is considering using them in hybrid and electric vehicles in order to suit their unique battery needs. Utilising lithium-ion batteries has several benefits, including their compact size, large storage capacity, high specific energy, good high-temperature performance, low maintenance requirements, and low self-discharge. These batteries have a modest discharge current, need a protective circuit, are subject to ageing and transportation laws, and cost a lot of money. Additionally, non-toxic, recyclable components with little heat production and the memory effect are used in this battery technology (Jayam Aditya, 2008). Over discharge is a possibility, which can be hazardous and might result in an explosion. Figure 2.12 shows that the Lithium-Ion Battery.

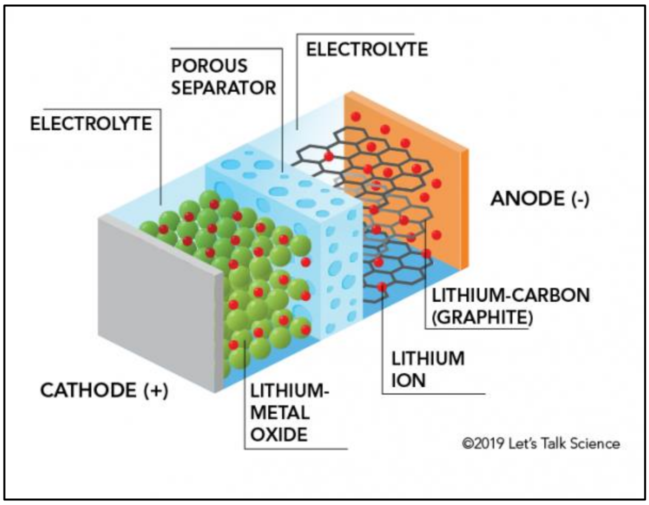


Figure 2.12: Lithium-Ion Battery

2.4.1.2 Nickel Metal Hydride Battery (NiMH)

Ni-MH batteries, which were regarded as the precursor to the technology utilised today, were the most cutting-edge technology available for use in hybrid and electric vehicles during the start of the 2000s. The demands placed on batteries created for use in the automobile industry were being met by Ni-MH technology. The benefits include high power and energy density, enabling an autonomy of over 300 km while using batteries with a specific energy density of 70 Wh/kg. Additionally, these batteries have a successful lifecycle (until 80% Depth of Discharge DOD) when employed in propulsion systems with electric engines of 320 V AC or 180 V DC (Iclodean et al., 2017). The ability to employ regenerative energy recovered from braking, the use of recyclable materials in their production, outstanding thermal qualities (working temperature ranging from - 30 °C up to + 70 °C), and the safety of battery charging and discharging are further benefits of Ni-MH batteries.

If frequently drained at high load currents, NiMH batteries have a limited-service life of roughly 200–300 cycles. These types of batteries operate most effectively at load currents of 0.2C to 0.5C (one-fifth to one-half of their rated capacity). NiMH batteries have a high self-discharge rate, although this can be reduced by adding additional chemical compounds, producing low energy density explosion. Figure 2.13 shows that the Nickel Metal Hydride Battery (NiMH).

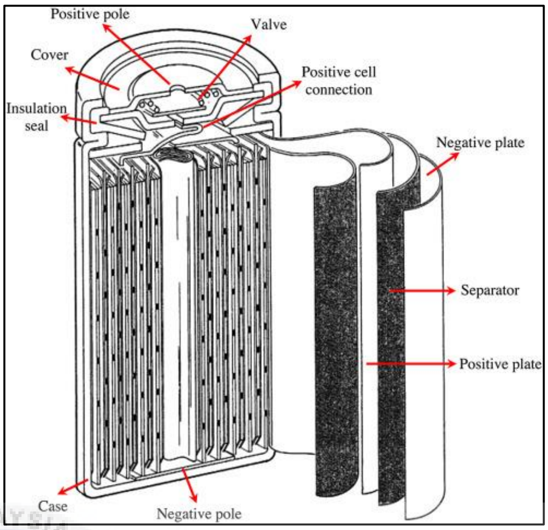


Figure 2.13: Nickel Metal Hydride Battery (NiMH)

CHAPTER 3

METHODOLOGY

3.1 Introduction

A research project's planning, resource gathering, and execution phases are crucial because they ensure a smooth and predictable flow of work. The appropriate steps, techniques, tools, and problem-solving methods were offered and addressed in this section of the research paper's methodology in order to describe the framework of the project's execution element. The research and process for simulating and implementing the hardware utilized in the project are exposed through the approach for modelling the electric vehicle system using MATLAB. The testing and troubleshooting procedures were also covered in this chapter of the study report in order to identify any flaws or mistakes in the techniques used for the project and perhaps suggest ways to fix the issues.

3.2 Flow Chart

The project flowchart outlines the processes that were done from the project's early stages, including its method for identifying problems, until the testing of the hardware. If there are any problems during any phase of the project's length, this flowchart can help to direct which step needs to be redone. Figure 3.1 shows the flowchart of this project.

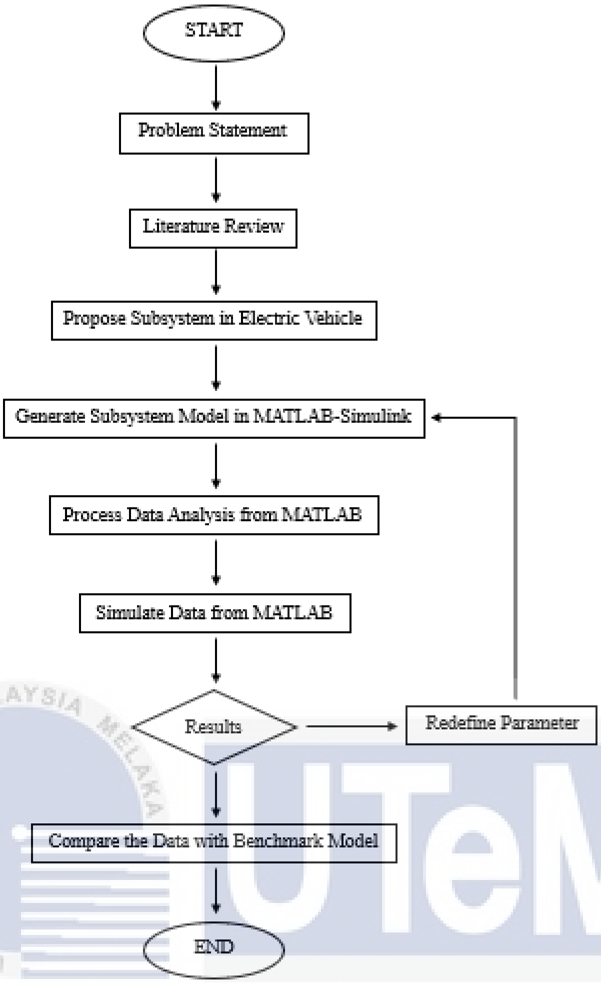


Figure 3.1: Flowchart of this Project

3.3 Subsystem in Electric Vehicles

3.3.1 Battery Subsystem

In an electric vehicle (EV), several subsystems work together to ensure its proper functioning. Firstly, the battery subsystem in electric vehicles (EVs) is a critical component responsible for storing and supplying electrical energy to power the vehicle’s electric motor. It plays a key role in determining the driving range, performance, and overall efficiency of the EV. Figure 3.2 shows the battery subsystem in electric vehicles.

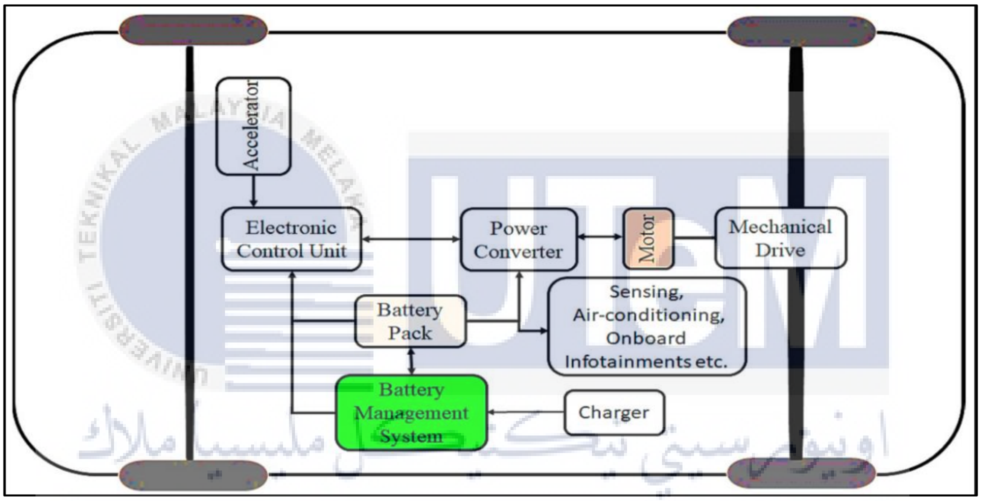


Figure 3.2: Battery Subsystem

In the battery subsystem, there are several components, such as battery pack. The battery pack is the main component of the battery subsystem. It is typically composed of numerous battery modules or cells connected in series and parallel configurations to achieve the desired voltage and capacity. The cells are usually lithium-ion (Li-ion) batteries, which are known for their high energy density, efficiency, and long cycle life. The size and capacity of the battery pack vary depending on the specific EV model and its intended range.

Next, the battery management system (BMS) is also a crucial part of the battery subsystem. It monitors and controls various aspects of the battery pack’s operation to ensure safe and efficient performance. The BMS collects real-time data on parameters such as cell voltage, temperature, state of charge (SOC), and state of health (SOH). It uses this information to balance the cell voltages, manage charging and discharging processes, prevent overcharging or over discharging, and protect the battery from harmful conditions.

3.3.2 Inverter Subsystem

Moreover, the inverter subsystem in electric vehicles (EVs) is an essential component that converts the direct current (DC) power from the vehicle's battery into alternating current (AC) power required to drive the electric motor. It plays a crucial role in controlling the speed and torque of the motor, enabling smooth and efficient operation. Figure 3.3 shows the inverter subsystem in electric vehicles.

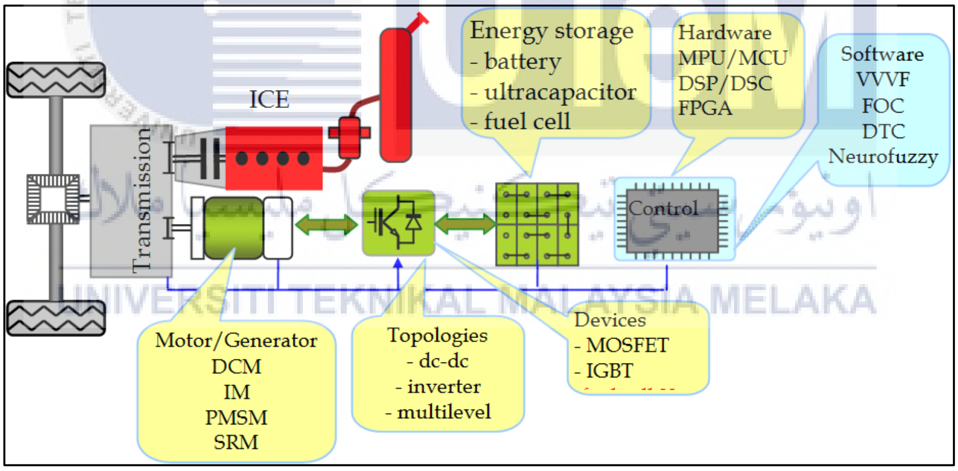


Figure 3.3: Inverter Subsystem

The inverter takes the DC power supplied by the battery pack and converts it into three-phase AC power. It uses power electronic devices, such as insulated-gate bipolar transistors (IGBTs) or silicon carbide (SiC) MOSFETs, to rapidly switch the voltage and current waveforms. By modulating the switching frequency and duty cycle, the inverter controls the output voltage and frequency of the AC power, which determines the speed and torque of the electric motor.

The inverter subsystem works in conjunction with the motor control unit (MCU) to precisely control the operation of the electric motor. The MCU uses feedback from various sensors, such as position sensors and torque sensors, to calculate the desired torque and speed commands. It then sends control signals to the inverter to adjust the switching patterns and voltage levels, ensuring the motor operates at the desired speed and torque with high efficiency.

3.3.3 Motor-Mechanical Subsystem

The motor-mechanical subsystem in electric vehicles (EVs) refers to the combination of the electric motor and mechanical components that work together to convert electrical energy into mechanical power to propel the vehicle. This subsystem is crucial for the movement and performance of the electric vehicle. Figure 3.4 shows the motor-mechanical subsystem in electric vehicles.

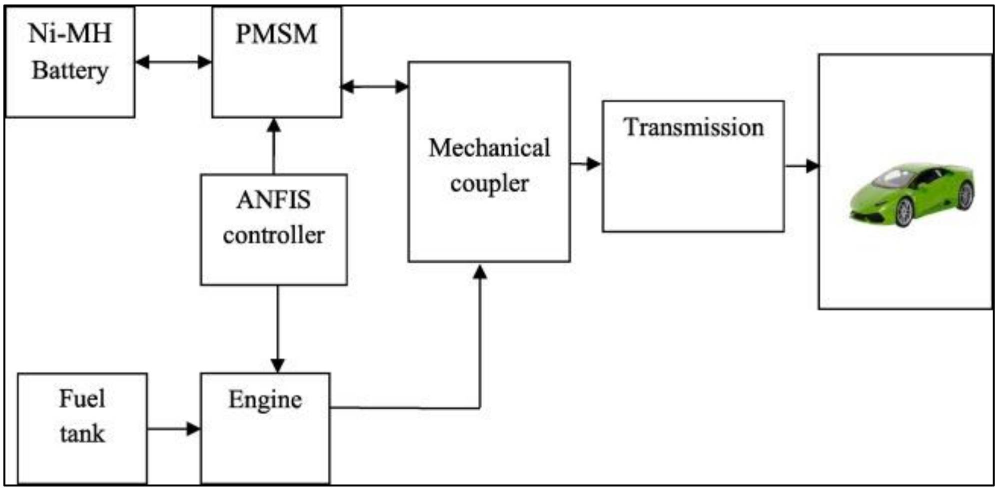


Figure 3.4: Motor-Mechanical Subsystem

The electric motor is the primary component of the motor-mechanical subsystem. It converts electrical energy from the battery into mechanical power to drive the vehicle. The electric vehicles (EVs) commonly use three types of electric motors which are Permanent Magnet Synchronous Motor (PMSM), Induction Motor and Switched Reluctance Motor (SRM). The PMSM uses permanent magnets on the rotor and stator windings to create a rotating magnetic field. They offer high efficiency, power density, and precise control. Then, the induction motors use electromagnetic induction to create a rotating magnetic field. They are known for their simplicity, robustness, and cost-effectiveness. Next, the SRMs utilize the principle of magnetic reluctance to generate torque. They are known for their high torque density and can operate efficiently over a wide range of speeds.

Besides that, the transmission system transmits rotational power from the electric motor to the wheels, enabling the vehicle to move. In EVs, the transmission system is usually simpler compared to internal combustion engine vehicles since electric motors offer a wide torque range. In electric vehicles, there are two main types of transmission systems which are Single-Speed Transmission and Multi-Speed Transmission. Many electric vehicles employ a single-speed transmission or direct-drive system. In this setup, the electric motor’s high torque at low speeds allows the vehicle to accelerate smoothly and efficiently without the need for multiple gears. Then, some electric vehicles, particularly high-performance models, may incorporate multi-speed transmissions. These transmissions provide different gear ratios to optimize performance, efficiency, and top speed.

3.4 Generate Subsystem Model in MATLAB-Simulink

To generate the subsystems model, MATLAB Simulink will be used as a software to design the subsystems model in electric vehicles. The battery electric car components were designed using MATLAB-Simulink, which also integrated the entire system. Additionally, the battery electric vehicle and its accompanying equation were simulated using MATLAB-Simulink for verification. Programming, computation, and visualisation are all combined in MATLAB, a technical programming language. It has been enhanced to address engineering and scientific issues, and it is presently utilised in a variety of fields. With its robust and varied graphic toolbox, MATLAB offers users a simple and relaxing working experience (IEEE Malaysia Section et al., 2017).

3.4.1 Battery Subsystem

The Simulink tools in MATLAB are used to create the battery subsystem, the first component of an electric vehicle. To model the battery electric car, all mathematical equations that apply each component in the battery electric vehicle simulation were chosen. The battery subsystem of an electric vehicle is depicted in Figure 3.5.

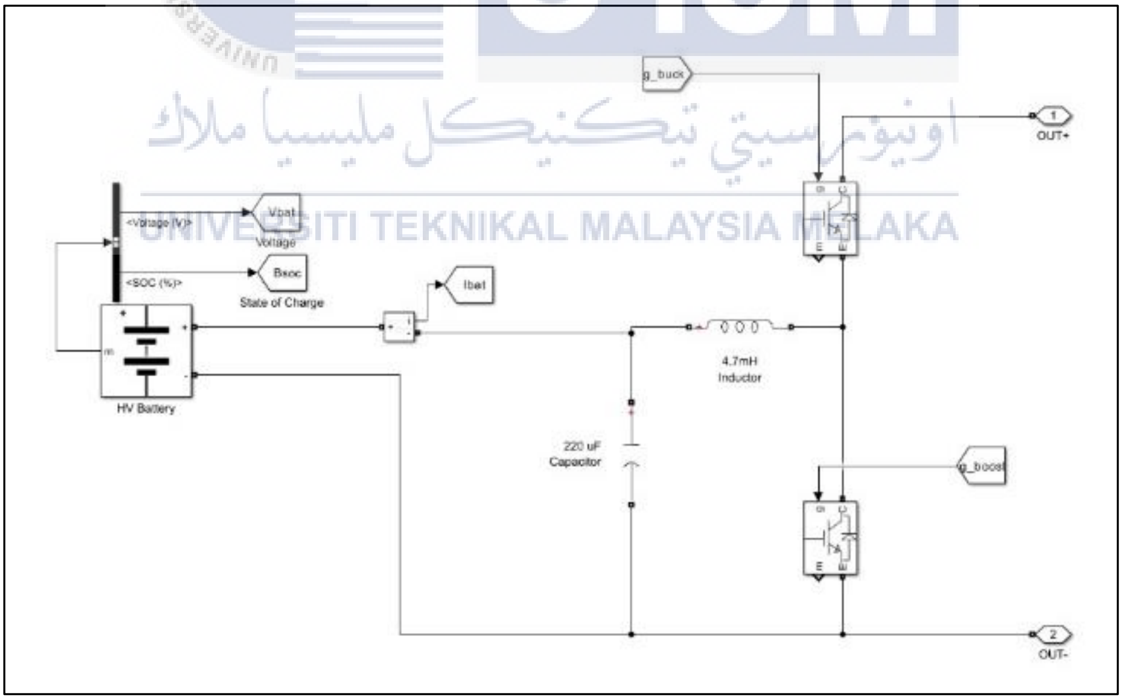


Figure 3.5: Battery Subsystem

The figure demonstrates that one of the sources for the battery subsystem is the HV battery. The HV battery will provide voltage and state of charge information to two additional ports. The voltage from that HV battery will provide an output value called Vbat. The subsystem also includes a current sensor that measures the amount of current leaving the HV battery, Ibat. The buck converter on the right side of this subsystem carries the incoming current and serves that increases power while the battery is charging. While the battery is discharging, the boost converter that sends the current out also works to generate extra power. The output of HV battery is channeled to inverter through Output 1 (Battery +) and Output 2 (Battery -).

3.4.2 Inverter Subsytem

The inverter subsystem is the second component found in electric cars. It continues in this subsystem and is connected to the prior battery subsystem. The current at the buck and boost converter will be fed from the preceding battery subsystem onto Inputs 1 and 2 at the inverter subsystem. The current at Inputs 1 and 2 is at its peak when the battery subsystem and inverter subsystem fuse. Vdc is the name of the voltage that is located in the centre of the inverter subsystem. After the current at Inputs 1 and 2 has increased, the voltage value can be monitored. The 3-phase inverter will then be used to convert the current supplied by Inputs 1 and 2 from direct current to alternating current. From points A, B, and C, the alternating current will split into three phases which are U, V, W before leaving to motor through Ports 3, 4, and 5. The alternating current also receives input from the pulse width modulation signal (pwm), which controls speed, at the same time. The inverter subsystem in electric vehicles is depicted in Figure 3.6.

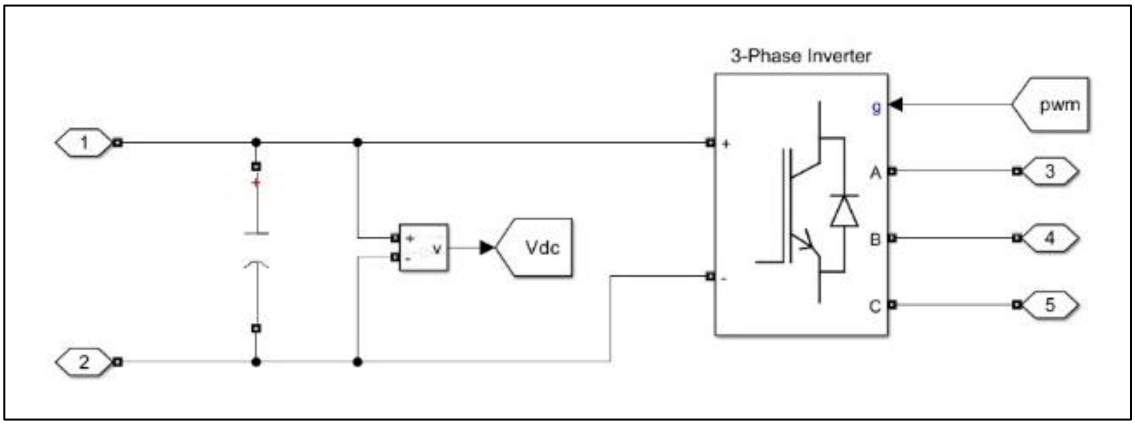


Figure 3.6: Inverter Subsystem

3.4.3 Motor Mechanical Subsystem

The motor mechanical subsystem is the third subsystem in electric cars. It continues and connects to the prior inverter subsystem in this subsystem. The current 5phase U, V, W of the prior inverter subsystems will enter the motor mechanical subsystem through Port 1,2 and 3. The torque, Tm, is present in the motor's mechanical subsystem. The motor mechanical subsystem will rotate till it reaches the desired torque, moving in accordance with the applied torque. The vehicle system, which is the car, will then receive the torque. The motor-mechanical subsystem of electric cars is depicted in Figure 3.7 and Figure 3.8.

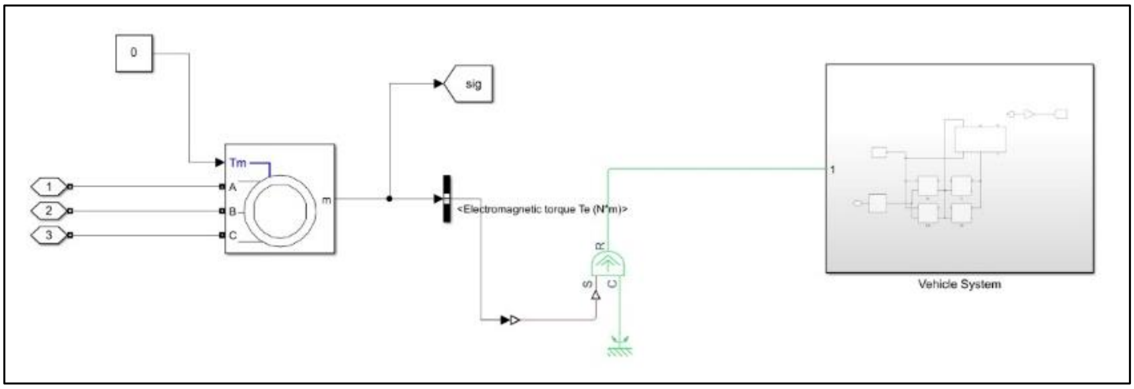


Figure 3.7: Motor-Mechanical Subsystem

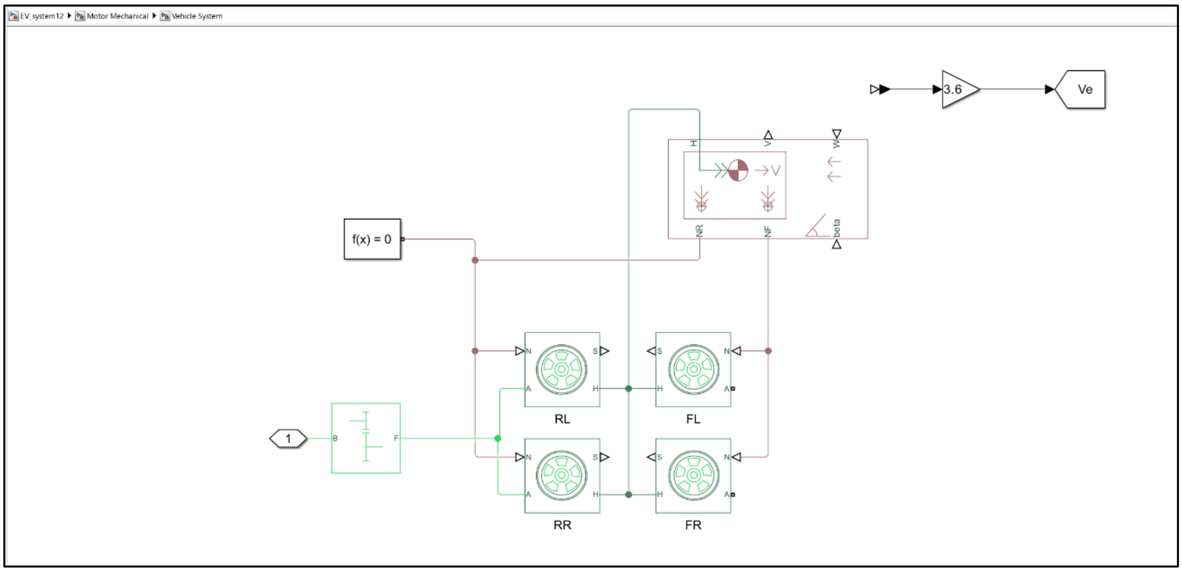


Figure 3.8: Motor-Mechanical Subsystem

3.4.4 Controller

In the subsystem of electric vehicles, there are one of external components which is controller. The controller is a crucial component that manages and controls various systems, including the motor, battery, charging, and other auxiliary systems. It acts as the “brain” of the vehicle, coordinating and regulating the flow of electrical energy to ensure optimal performance, efficiency, and safety. There are three of controller in this subsystem of electric vehicles. Figure 3.9 shows that the controller in electric vehicles.

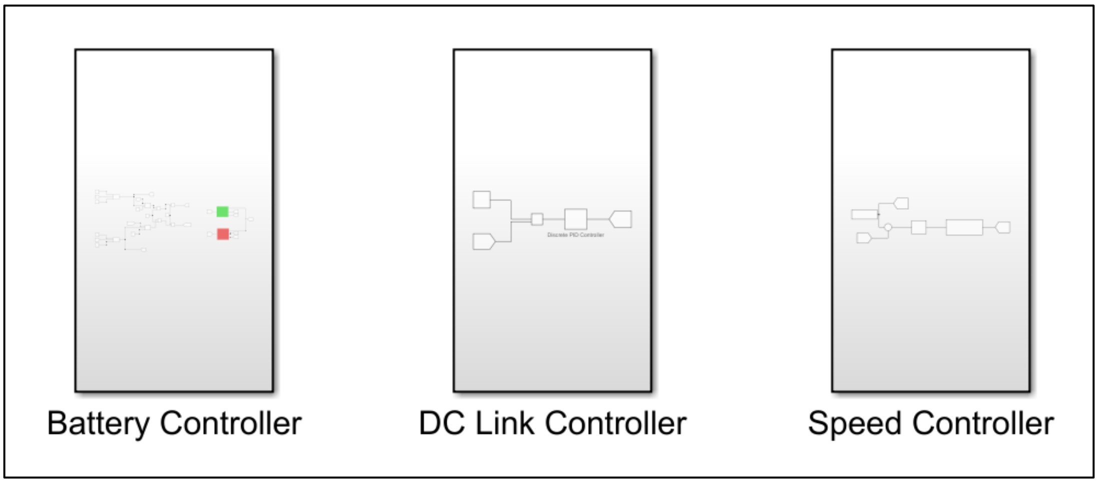


Figure 3.9: Controller

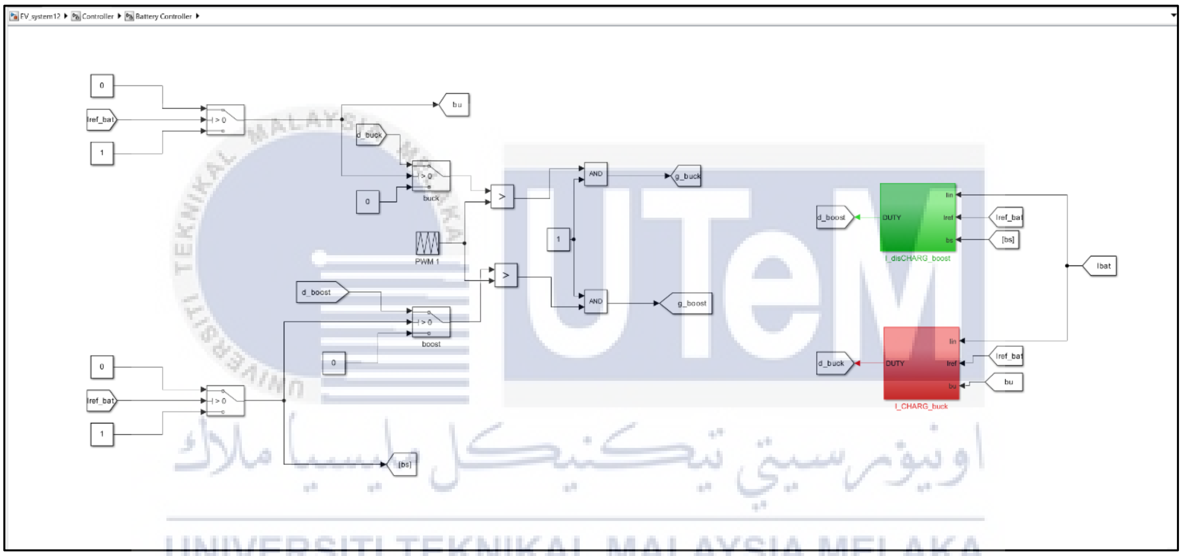


Figure 3.10: Battery Controller

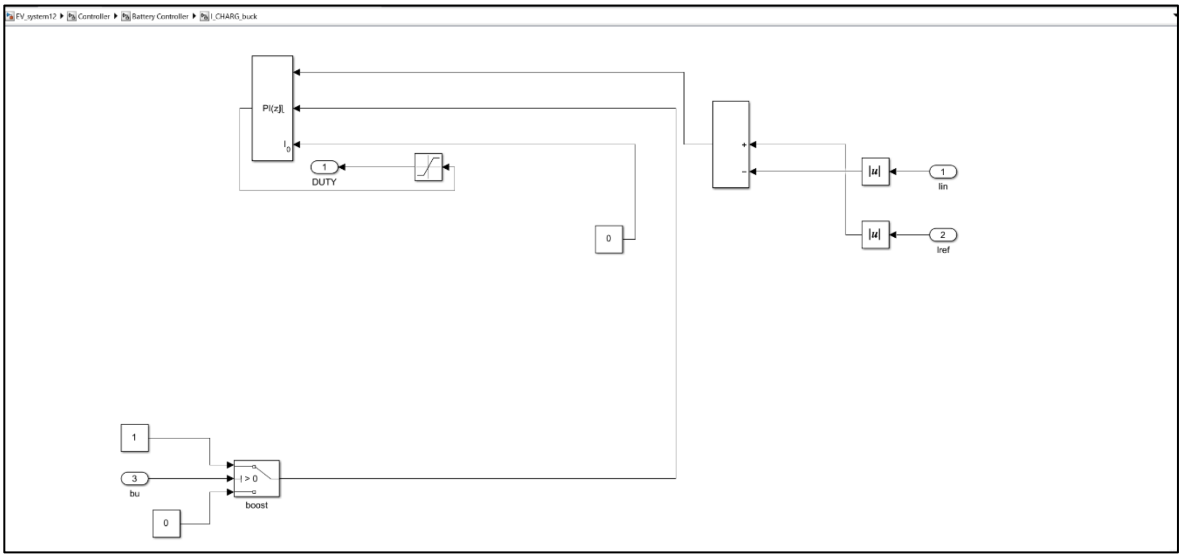


Figure 3.11: Battery Charging Controller

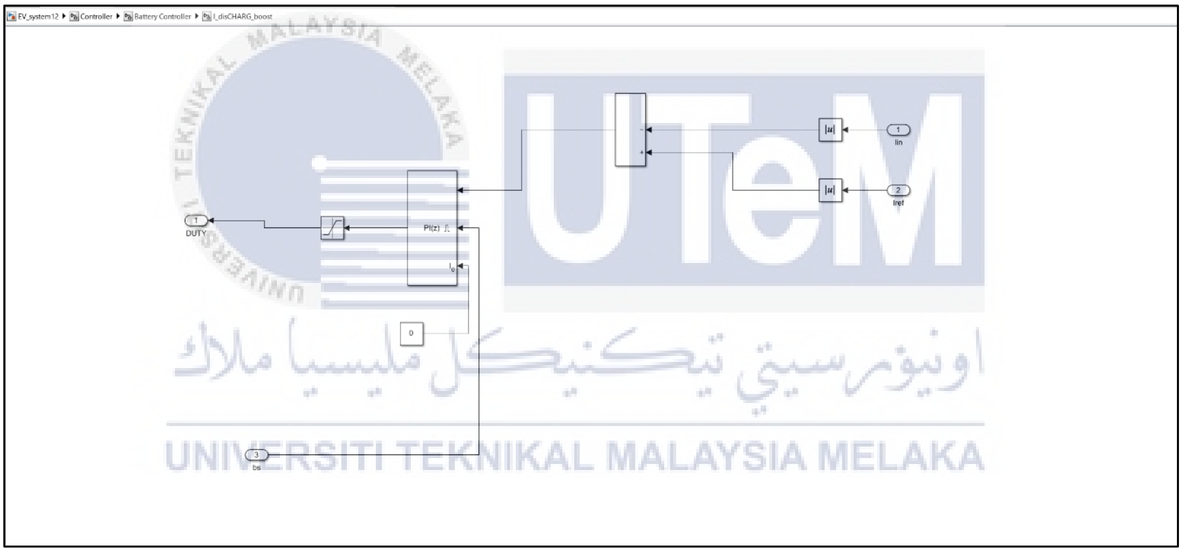


Figure 3.12: Battery Discharging Controller

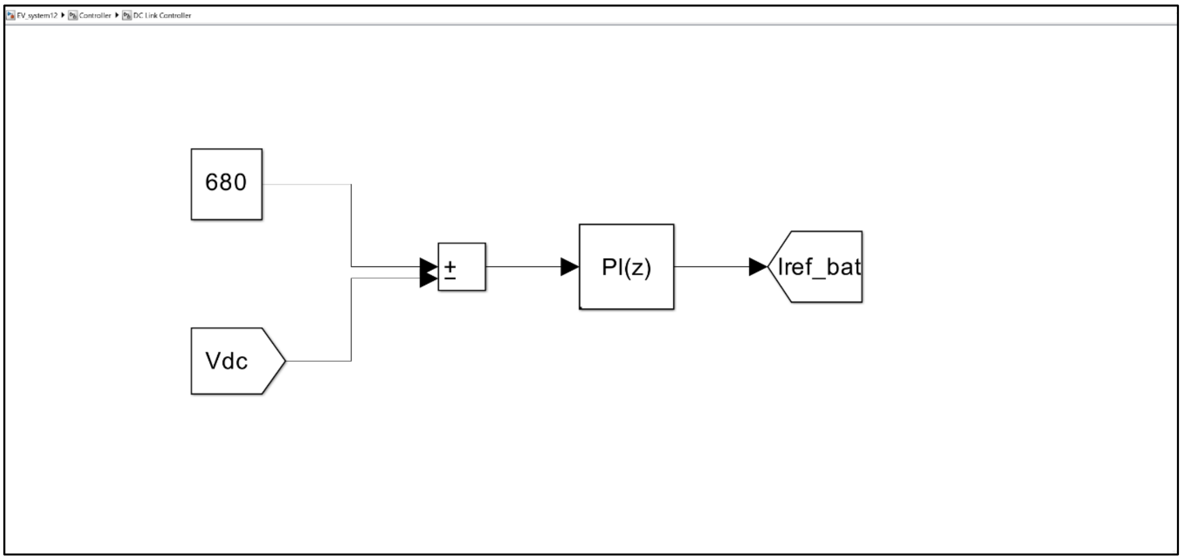


Figure 3.13: DC Link Controller

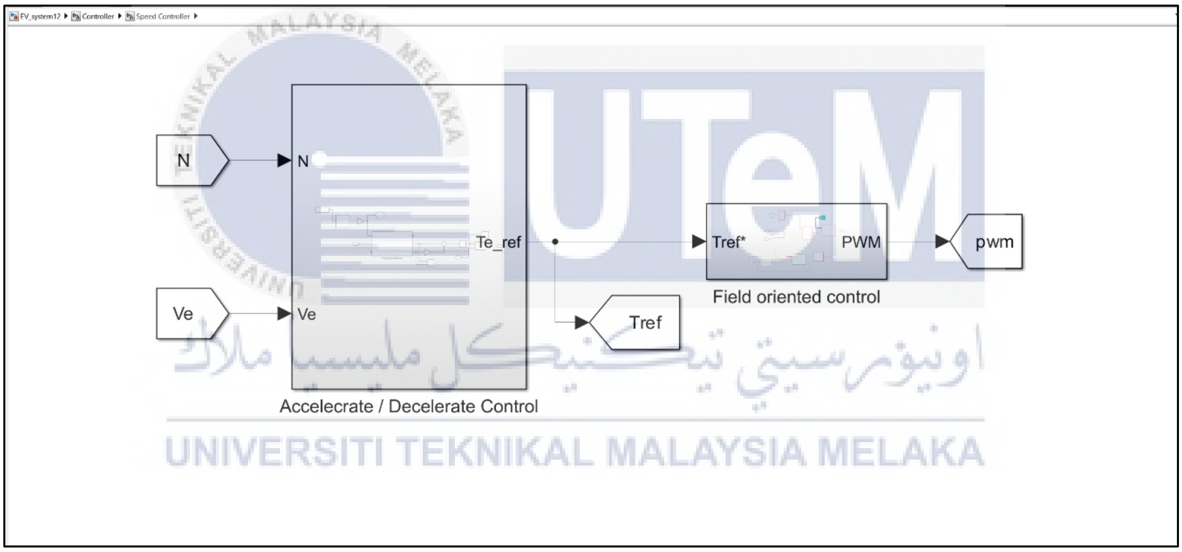


Figure 3.14: Speed Controller

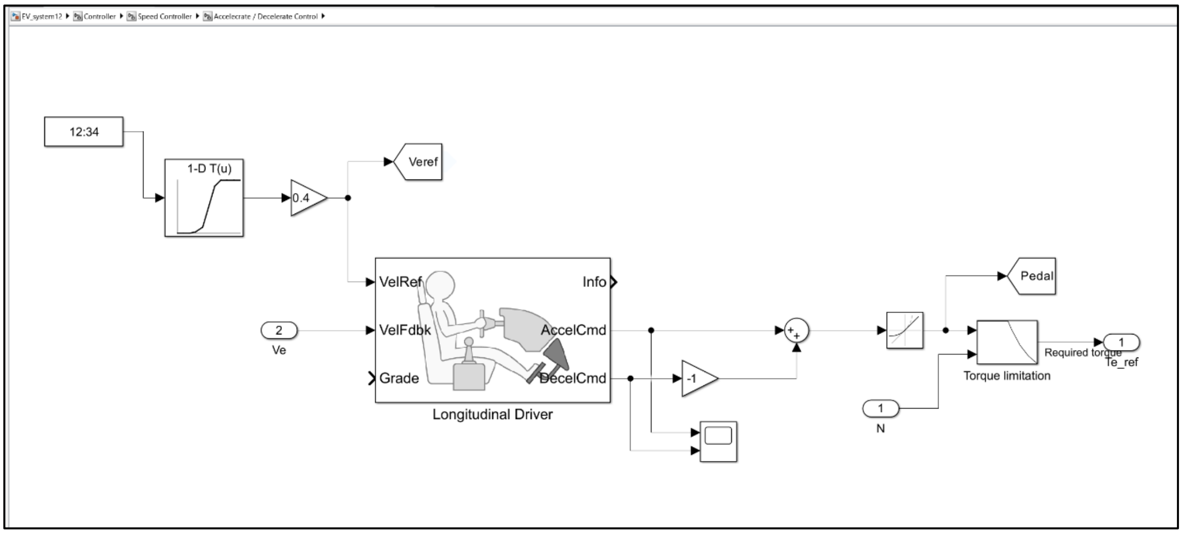


Figure 3.15: Speed Controller (Accelerate or Decelerate Control)

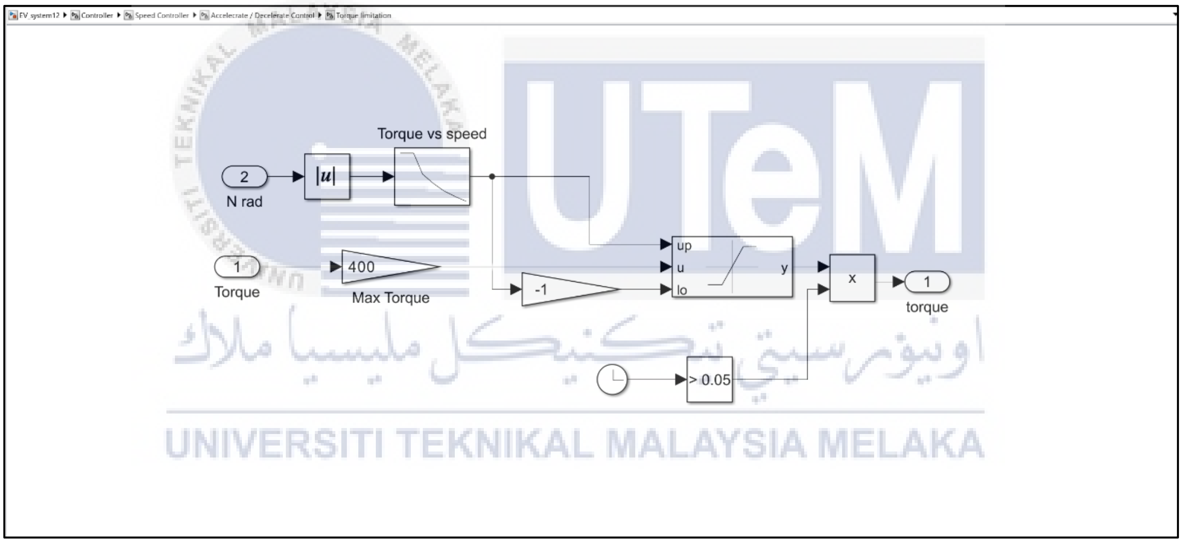


Figure 3.16: Speed Controller (Torque Limitation)

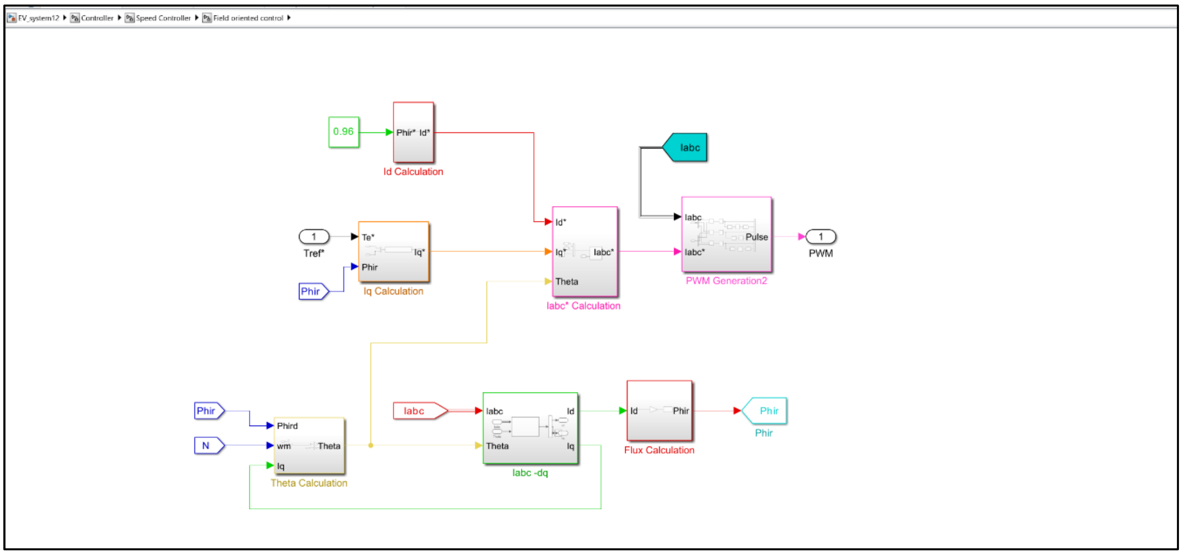


Figure 3.17: Speed Controller (Field Oriented Control)

The Battery Controller in electric vehicles (EVs) is a vital component that manages and controls the operation of the battery subsystem. It serves as the interface between the battery pack and the rest of the vehicle's electrical systems, ensuring safe and efficient performance. Next, the DC Link Controller is an essential component in electric vehicles (EVs) that manages and regulates the DC voltage between the battery and the inverter in the powertrain system. It ensures the smooth and efficient transfer of power from the battery to the electric motor. Then, the Speed Controller in electric vehicles (EVs) is a crucial component that regulates the vehicle's speed by controlling the power delivered to the electric motor. It interprets driver inputs and adjusts the motor's torque and speed to achieve the desired acceleration and deceleration.

3.4.5 Measurement

In the subsystem of electric vehicles, there is important external components which is measurement that function as to generates the data such as value of current and voltage. From the Table 3.1 below it shows that the significance of value of current and voltage. Then, figure 3.9 shows that the measurement of the electric vehicles.

Table 3.1: Symbol of Measurement

Symbol	Meaning
lbat	The data output which is value of current that can be obtained from the battery.
lref_bat	The reference value of current in the battery
Vbat	The data output which is value of voltage that can be obtained from the battery.

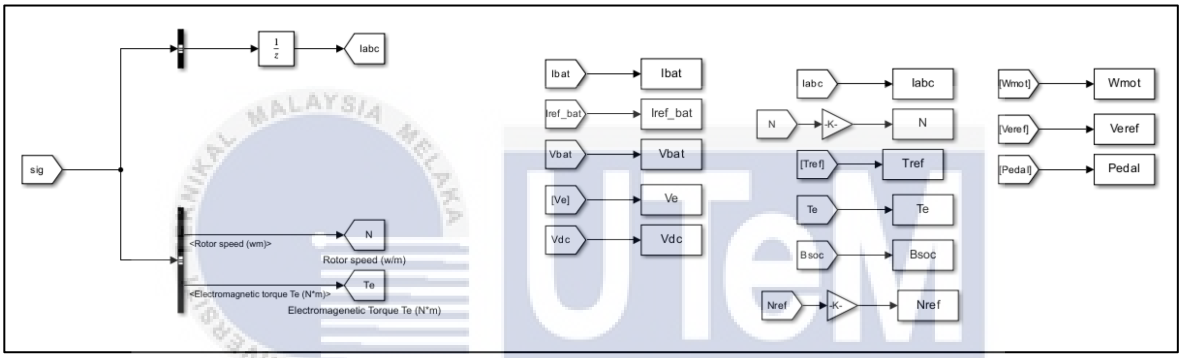


Figure 3.18: Measurement

3.5 Subsystems Model in Physical of E-Buggy

The already-built e-buggy has the hardware for the power monitoring system fitted. The battery, voltage sensor, current sensor, and wiring for the sensor signal were all installed during the process. 20 battery cells divided into two sets of 10 battery cells each were fitted in a parallel manner under the driver's seat for the LIB. Additionally, in order to control each battery, set independently, two distinct switches were included with both of these battery cells. The sensor's thickness was placed close to the controller at the back of the buggy. The lead-acid battery served as the source of power for the voltage and current sensors, which were arranged in a series manner. Figure 3.10 shows the wiring of the E-Buggy.

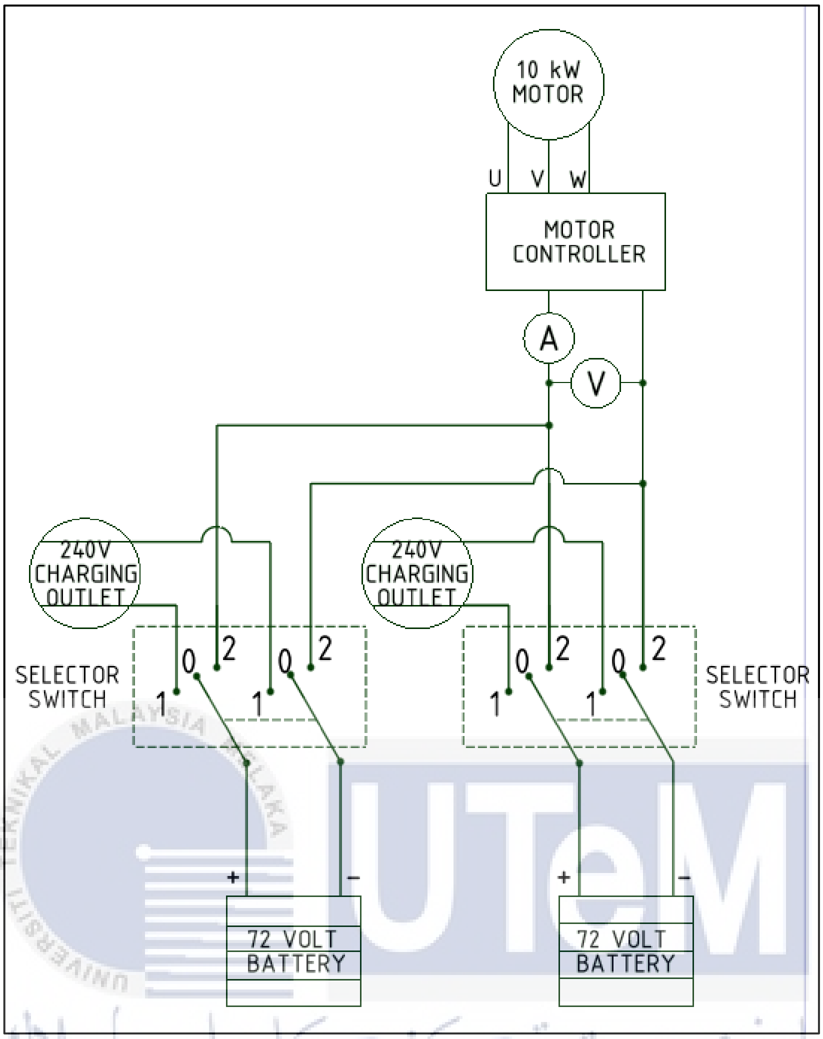


Figure 3.19: Wiring of E-Buggy

3.5.1 Battery Subsystems Model in Physical of E-Buggy

The e-buggy is using the types of battery which is Nickel-Metal Hydride Battery (NiMH). This battery is installed in a parallel connection. Table 3.2 shows that the Nickel-Metal Hydride Battery (NiMH) specification.

Table 3.2: The Nickel-Metal Hydride Battery (NiMH) Specification

Nominal Voltage	7.2 V 7.2 × 10 = 72 V
Nominal Capacity	6.5 Ah 6.5 × 10 = 65 Ah
Weight	1.04 kg 1.04 × 10 = 10.4 kg

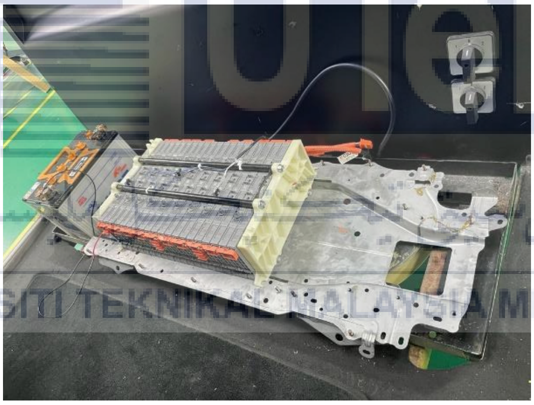


Figure 3.20: NiMH Battery

3.5.2 Inverter Subsystems Model in Physical of E-Buggy

The e-buggy is using the Field Oriented Controller which is VEC500 model. The maximum current from this controller is about 500 A. The Field Oriented Controller also has sine wave controller which is the analogue control that function as to adjust the speed of system. Figure 3.12 shows that the Field Oriented Controller that used in e-buggy.

Figure 3.21: Field Oriented Controller

3.5.3 Motor-Mechanical Subsystems Model in Physical of E-Buggy

In this application of e-buggy, the 10kW of BLDC Motor is use for the motor-mechanical subsystem. The specifications of this motor can be referred to Table 3.3 below. The specific result for 72V can be refereed to the appendix. The Figure 3.13 also shows the 10kW of BLDC Motor.

Table 3.3: Specifications of the Motor

Company	Golden Motor
Type	HPM72-10000
Rated Voltage	72 V
Rated Current	160 A
Rated Power	10000 W
Rated Speed	3500 RPM

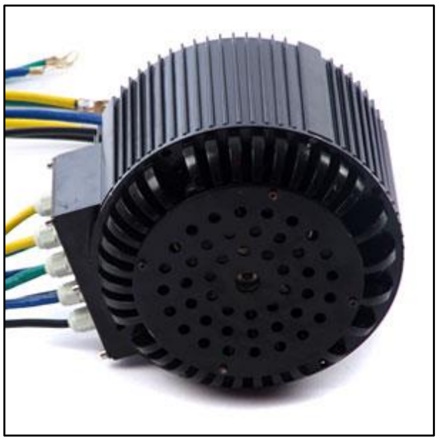


Figure 3.22: 10kW of BLDC Motor

3.6 Summary

For electric vehicles (EVs) to operate effectively and dependably, subsystems are essential. The Battery Management System (BMS), which is in charge of controlling charge and discharge cycles, keeping an eye on the condition of the battery pack, and guaranteeing the general wellbeing of individual cells, is one important subsystem. The Inverter Subsystem is a crucial element that transforms the battery's direct current (DC) power into alternating current (AC) power for the electric motor. To maximise power transfer, this calls for the usage of complex inverters, converters, and controllers. The electric motor is a crucial part of the Motor-Mechanical Subsystem, which is essential for transforming electrical energy into mechanical energy for vehicle propulsion. In order to control torque, speed, and overall efficiency in this subsystem, a complete control system is essential.

Additionally, the Controller and Measurement Subsystem functions as the central nervous system of the electric car, coordinating the integration of different parts, controlling communication, and carrying out control algorithms. It guarantees smooth subsystem coordination, which improves the performance and stability of the car. Concurrently, the measurement component includes sensors and instrumentation to track important variables like as temperature, velocity, and battery level, giving the control system useful information.

A methodical methodology is used in MATLAB-Simulink to construct subsystem models. Each subsystem's individual components must be identified, their interconnections must be represented through a block diagram, pertinent parameters and variables must be defined, mathematical models must be established using Simulink blocks, control logic must be implemented to regulate the behaviour of the subsystems, and simulations must be run for verification and analysis. A crucial stage is the integration of the Motor-Mechanical Subsystem, Battery Subsystem, Inverter Subsystem, Controller, and Measurement Subsystem into the overall EV model. Subsystems within the electric car are then tested and validated to make sure they meet industry standards and particular design specifications and work together flawlessly. The development of reliable and efficient electric vehicle systems is aided by this in-depth MATLAB-Simulink modelling technique, which makes it easier to comprehend the interactions and dynamics between the many subsystems of an electric car.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

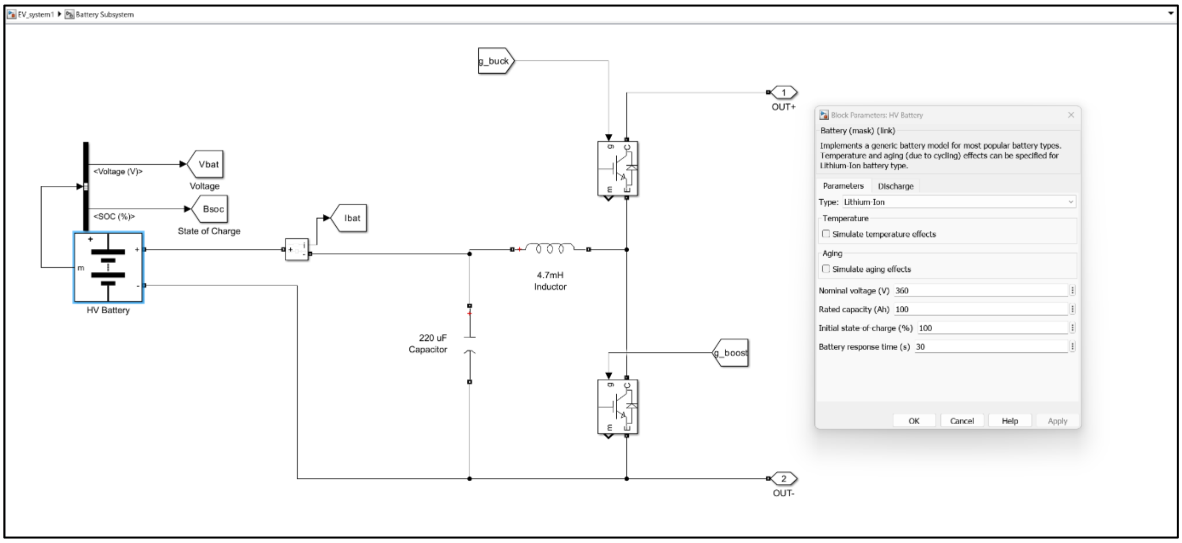
This chapter will present the result of the MATLAB simulation obtained in this research study and the comparison of the new e-buggy model of electric vehicle system with the benchmark model of electric vehicle system to determine the vehicle performance which is the efficiency. The main purpose is to validate the previous study about the mathematical model of electric vehicle system using MATLAB.

4.2 Mathematical Model Optimization

There is one mathematical model new e-buggy tested in this study with one benchmark model. A different mass of vehicle, type of battery and time of simulation optimization is tested on this one mathematical model. This is to evaluate the vehicle efficiency for the new e-buggy model. During the analysis, it was found that this new e-buggy model shows a little bit different value of vehicle efficiency. The table below shows the changes made to the new e-buggy model. Figure 4.1 and Figure 4.2 show a benchmark model of the electric vehicle system. The new e-buggy model made for this study is described in Table 4.1 and Figure 4.3 until Figure 4.4.

Table 4.1: Mathematical Model Optimization Description

	Benchmark Model	New E-Buggy Model
Type of Battery	Lithium Ion	Nickel-Metal-Hydride
Nominal Voltage of Battery	360 V	72 V
Rated Capacity of Battery	100 Ah	65 Ah
Mass of Vehicle	1200 kg	712.75 kg
Horizontal From Center Point to Front	1.4 m	1.07715 m
Horizontal From Center Point to Rear	1.6 m	1.42785 m
Time of simulation	100 seconds	800 seconds This time of simulation is different because of within 800 seconds, its suitable for new e-buggy to move around UTeM main campus area that including different operating condition such as the new e-buggy must lower its speed because of a lot of road bump that exist in UTeM main campus area.



Block Parameters: HV Battery

Battery (mask) (link)

Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.

Parameters | Discharge

Type: Lithium-Ion

Temperature

☐ Simulate temperature effects

Aging

☐ Simulate aging effects

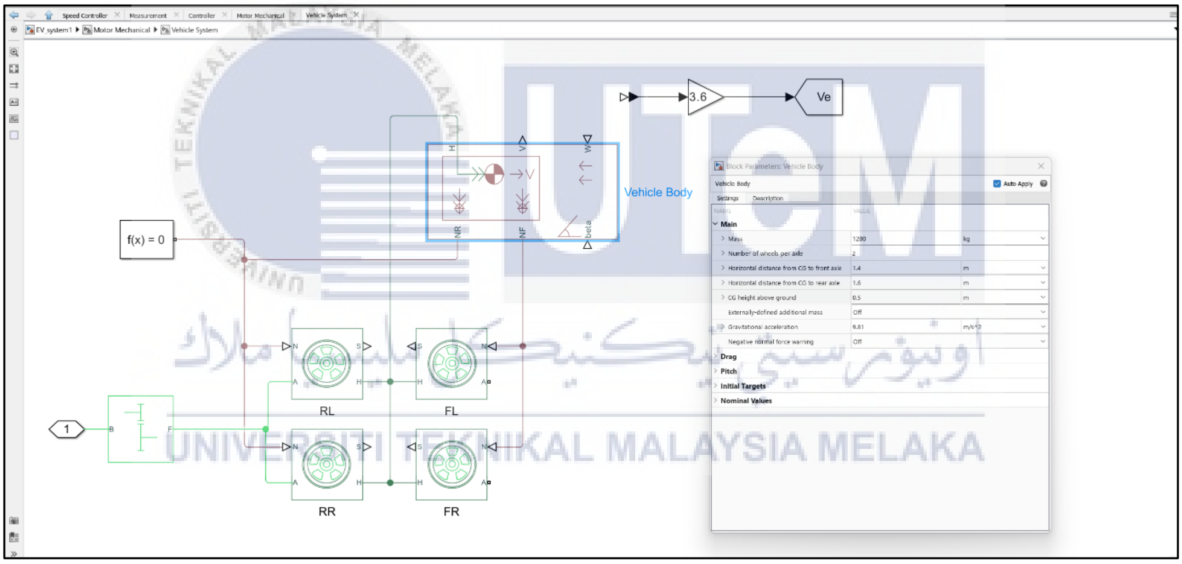
Nominal voltage (V): 360

Rated capacity (Ah): 100

Initial state-of-charge (%): 100

Battery response time (s): 30

Figure 4.1: Battery Parameters for Benchmark Model



Block Parameters: Vehicle Body

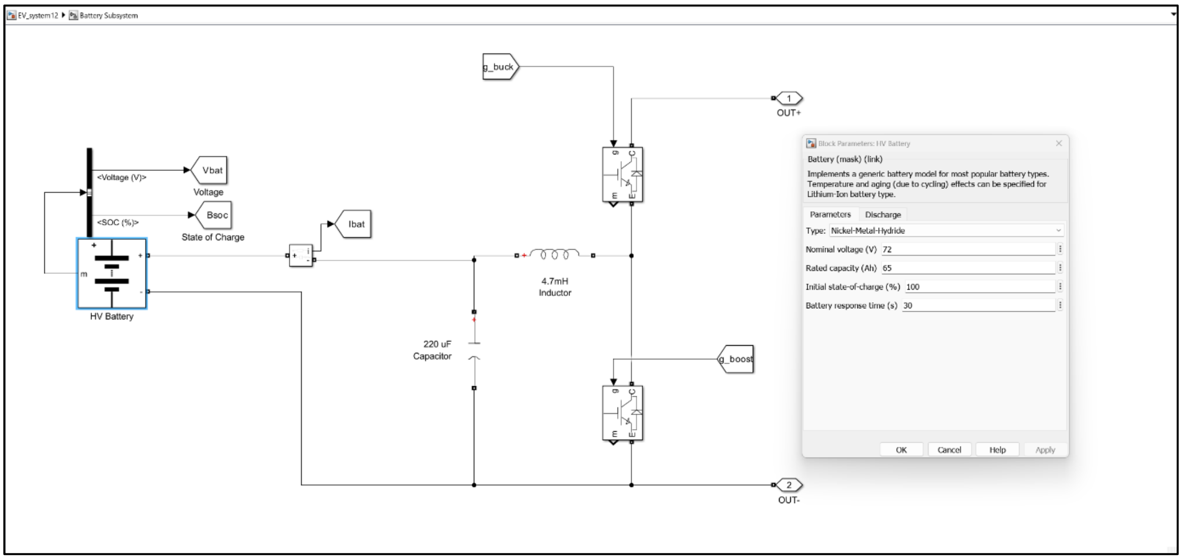
Vehicle Body

☑ Auto Apply

Settings | Description

NAME	VALUE	
Main		
Mass	1200	kg
Number of wheels per axle	2	
Horizontal distance from CG to front axle	1.4	m
Horizontal distance from CG to rear axle	1.6	m
CG height above ground	0.5	m
Externally-defined additional mass	Off	
Gravitational acceleration	9.81	m/s^2
Negative normal force warning	Off	
Drag		
Pitch		
Initial Targets		
Nominal Values		

Figure 4.2: Vehicle Body Parameters for Benchmark Model



Block Parameters: HV Battery

Battery (mask) (link)

Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.

Parameters | Discharge

Type: Nickel-Metal-Hydride

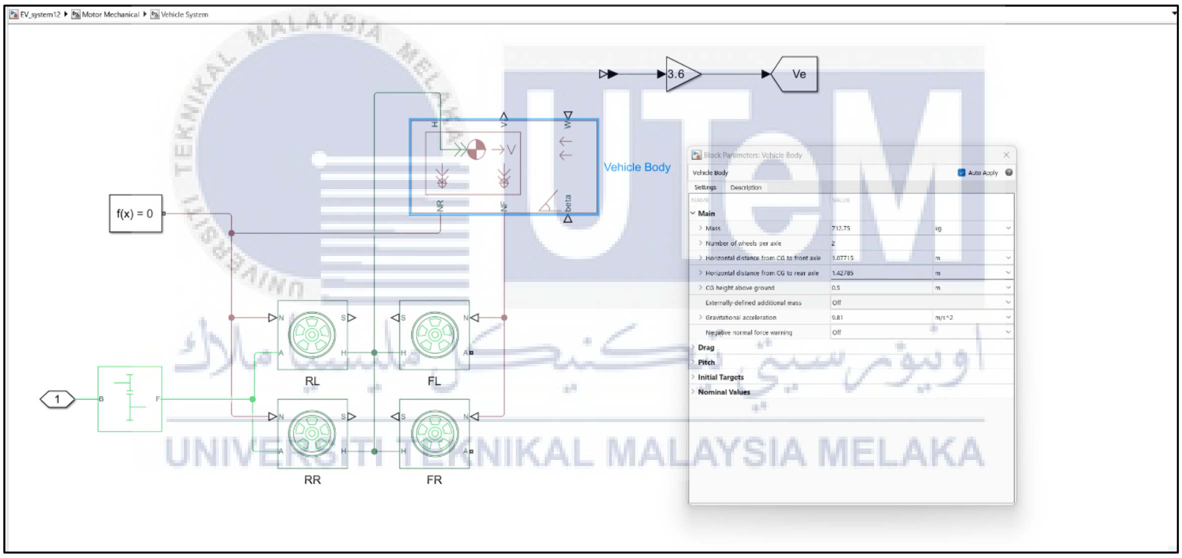
Nominal voltage (V) 72

Rated capacity (Ah) 65

Initial state-of-charge (%) 100

Battery response time (s) 30

Figure 4.3: Battery Parameters for New E-Buggy Model



Block Parameters: Vehicle Body

Vehicle Body

Settings | Description

NAME	VALUE	
Main		
Mass	712.75	kg
Number of wheels per axle	2	
Horizontal distance from CG to front axle	1.07715	m
Horizontal distance from CG to rear axle	1.42785	m
CG height above ground	0.5	m
Externally-defined additional mass	Off	
Gravitational acceleration	9.81	m/s^2
Negative normal force warning	Off	
Drag		
Pitch		
Initial Targets		
Nominal Values		

Figure 4.4: Vehicle Body Parameters for New E-Buggy Model

4.3 Result and Discussion

To carry out the result of the electric vehicle efficiency, a MATLAB simulation was done on this new e-buggy model. Table 4.2 shows the result of the electric vehicle efficiency based on Worldwide Harmonized Light Vehicles Test Procedure (WLTP) driving cycle.

Table 4.2: Result of Electric Vehicle Efficiency

Mathematical Model of Electric Vehicle	Benchmark Model	New E-Buggy Model
Efficiency Value of Electric Vehicle	89.68 %	92.70 % The increasement of efficiency value in new e-buggy model is due to the reduction of mass electric vehicle, which is 712.75 kg.

According to Table 4.2, the best value of efficiency in electric vehicles is from the new e-buggy model. The enlargement value of efficiency electric vehicle from new e-buggy is caused by reducing the mass of vehicle and aerodynamic improvements. Utilizing lighter materials and enhancing aerodynamics can help reduce the energy needed to move the vehicle. Higher overall efficiency is a result of this decrease in energy use. The different mathematical model will give a different result. This will be discussed in the following section.

4.3.1 Speed of Electric Vehicle

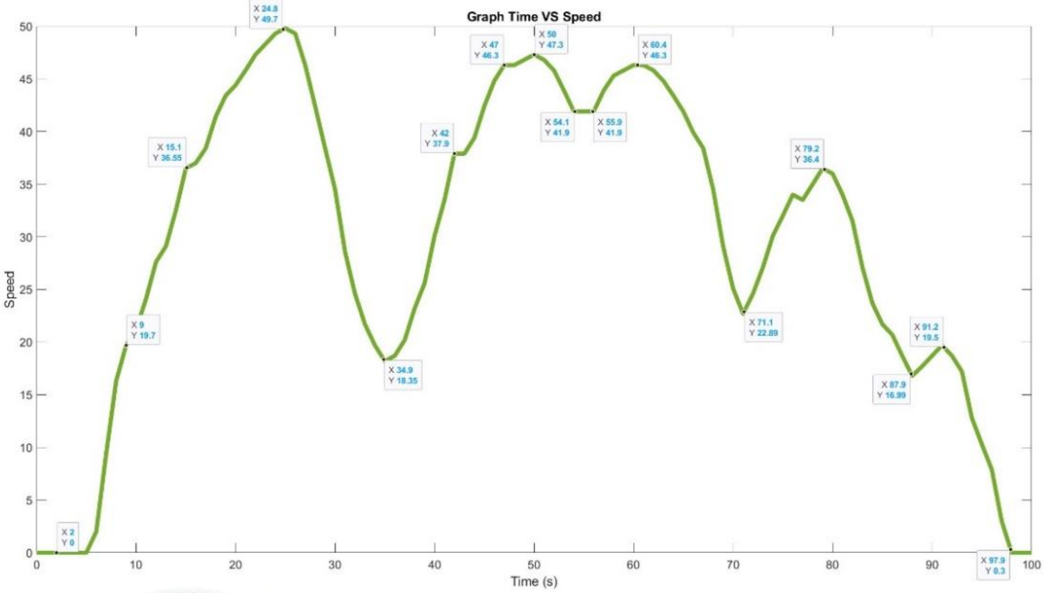


Figure 4.5: Speed of Electric Vehicle on Benchmark Model

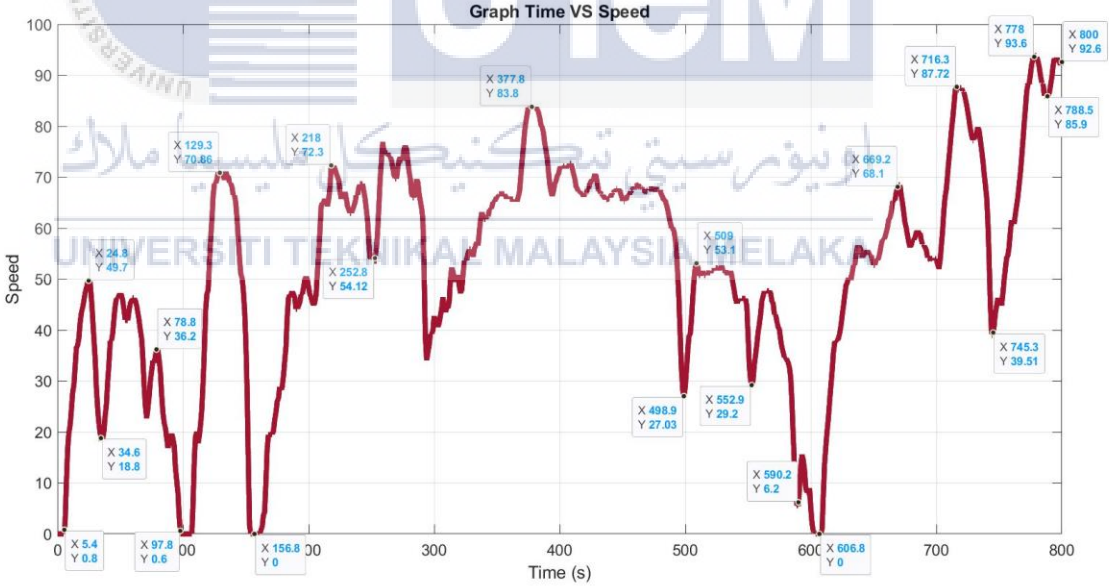


Figure 4.6: Speed of Electric Vehicle on New E-Buggy Model

The major focus of this study is to increase efficiency of electric vehicles, yet the investigation on speed of electric vehicle needs to be considered. Figure 4.5 visualizes the result of speed from validation of benchmark model in previous study by Nur Faqira Binti Mad Rusni. Based on benchmark model of electric vehicle, it shows that the previous study uses Worldwide Harmonized Light Vehicles Test Procedure (WLTP) which includes rural driving. This is due to the goal of the WLTP driving cycle is to imitate actual driving circumstances. Generally, it shows that the higher speed occurs at 25 seconds of simulation, which is 50 km/h. It shows that the vehicle's lithium-ion battery and electric motor combination are running at peak efficiency 25 seconds into the rural driving phase, enabling a quick acceleration to the top speed of 50 km/h. From the speed graph, the efficiency of electric vehicles can be determined. Based on Worldwide Harmonized Light Vehicles Test Procedure (WLTP), the distance travelled by the vehicle in 100 seconds is 0.516 km. This data can be applied to calculate the time delays for one of electric vehicles. The calculation for efficiency of electric vehicles based on benchmark model is shown below,

$$Time\ Delay = \frac{Distance\ Travel}{Maximum\ Speed}$$

$$Time\ Delay = \frac{156}{50}$$

$$Time\ Delay = 10.32$$

$$Efficiency = \frac{100 - 10.32}{100} \times 100$$

$$Efficiency = 89.68\ \%$$

Meanwhile, for the new e-buggy model, the higher speed occurs at 778 seconds of simulation, which is 94 km/h. Regarding the rural driving cycle, the required alterations in velocity to overtake other vehicles can be executed with minimal instances of abrupt acceleration or slowdown (Almatrafi et al., 2023). Drivers should expect to see fewer instances of frequent stops and starts as well as slower speed changes when travelling through rural areas. But it's important to remember that rural places may not always have road conditions that are up to satisfactory levels, so when driving in these areas, it's essential to be alert and flexible. The calculation for efficiency of electric vehicles based on new e-buggy model is shown below,

$$Time\ Delay = \frac{Distance\ Travel}{Maximum\ Speed}$$

$$Time\ Delay = \frac{5476}{94}$$

$$Time\ Delay = 58.26$$

$$Efficiency = \frac{800 - 58.26}{800} \times 100$$

$$Efficiency = 92.70\ \%$$

So, the performance of the vehicle is around 90% from verification model and 93% from new e-buggy model with the given Worldwide Harmonized Light Vehicles Test Procedure (WLTP) cycle, some losses and inertia of the vehicle does not allow to achieve 100% with the Drive Cycle (Kohar et al., 2023).

4.3.2 Torque of Electric Vehicle

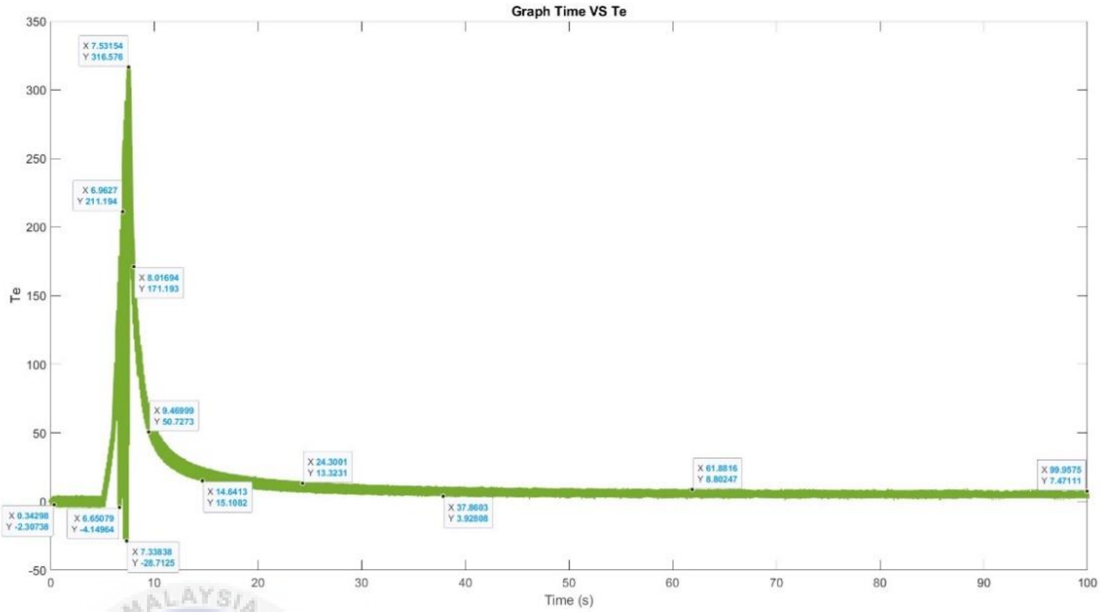


Figure 4.7: Torque of Electric Vehicle on Benchmark Model

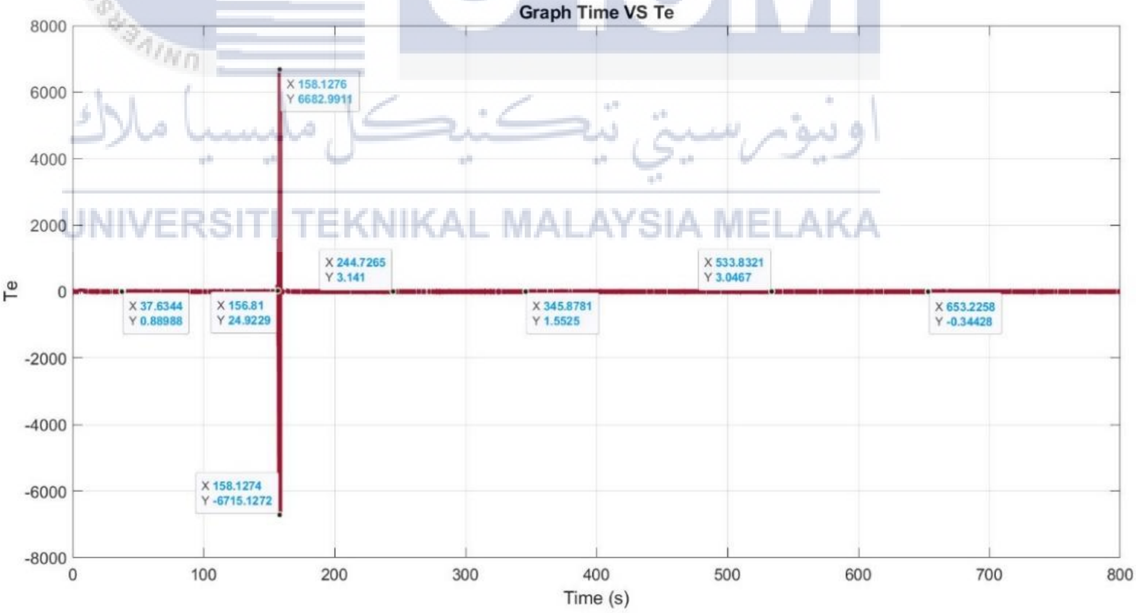
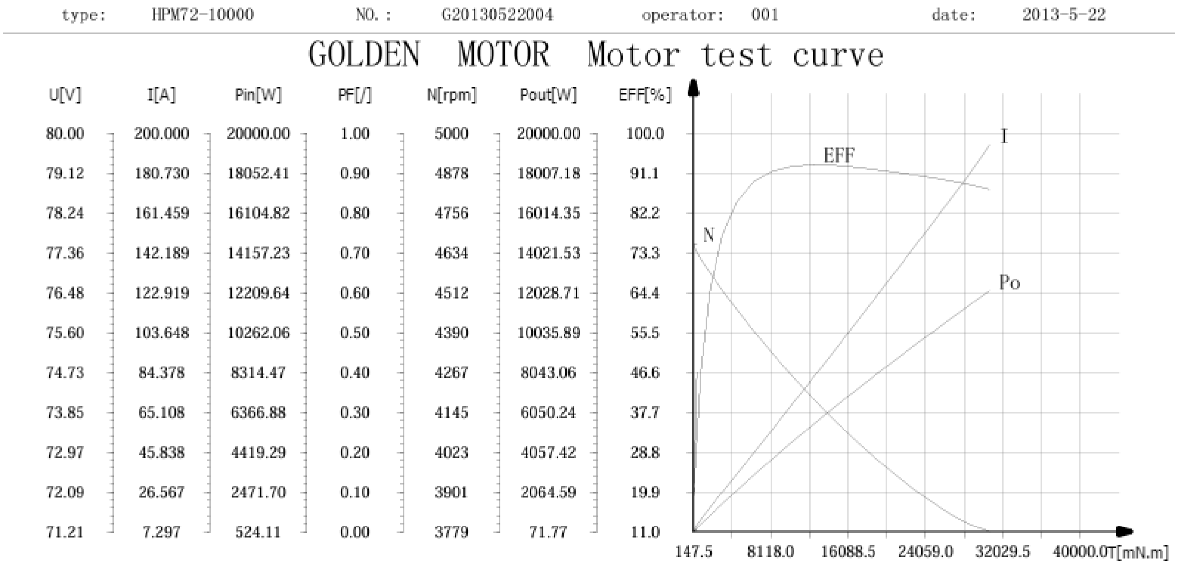


Figure 4.8: Torque of Electric Vehicle on New E-Buggy Model

Figure 4.7 shows the torque of electric vehicle when the benchmark model was in simulation. The WLTP drive cycle, which is specifically engineered to replicate rural driving conditions, allows the electric vehicle in question to reach its maximum torque output of 316 Nm for a length of 100 seconds. The torque performance of the vehicle is a critical determinant of its capacity to provide strong acceleration and top performance in situations that are frequently experienced in rural areas (Parra et al., 2018). The sustained high torque for a substantial length demonstrates the electric vehicle's efficiency and capability to negotiate different terrains and hard driving conditions commonly seen in rural locations, offering drivers with a responsive and reliable driving experience.

Figure 4.8 shows the torque of electric vehicle when the new e-buggy model was in simulation. A stunning 800 seconds are needed to sustain a peak torque of 6682 Nm, which is a significant milestone in the field of electric vehicle advancement. This exceptional torque performance is carefully assessed within the parameters of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), an internationally accepted benchmark for evaluating the effectiveness and performance of automobiles. However, during time equal to 158 seconds, the value of torque is quite high which is 6682 Nm. This is because the new e-buggy has to go through an area that goes uphill.

Based on previous Chapter 3 which is Methodology, it states that the motor is used BLDC Motor which is 10kW Fan Cooling. Figure 4.9 shows the Golden Motor Test Curve, the lowest torque is 147.5 Nm meanwhile the new e-buggy model simulation can achieve the highest torque is 6682 Nm. This ends up resulting in a motor extremely suitable for rural driving.



type: HPM72-10000 NO.: G20130522004 operator: 001 date: 2013-5-22

GOLDEN MOTOR Motor test curve

U[V]	I[A]	Pin[W]	PF[/]	N[rpm]	Pout[W]	EFF[%]
80.00	200.000	20000.00	1.00	5000	20000.00	100.0
79.12	180.730	18052.41	0.90	4878	18007.18	91.1
78.24	161.459	16104.82	0.80	4756	16014.35	82.2
77.36	142.189	14157.23	0.70	4634	14021.53	73.3
76.48	122.919	12209.64	0.60	4512	12028.71	64.4
75.60	103.648	10262.06	0.50	4390	10035.89	55.5
74.73	84.378	8314.47	0.40	4267	8043.06	46.6
73.85	65.108	6366.88	0.30	4145	6050.24	37.7
72.97	45.838	4419.29	0.20	4023	4057.42	28.8
72.09	26.567	2471.70	0.10	3901	2064.59	19.9
71.21	7.297	524.11	0.00	3779	71.77	11.0

Figure 4.9: Golden Motor Test Curve

4.3.3 Voltage and Current Battery of Electric Vehicle

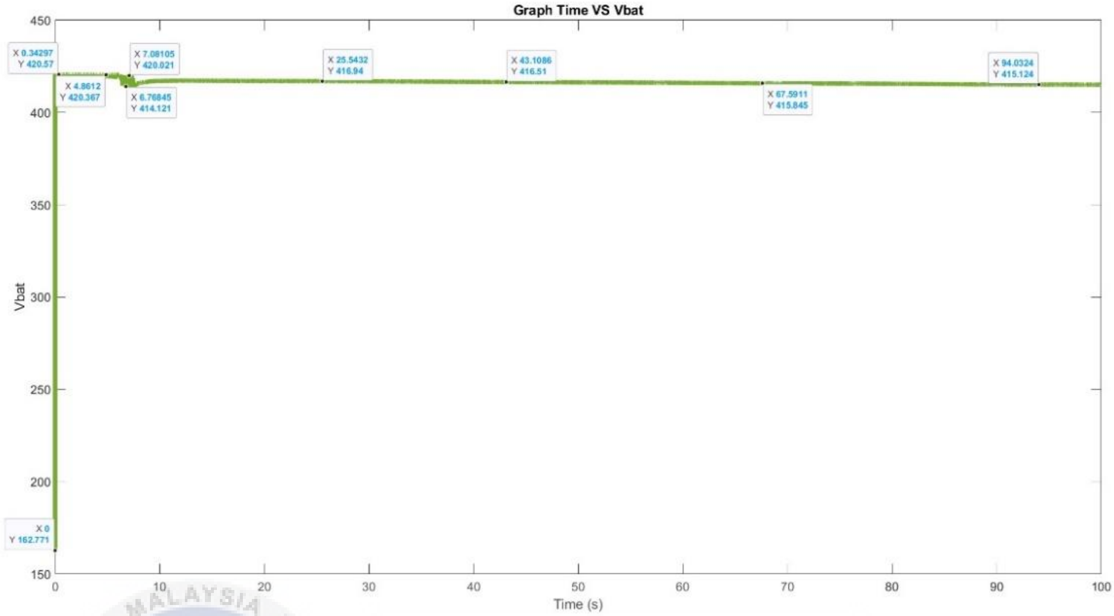


Figure 4.10: Voltage Battery of Electric Vehicle on Benchmark Model

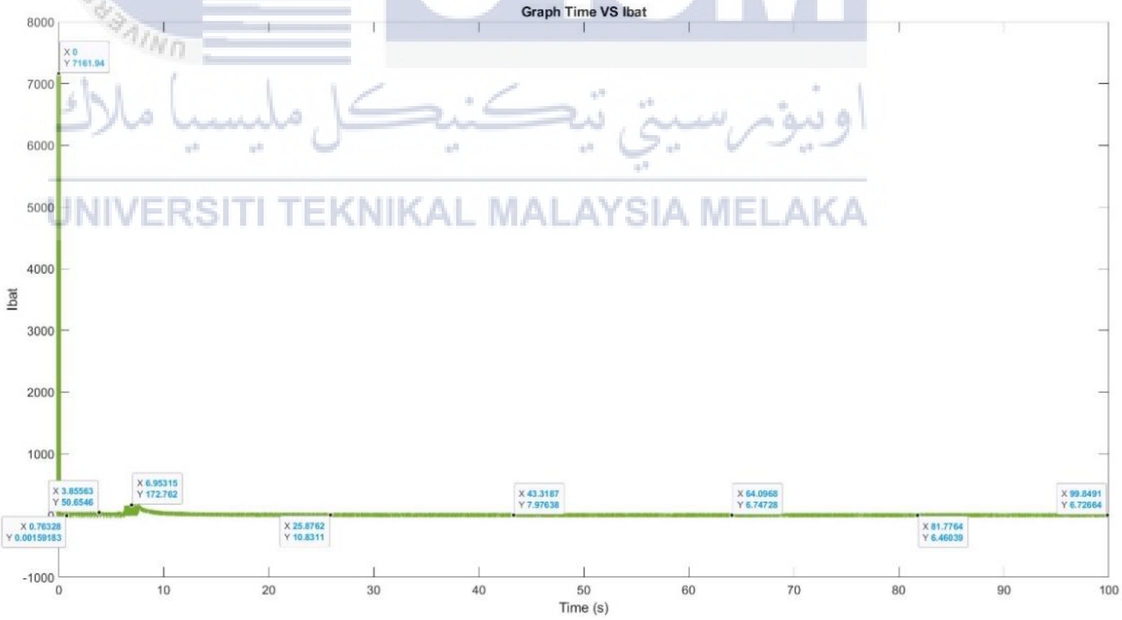


Figure 4.11: Current Battery of Electric Vehicle on Benchmark Model

As seen in Figure 4.10, which is result for voltage battery of electric vehicle when the benchmark model being simulated. Based on the graph, the starting voltage is 152 V, and the operating voltage is 420 V. However, during time simulation on 6 seconds, the voltage is dropped at 414 V. This is due to the coil or winding splitting the magnetic field as the motor shaft turns, producing a voltage that is opposite to the applied voltage. This is the rear electromagnetic field. This is aligned with the study from (H. Kim & Bhattacharya, 2019) mention that when the motor is initially at rest, the internal resistance causes a large voltage to drop across the motor's winding since the back EMF is low and the current is high. Based on Figure 4.11, the current battery of electric vehicle when the benchmark model is being simulated. According to the graph, the starting current battery is at lower point such as 0.25 A. Then, the operating current is 7161 A meanwhile during time simulation on 6 seconds, the current battery is increase significantly at 172 A.

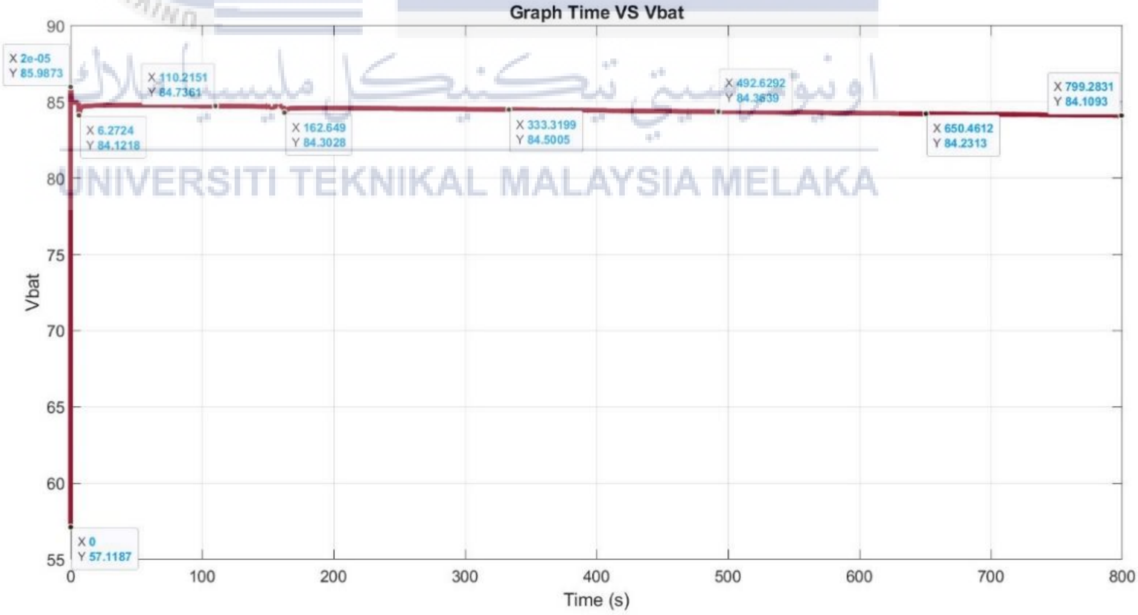


Figure 4.12: Voltage Battery of Electric Vehicle on New E-Buggy Model

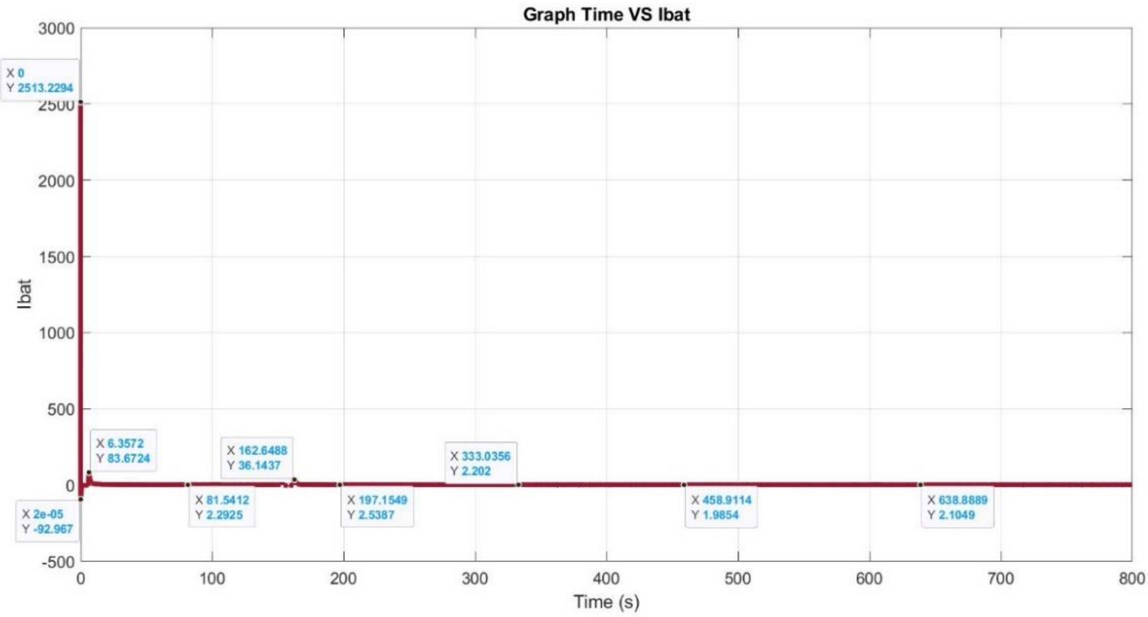


Figure 4.13: Current Battery of Electric Vehicle on New E-Buggy Model

As seen in Figure 4.12, which is result for voltage battery of electric vehicle when the new e-buggy model is on simulation. Based on the graph, the starting voltage is 57 V. After that, the operating voltage is 86 V. This is due to a motor's initial stage of movement requiring more power since it must overcome surface resistance, inertia, static friction, and other mechanical losses when it must move a tire from a standstill (J.-Y. Kim et al., 2022). However, during time simulation on 6 seconds, the voltage is dropped to 84 V. This is due to when the tire starts moving, it starts to overcome kinetic friction and needs less effort to stay moving, so the amount of power needed may go down. Based on Figure 4.13, the current battery of electric vehicle when the new e-buggy model is being simulated. According to the graph, the starting current battery is at a lower point such as 0.5 A. Then, the operating current is 2513 A meanwhile during time simulation on 6 seconds, the current battery is increase significantly at 83 A.

4.3.4 Battery State of Charge of Electric Vehicle

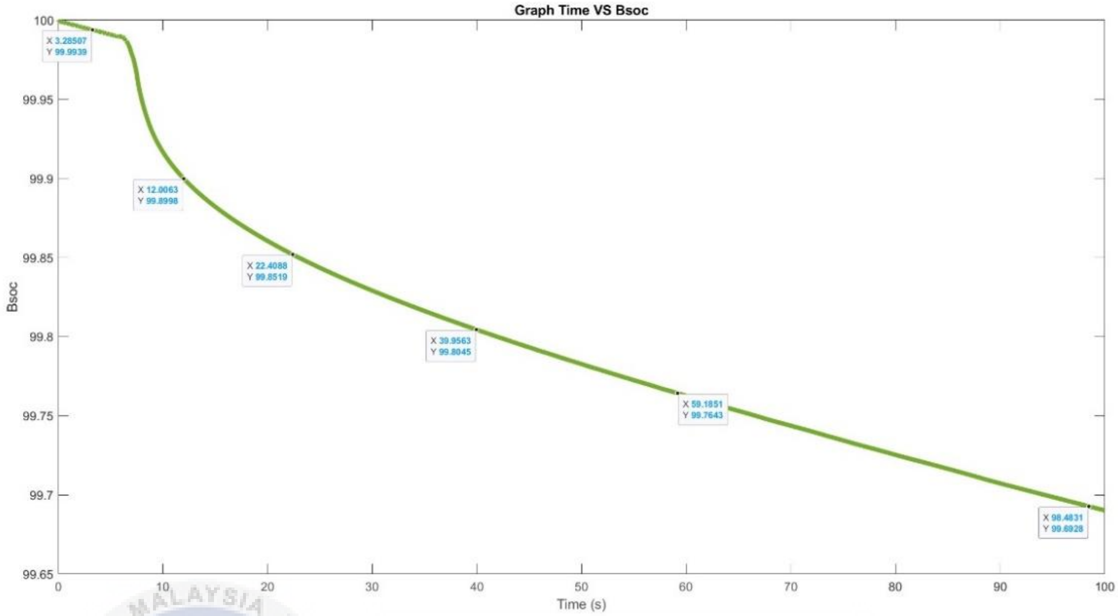


Figure 4.14: Battery State of Charge of Electric Vehicle on Benchmark Model

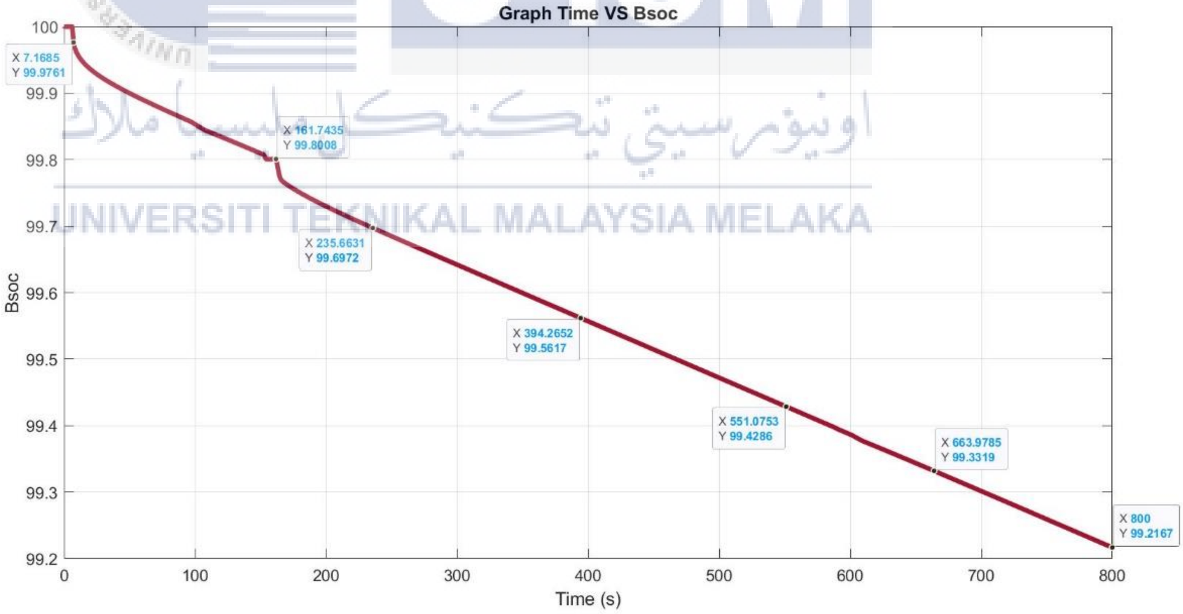


Figure 4.15: Battery State of Charge of Electric Vehicle on New E-Buggy Model

Figure 4.14 shows the battery state of charge in benchmark mathematical model that uses Lithium-Ion battery is remaining at 98.3 %. The ability of the electric vehicle to maintain a battery state of charge of 98.3% for the entire 100-second drive cycle of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) under rural conditions is an indication of the power system's remarkable energy retention and efficiency. This discovery implies that the car either used very little energy or had effective regeneration during this rural interval. The continuous high State of Charge may be caused by elements like seamless acceleration, efficient regenerative braking, and possibly reasonably flat terrain (Kohar et al., 2023). This performance demonstrates how well the energy management system of the electric car adjusts to the demands of driving in rural areas while adhering to the WLTP framework. The data highlights the potential for increased efficiency and range, demonstrating how electric vehicles can adapt to a variety of driving conditions while keeping an amazing state of charge. The low value of efficiency on this benchmark mathematical model is due to the larger number of mass electric vehicles.

Figure 4.15 shows the battery state of charge in new e-buggy model that uses Nickel-Metal-Hydride battery is remaining at 99.2 %. It is a sign of a strong and effective energy management system that a battery state of charge of 99.2% was observed during an extended 800-second timeframe during the drive cycle of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) in rural conditions. This endurance is particularly noteworthy considering the dynamic hurdles that driving in rural areas can provide, including shifting terrain and driving habits. The continued high State of Charge suggests effective energy use, which might be attained by using conservative power consumption techniques and enhanced regenerative braking (Kohar et al., 2023). Such performance is a sign of a modern battery-equipped electric car that has been well-engineered. In this scenario, the battery system, likely incorporating high-capacity and high-performance cells, displays its capability to withstand the demands of rural driving while retaining an extraordinarily high level of charge.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter will conclude the overall electric vehicle system modelling such as battery subsystem, inverter subsystem, motor mechanical subsystem, controller, and measurement using MATLAB. Recommendations for future study are listed as well in this chapter to improve the finding in this study.

5.2 Conclusion

Generally, this study has successfully achieved the main objective of this study to validate the new e-buggy model of electric vehicle system modelling with the benchmark model. As stated in the Problem Statement before, the first objective of this study is to create a mathematical model of an electric vehicle system that can precisely anticipate how the system would perform under various operating circumstances. The battery, motor, power electronics, and other important EV system parts should all be represented in the model. The system modelling has been designed and produced using MATLAB software.

On the other hand, the second objective of this study is to design the NiMH battery performance simulation and validate the result with a benchmark model. First, after the benchmark model had been chosen, the subsystem simulation and analysis are done to determine the current, voltage, speed, torque, and velocity of the electric vehicle. This simulation is done by using the MATLAB, as mentioned in Chapter 3, Methodology. The result of maximum torque in electric vehicle based on WLTP driving cycle is 6682 Nm.

Then, the maximum voltage and current of battery in electric vehicle based on NiMH battery is 86 V and 2513 A.

As a conclusion, this research has successfully achieved all the objective that mentioned early in the introduction as the proposed different mathematical model and analyzing the results to evaluate performance and identify opportunities for improvement.

5.3 Recommendation for Future Work

Since this study in just focusing on the design of mathematical model in electric vehicle using MATLAB-Simulink with simulation and analysis of the EV system based on WLTP driving cycle and analyzing the results to evaluate performance and identify opportunities for improvement, it is recommended to do the study on emphasizes even more how important this model is for analyzing power flow in motoring and regeneration, as well as for figuring out energy flow and drive performance (Mohd et al., 2015).

Besides that, this study can be continued by studying the application of an advanced power management algorithm to maximize the efficiency of the engine and motor/generator (Avani Meshram et al., 2022). All this research points to the necessity of developing a more sophisticated and effective MATLAB-based mathematical model for electric vehicle systems. Therefore, here are some recommendations that can be applied in future work.

5.4 Project Potential

Electric vehicle (EV) system modelling using MATLAB has a great deal of project potential and is crucial to the advancement of sustainable transportation. The broad range of simulation tools available in MATLAB, especially in the Simulink environment, provide a comprehensive toolkit for simulating intricate interactions in an electric vehicle system. Potential initiatives in this field take many forms, the first of which is the intricate modelling of cutting-edge battery technology. Projects can concentrate on creating complex models that take state-of-charge dynamics, degradation, and thermal management into account as EV batteries continue to advance. This will help to maximise battery longevity and performance.

Moreover, projects might investigate the incorporation of machine learning and artificial intelligence techniques inside the MATLAB framework, given the growing significance of electric vehicles in intelligent and interconnected ecosystems. This entails creating predictive maintenance models, putting advanced driver assistance systems into place, and applying machine learning approaches to optimise the charging infrastructure.

In a nutshell there is a wide range of project potential for MATLAB-based electric car system modelling, from component-level analysis to whole system simulation. Leveraging MATLAB's strengths can result in improvements in performance, efficiency, and sustainability as the electric vehicle sector develops, which will further the overarching objective of establishing a cleaner and more sustainable transportation future.

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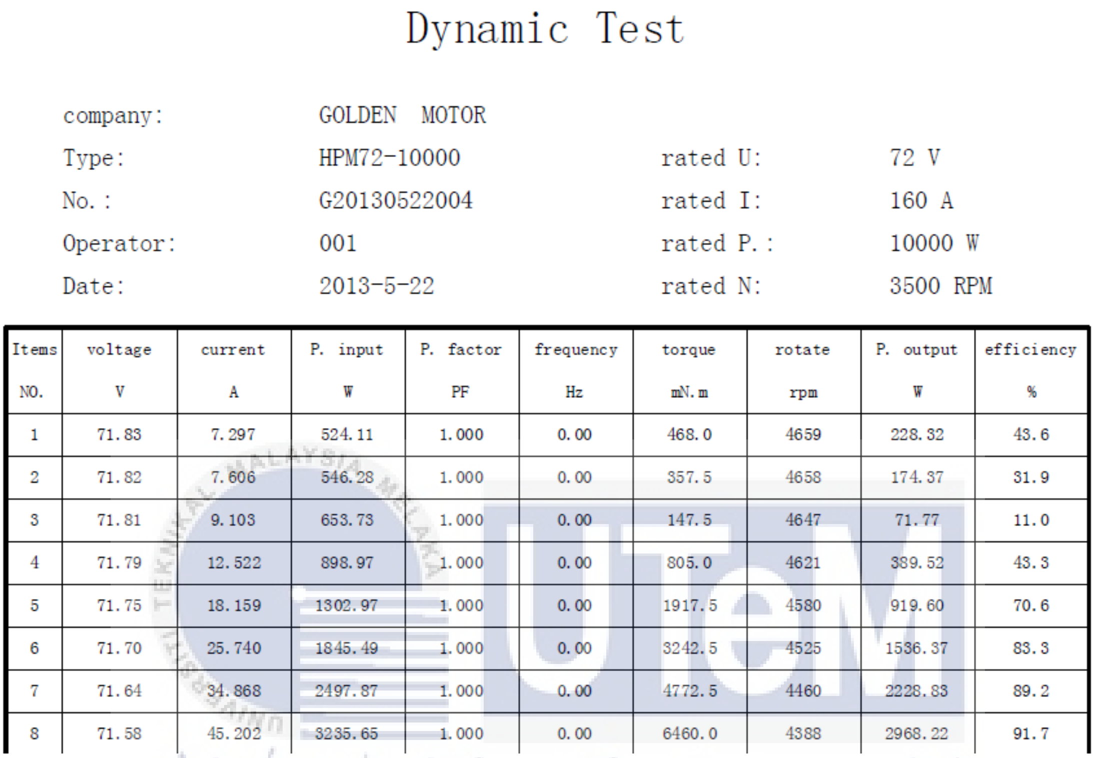
APPENDICES

APPENDIX A Result for 72 V

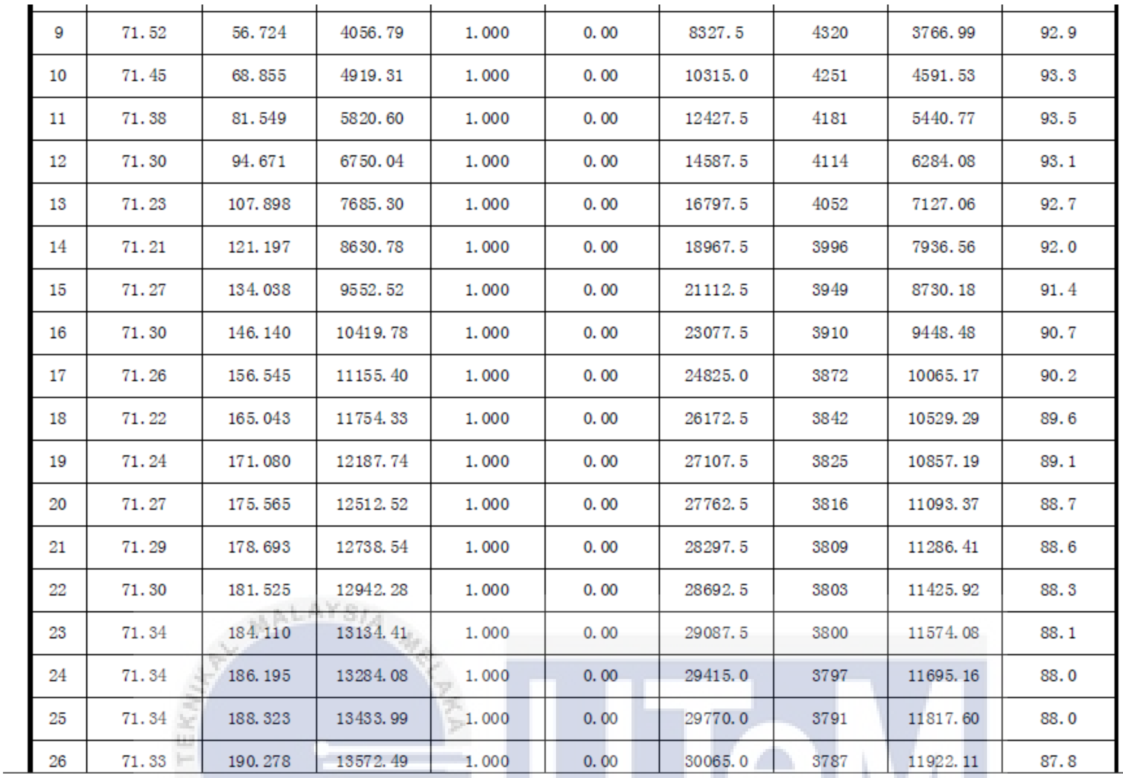


Dynamic Test

company:	GOLDEN MOTOR		
Type:	HPM72-10000	rated U:	72 V
No. :	G20130522004	rated I:	160 A
Operator:	001	rated P. :	10000 W
Date:	2013-5-22	rated N:	3500 RPM

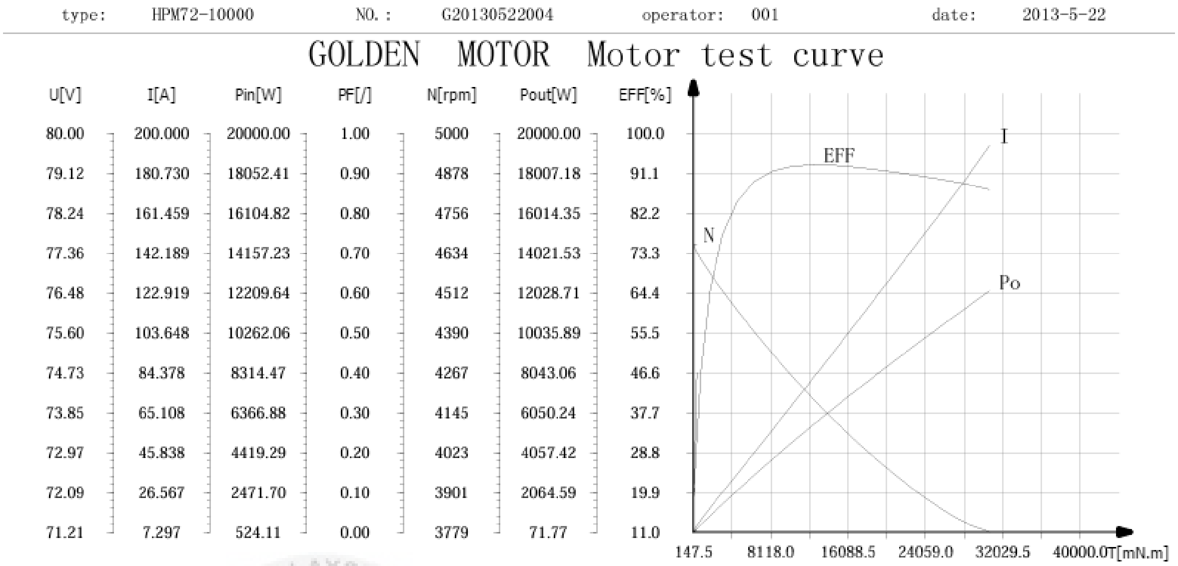
Items NO.	voltage V	current A	P. input W	P. factor PF	frequency Hz	torque mN. m	rotate rpm	P. output W	efficiency %
1	71. 83	7. 297	524. 11	1. 000	0. 00	468. 0	4659	228. 32	43. 6
2	71. 82	7. 606	546. 28	1. 000	0. 00	357. 5	4658	174. 37	31. 9
3	71. 81	9. 103	653. 73	1. 000	0. 00	147. 5	4647	71. 77	11. 0
4	71. 79	12. 522	898. 97	1. 000	0. 00	805. 0	4621	389. 52	43. 3
5	71. 75	18. 159	1302. 97	1. 000	0. 00	1917. 5	4580	919. 60	70. 6
6	71. 70	25. 740	1845. 49	1. 000	0. 00	3242. 5	4525	1536. 37	83. 3
7	71. 64	34. 868	2497. 87	1. 000	0. 00	4772. 5	4460	2228. 83	89. 2
8	71. 58	45. 202	3235. 65	1. 000	0. 00	6460. 0	4388	2968. 22	91. 7

APPENDIX B Continue Result for 72 V



9	71.52	56.724	4056.79	1.000	0.00	8327.5	4320	3766.99	92.9
10	71.45	68.855	4919.31	1.000	0.00	10315.0	4251	4591.53	93.3
11	71.38	81.549	5820.60	1.000	0.00	12427.5	4181	5440.77	93.5
12	71.30	94.671	6750.04	1.000	0.00	14587.5	4114	6284.08	93.1
13	71.23	107.898	7685.30	1.000	0.00	16797.5	4052	7127.06	92.7
14	71.21	121.197	8630.78	1.000	0.00	18967.5	3996	7936.56	92.0
15	71.27	134.038	9552.52	1.000	0.00	21112.5	3949	8730.18	91.4
16	71.30	146.140	10419.78	1.000	0.00	23077.5	3910	9448.48	90.7
17	71.26	156.545	11155.40	1.000	0.00	24825.0	3872	10065.17	90.2
18	71.22	165.043	11754.33	1.000	0.00	26172.5	3842	10529.29	89.6
19	71.24	171.080	12187.74	1.000	0.00	27107.5	3825	10857.19	89.1
20	71.27	175.565	12512.52	1.000	0.00	27762.5	3816	11093.37	88.7
21	71.29	178.693	12738.54	1.000	0.00	28297.5	3809	11286.41	88.6
22	71.30	181.525	12942.28	1.000	0.00	28692.5	3803	11425.92	88.3
23	71.34	184.110	13134.41	1.000	0.00	29087.5	3800	11574.08	88.1
24	71.34	186.195	13284.08	1.000	0.00	29415.0	3797	11695.16	88.0
25	71.34	188.323	13433.99	1.000	0.00	29770.0	3791	11817.60	88.0
26	71.33	190.278	13572.49	1.000	0.00	30065.0	3787	11922.11	87.8

APPENDIX C Golden Motor Test Curve

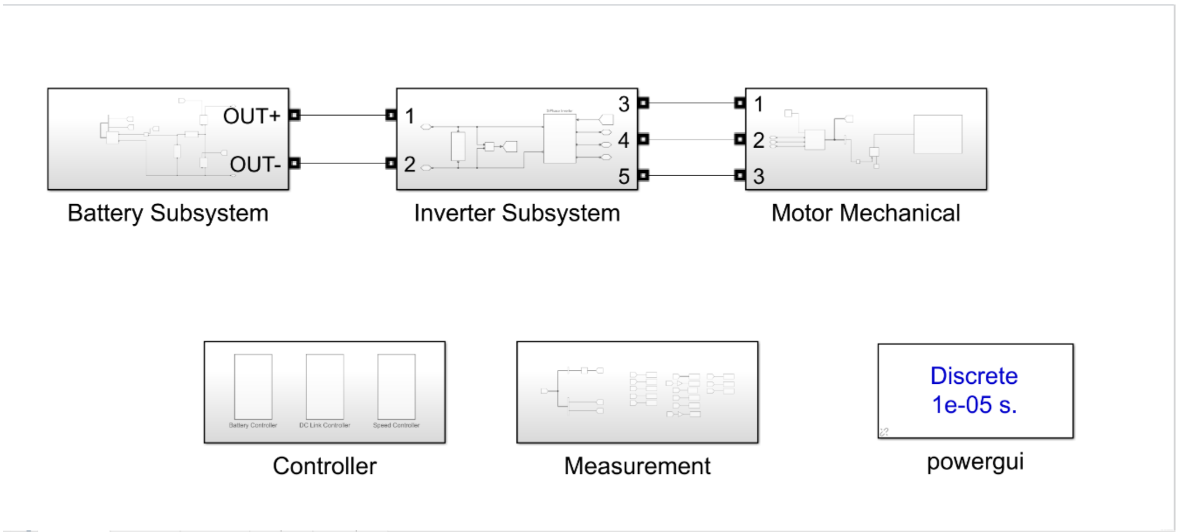


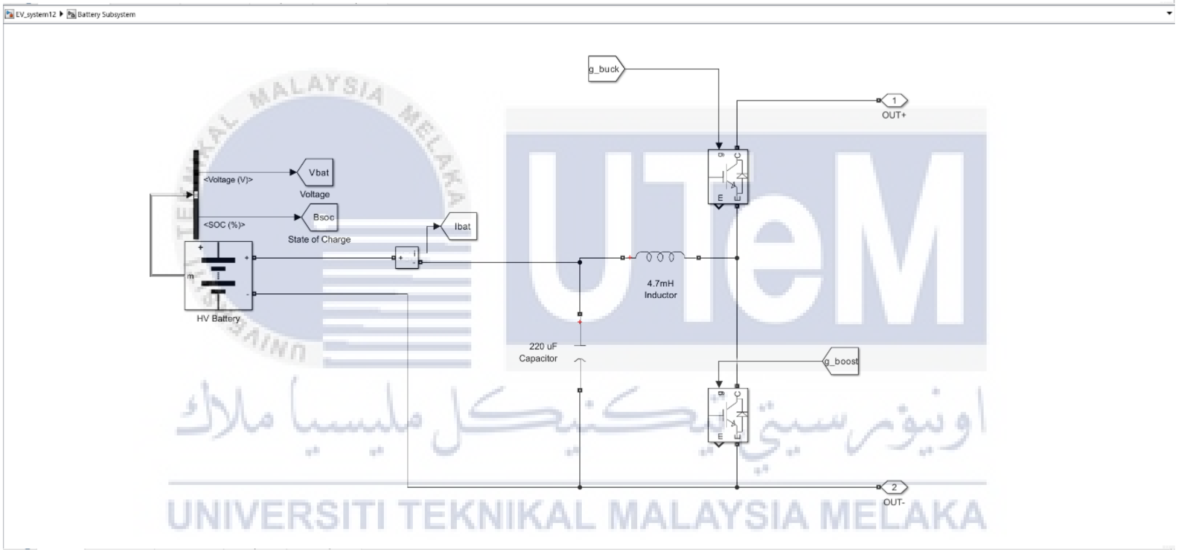
type: HPM72-10000 NO.: G20130522004 operator: 001 date: 2013-5-22

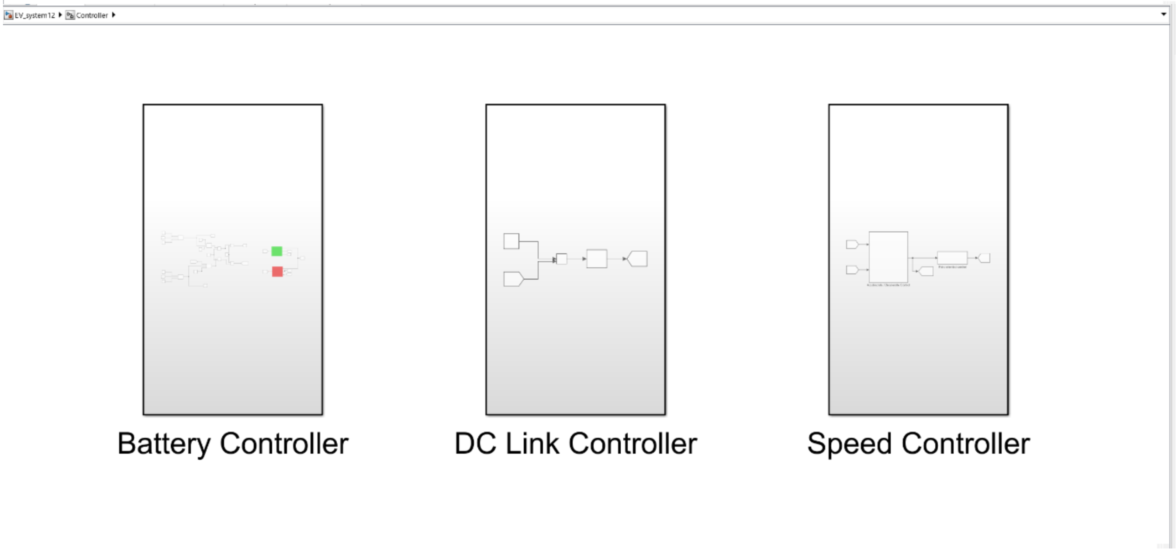
GOLDEN MOTOR Motor test curve

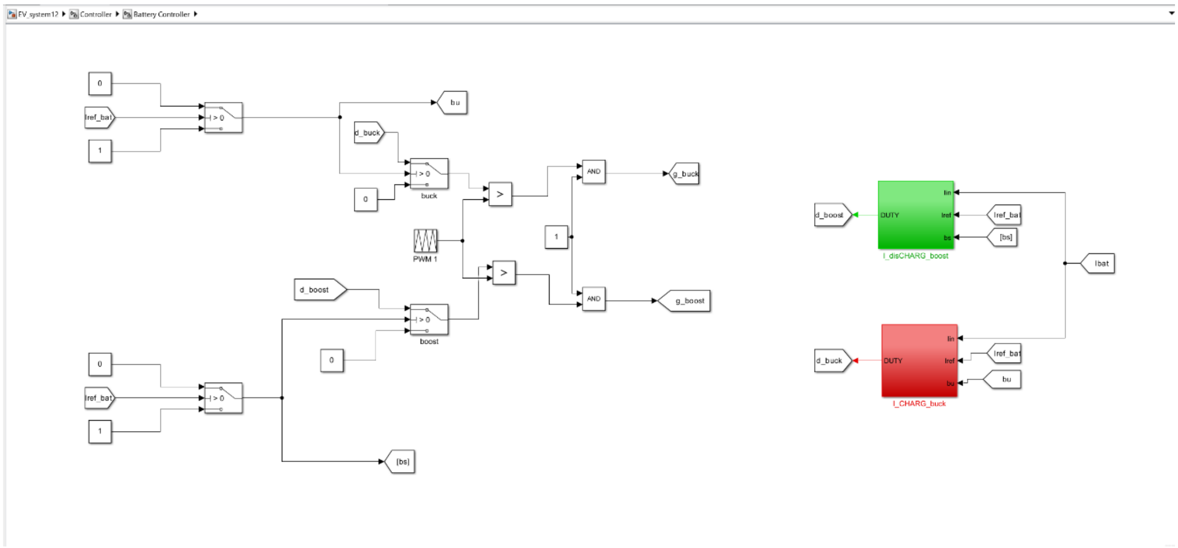
U[V]	I[A]	Pin[W]	PF[/]	N[rpm]	Pout[W]	EFF[%]
80.00	200.000	20000.00	1.00	5000	20000.00	100.0
79.12	180.730	18052.41	0.90	4878	18007.18	91.1
78.24	161.459	16104.82	0.80	4756	16014.35	82.2
77.36	142.189	14157.23	0.70	4634	14021.53	73.3
76.48	122.919	12209.64	0.60	4512	12028.71	64.4
75.60	103.648	10262.06	0.50	4390	10035.89	55.5
74.73	84.378	8314.47	0.40	4267	8043.06	46.6
73.85	65.108	6366.88	0.30	4145	6050.24	37.7
72.97	45.838	4419.29	0.20	4023	4057.42	28.8
72.09	26.567	2471.70	0.10	3901	2064.59	19.9
71.21	7.297	524.11	0.00	3779	71.77	11.0

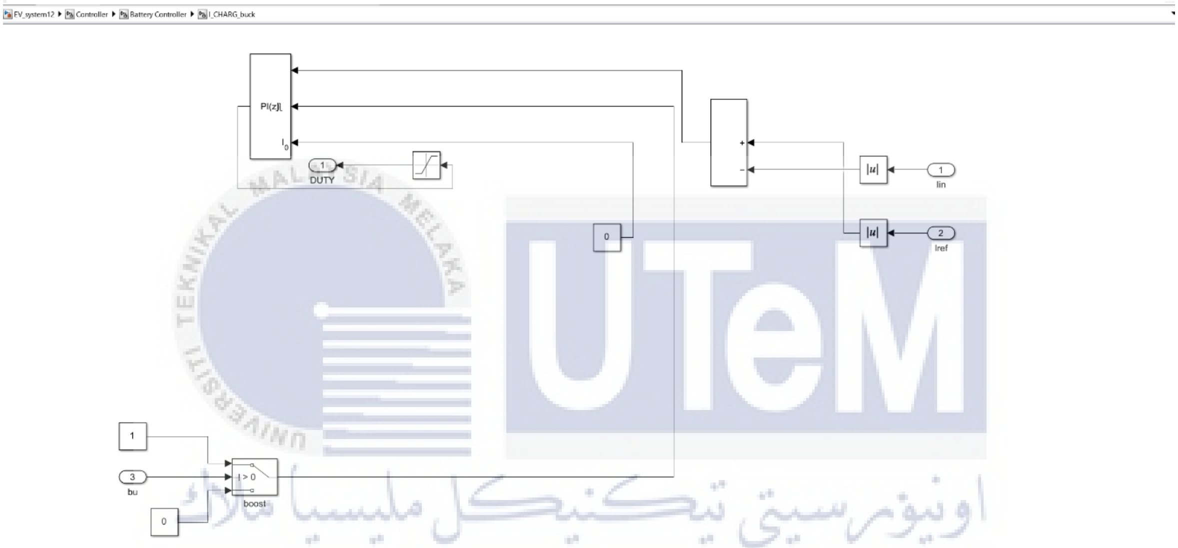
APPENDIX D Generate Subsystem in MATLAB-Simulink

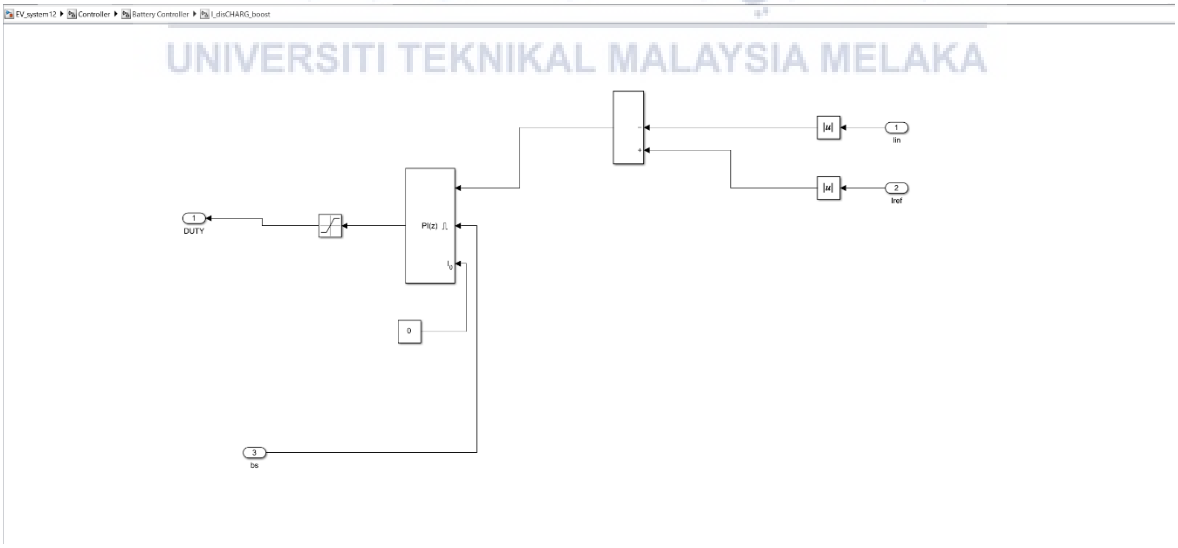


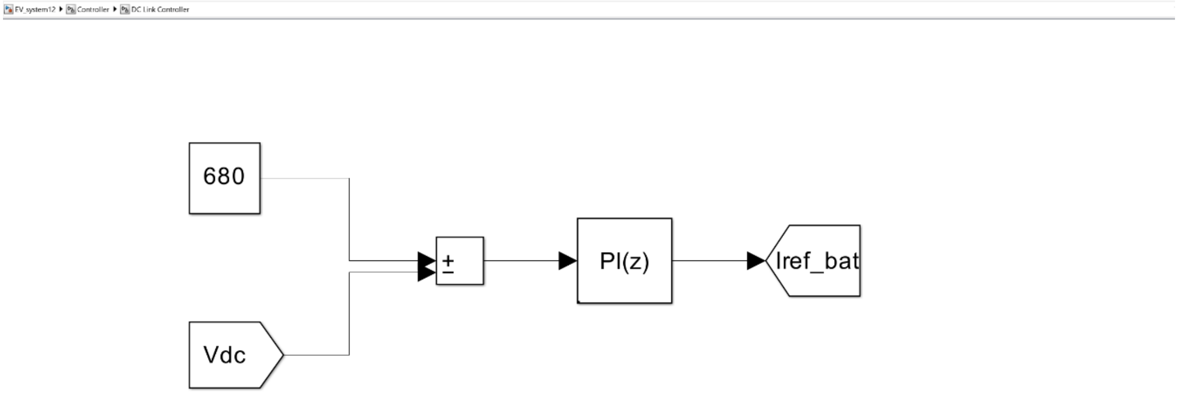


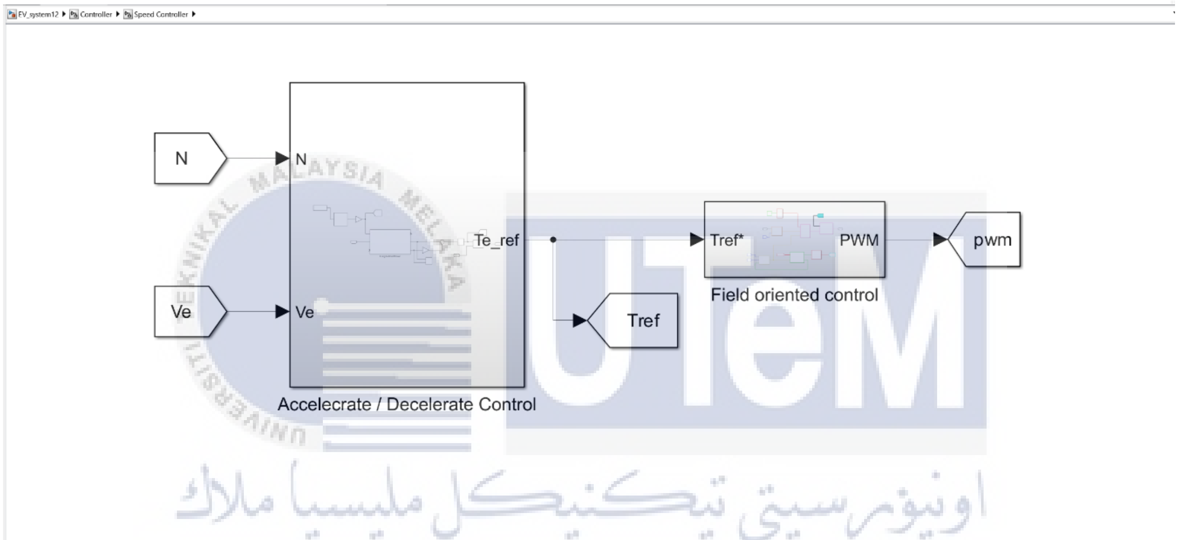


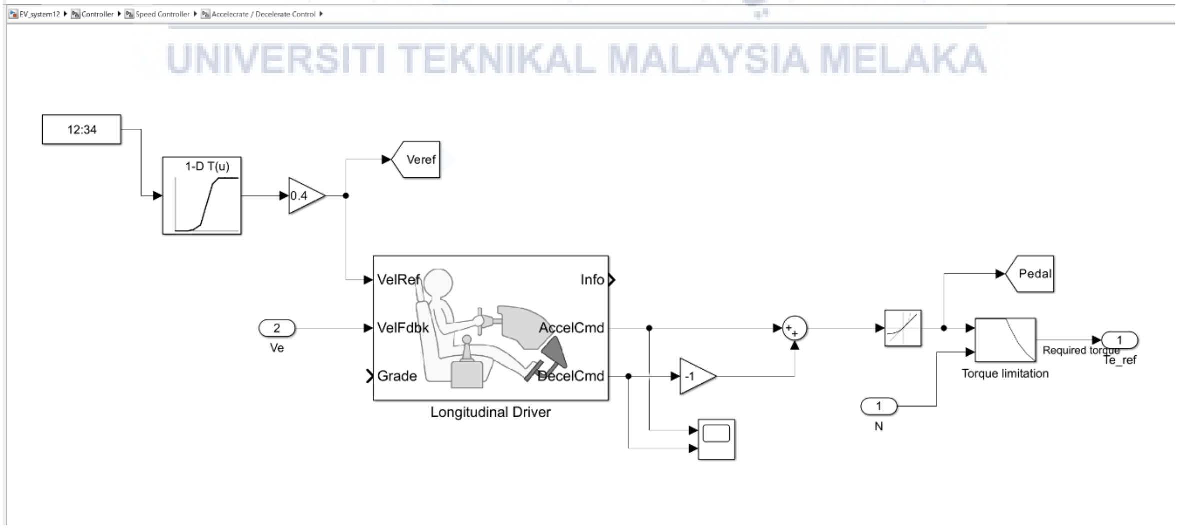

EV_system12 ▸ Controller ▸ Battery Controller ▸
0
Iref_bat
1
u > 0
bu
d_buck
u > 0
buck
0
>
AND
g_buck
PWM 1
1
>
d_boost
u > 0
boost
0
AND
g_boost
0
Iref_bat
u > 0
1
[bs]
d_boost
DUTY
Iin
Iref
bs
I_disCHARG_boost
Iref_bat
[bs]
Ibat
d_buck
DUTY
Iin
Iref
bu
I_CHARG_buck
Iref_bat
bu

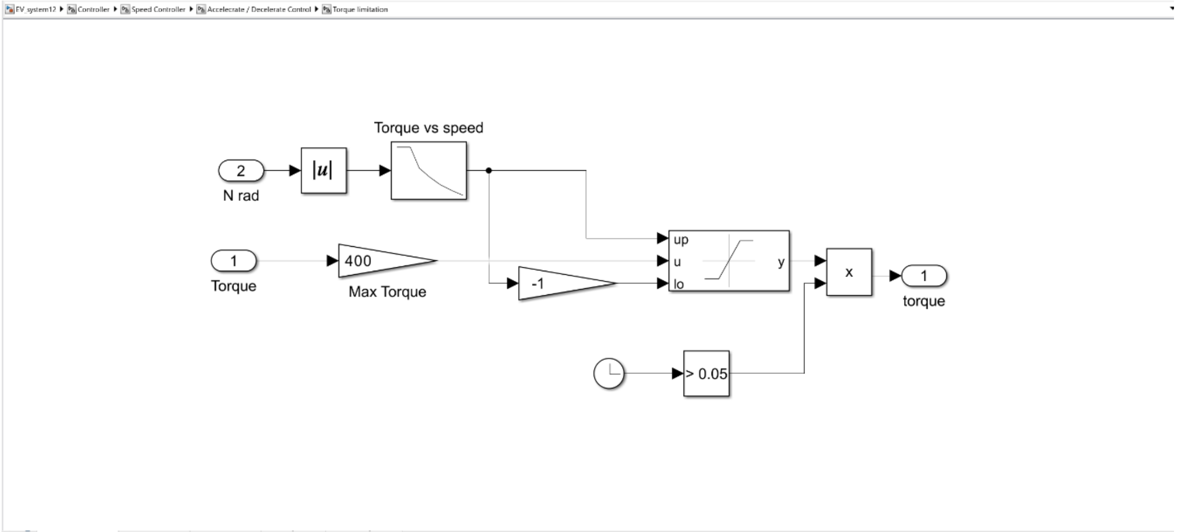

EV_system12 ▸ Controller ▸ Battery Controller ▸ I_CHARG_buck
PI(z)
I0
1
DUTY
+
-
|u|
1
Iin
0
|u|
2
Iref
1
3
bu
u > 0
boost
0

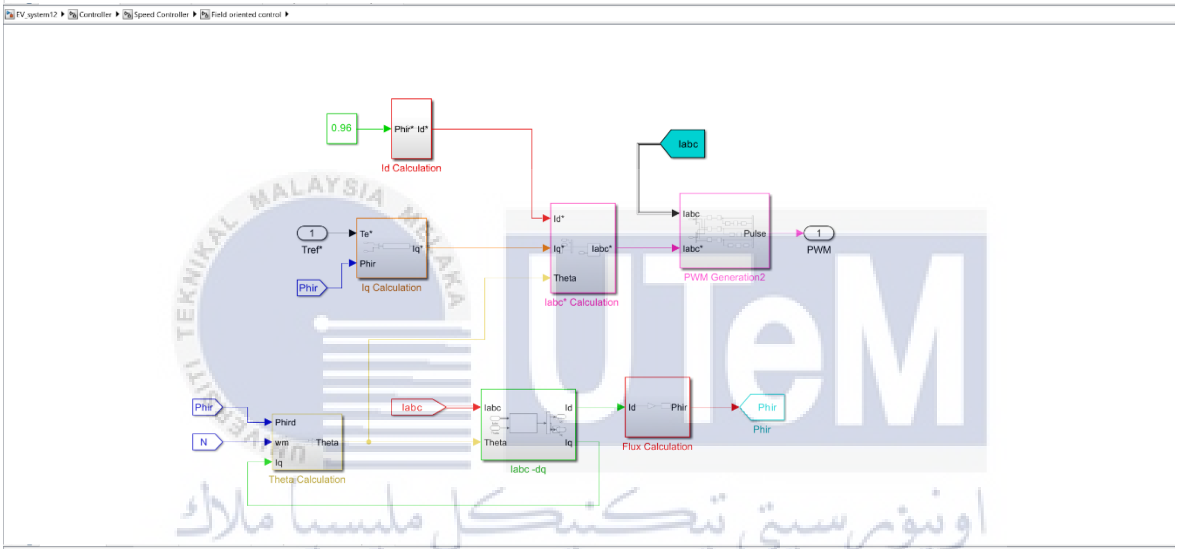

EV_system12 ▸ Controller ▸ Battery Controller ▸ I_disCHARG_boost
-
+
|u|
1
Iin
|u|
2
Iref
1
DUTY
PI(z)
I0
0
3
bs

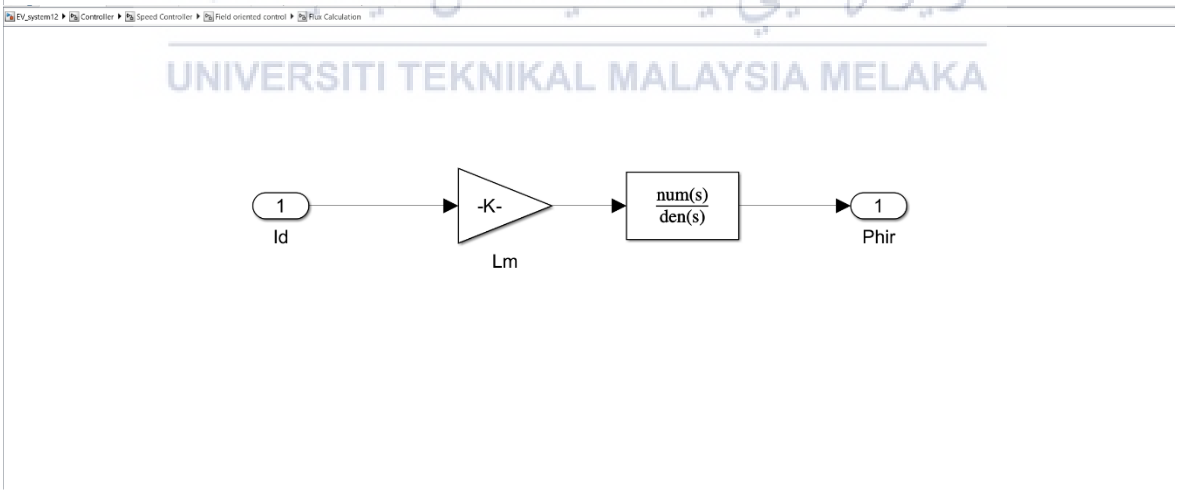

FV_system12 ▸ Controller ▸ DC Link Controller
680
Vdc
±
PI(z)
Iref_bat

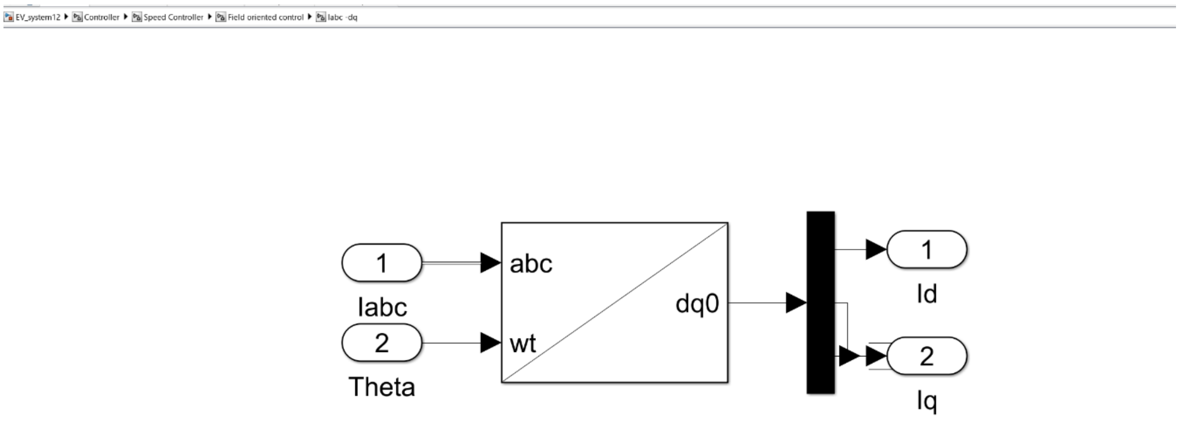

FV_system12 ▸ Controller ▸ Speed Controller ▸
N
Ve
N
Ve
Te_ref
Accelecrate / Decelerate Control
Tref*
PWM
Field oriented control
pwm
Tref

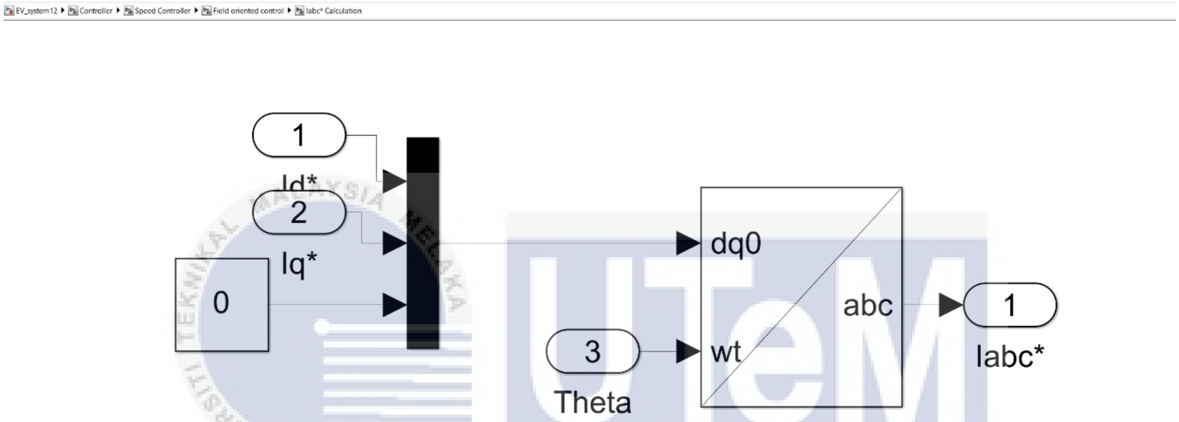

FV_system12 ▸ Controller ▸ Speed Controller ▸ Accelecrate / Decelerate Control ▸
12:34
1-D T(u)
0.4
Veref
VelRef
VelFdbk
Grade
Info
AccelCmd
DecelCmd
Longitudinal Driver
2
Ve
-1
Pedal
Torque limitation
Required torque
1
Te_ref
1
N

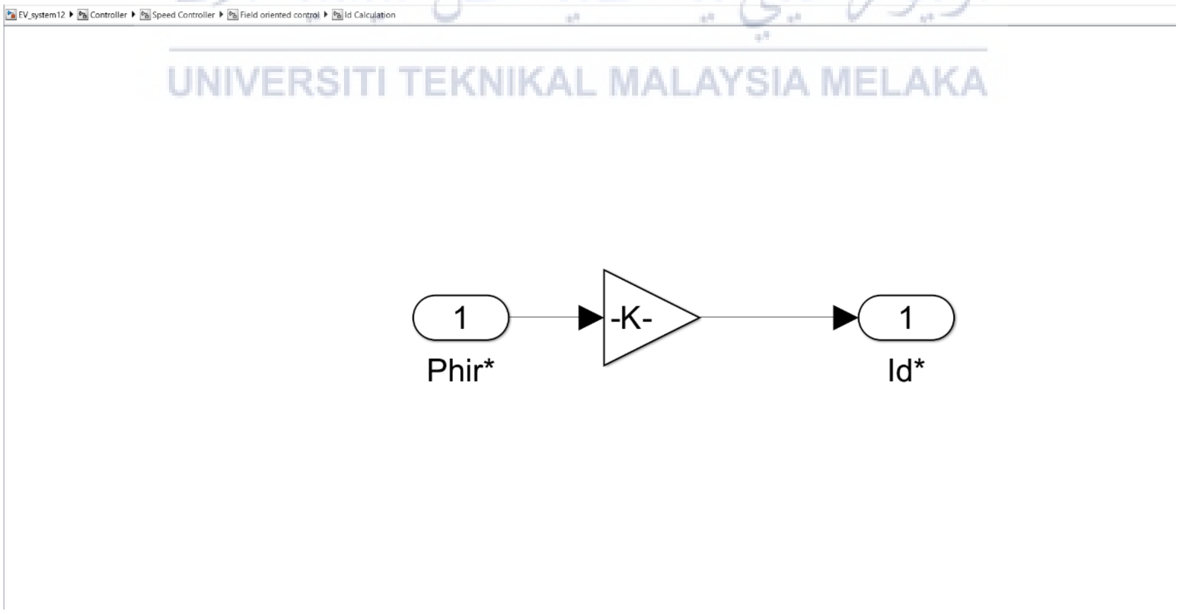

EV_system12 ▸ Controller ▸ Speed Controller ▸ Accelecrate / Decelerate Control ▸ Torque limitation
Torque vs speed
2
N rad
|u|
1
Torque
400
Max Torque
-1
up
u
lo
y
x
1
torque
> 0.05

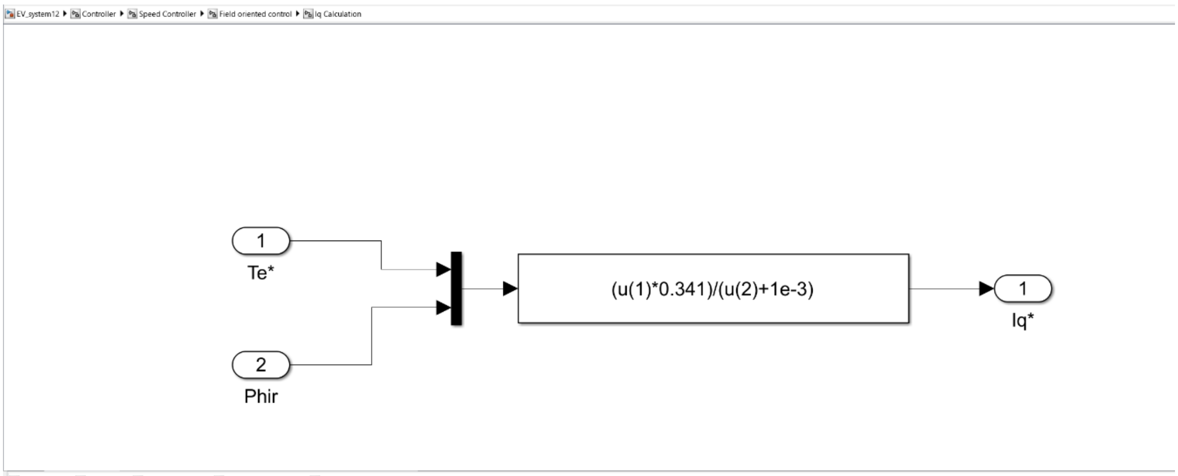

EV_system12 ▸ Controller ▸ Speed Controller ▸ Field oriented control ▸
0.96
Phir* Id*
Id Calculation
Iabc
1
Tref*
Te*
Iq*
Phir
Phir
Iq Calculation
Id*
Iq*
Iabc*
Theta
Iabc* Calculation
Iabc
Pulse
Iabc*
PWM Generation2
1
PWM
Phir
N
Phird
wm
Theta
Iq
Theta Calculation
Iabc
Iabc
Id
Theta
Iq
Iabc -dq
Id
Phir
Flux Calculation
Phir
Phir

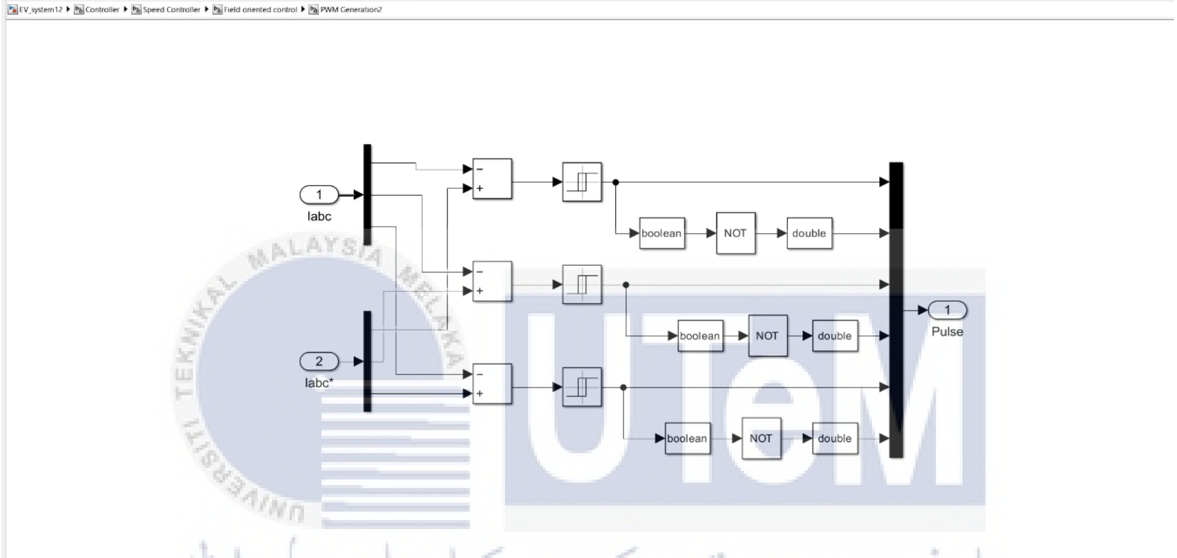

EV_system12 ▸ Controller ▸ Speed Controller ▸ Field oriented control ▸ Flux Calculation
1
Id
-K-
Lm
num(s)
den(s)
1
Phir

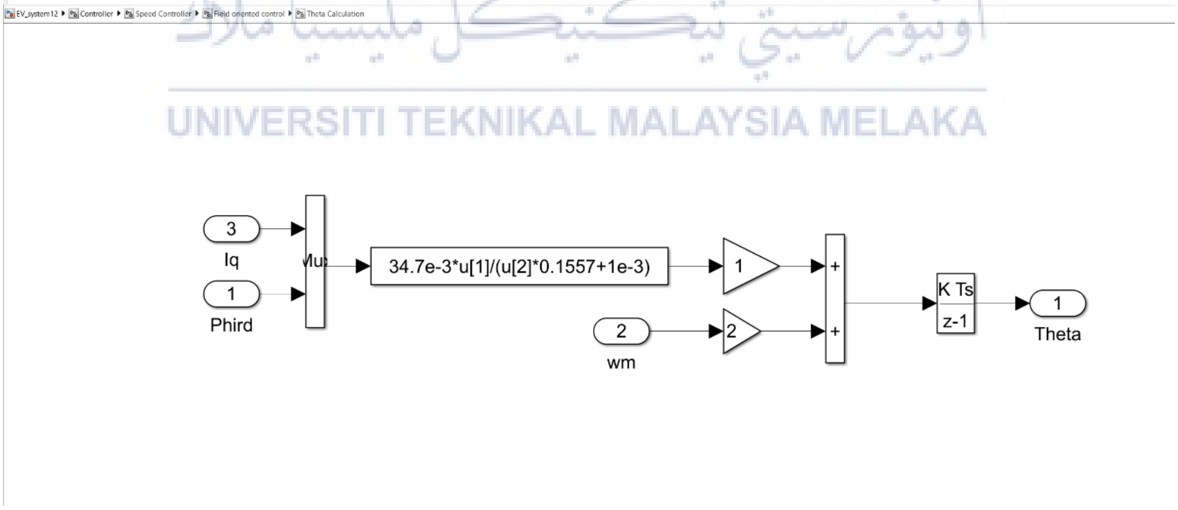

EV_system12 ▶ Controller ▶ Speed Controller ▶ Field oriented control ▶ Iabc -dq
1
Iabc
2
Theta
abc
wt
dq0
1
Id
2
Iq

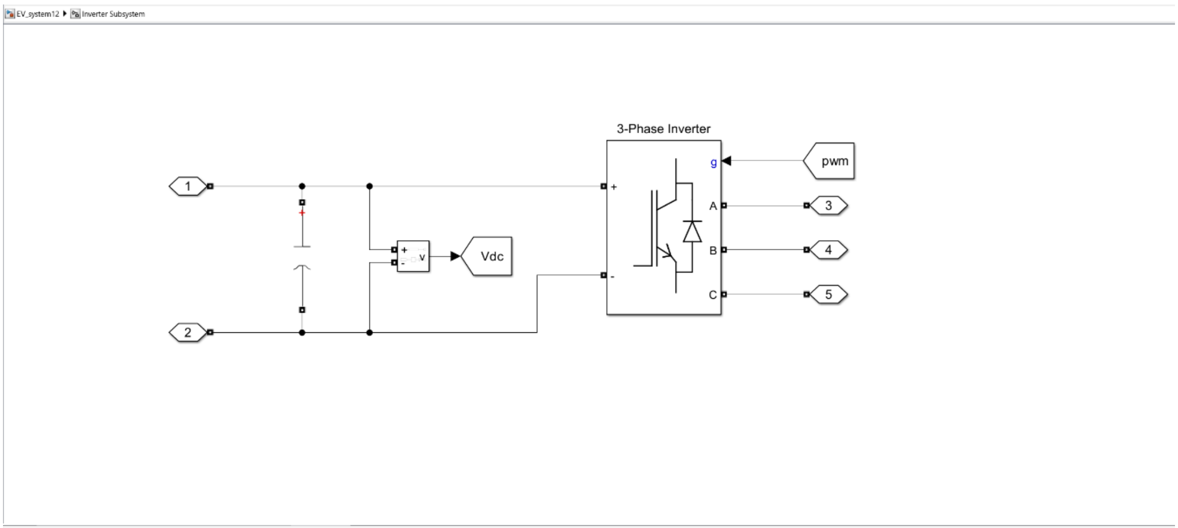

EV_system12 ▶ Controller ▶ Speed Controller ▶ Field oriented control ▶ Iabc* Calculation
1
Id*
2
Iq*
0
dq0
3
Theta
wt
abc
1
Iabc*

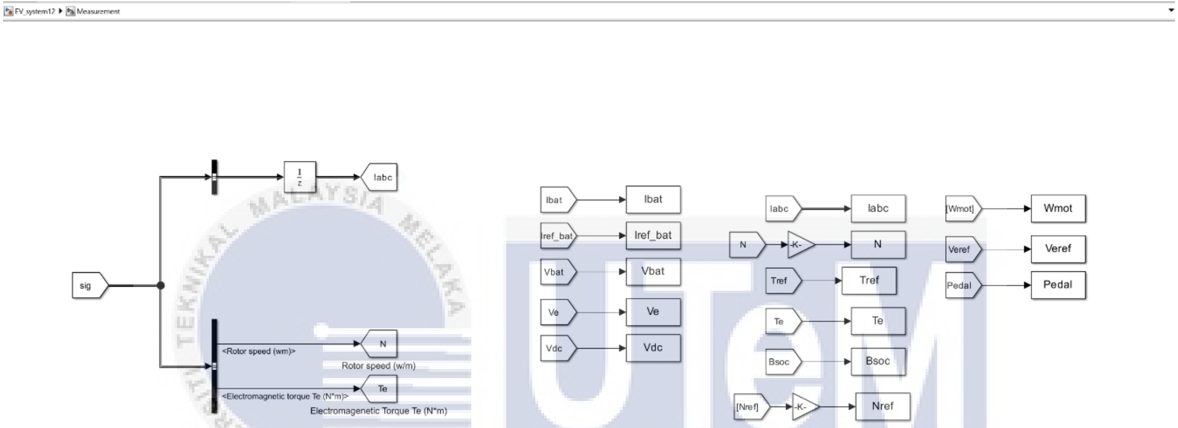

EV_system12 ▶ Controller ▶ Speed Controller ▶ Field oriented control ▶ Id Calculation
1
Phir*
-K-
1
Id*

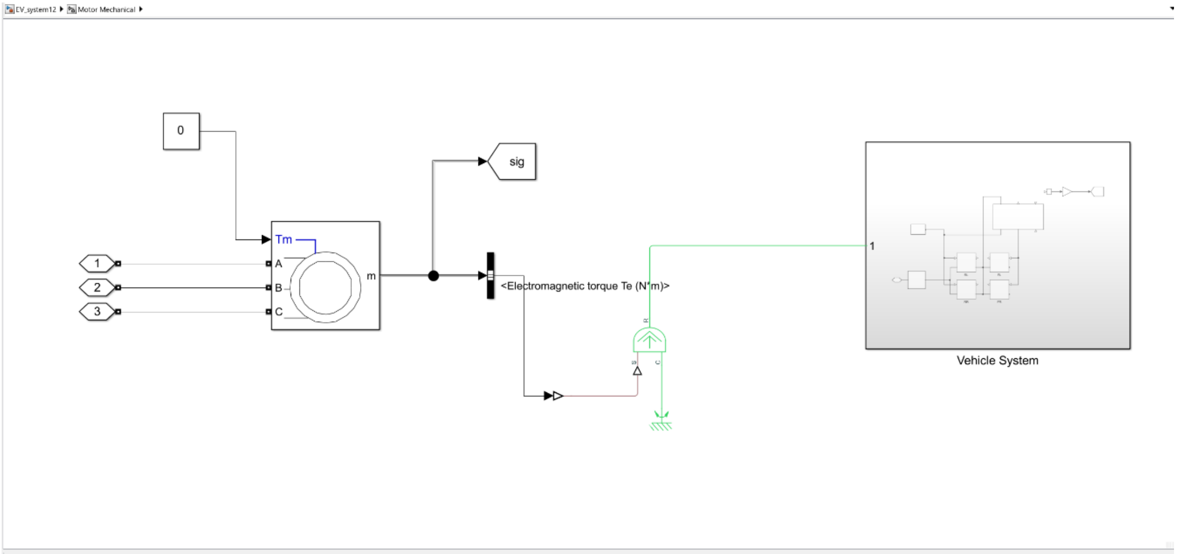

EV_system12 ▸ Controller ▸ Speed Controller ▸ Field oriented control ▸ Iq Calculation
1
Te*
2
Phir
(u(1)*0.341)/(u(2)+1e-3)
1
Iq*

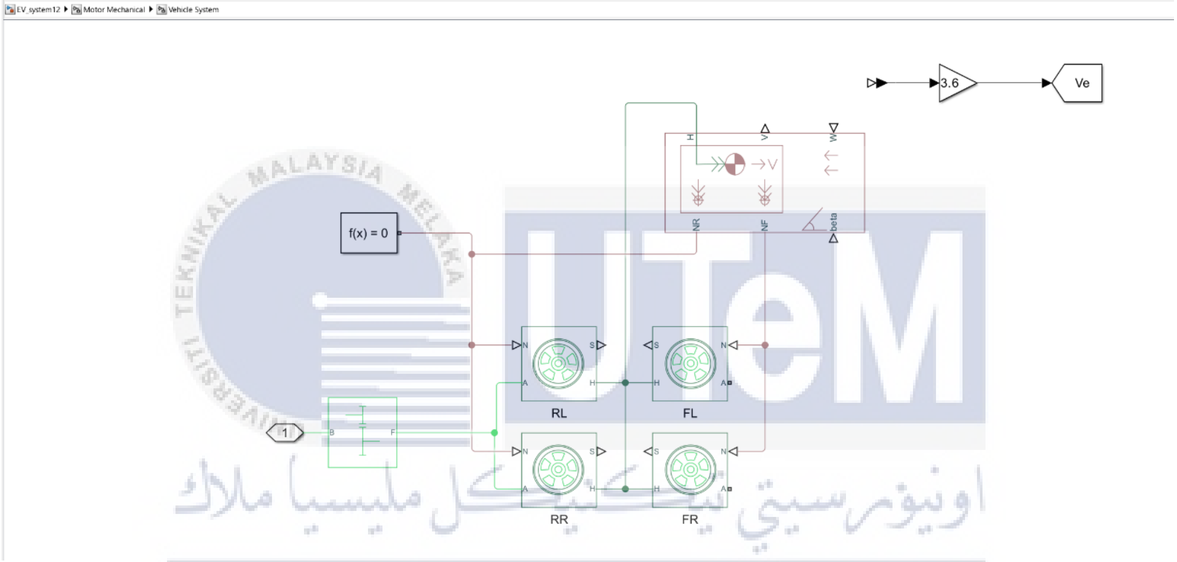

EV_system12 ▸ Controller ▸ Speed Controller ▸ Field oriented control ▸ PWM Generation2
1
Iabc
2
Iabc*
-
+
-
+
-
+
boolean
NOT
double
boolean
NOT
double
boolean
NOT
double
1
Pulse


EV_system12 ▸ Controller ▸ Speed Controller ▸ Field oriented control ▸ Theta Calculation
3
Iq
1
Phird
Mux
34.7e-3*u[1]/(u[2]*0.1557+1e-3)
1
2
wm
2
+
+
K Ts
z-1
1
Theta

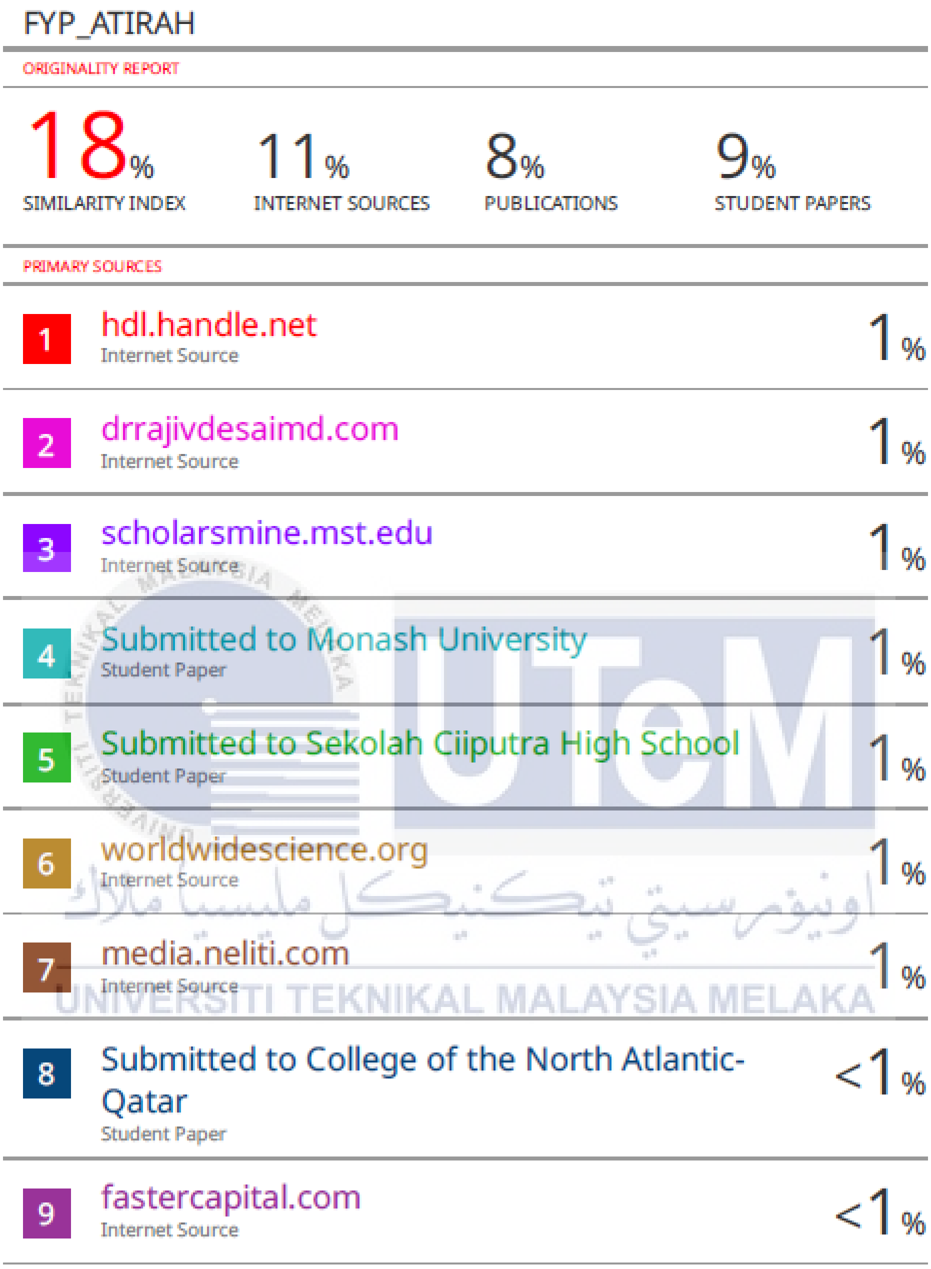

EV_system12 ▸ Inverter Subsystem
3-Phase Inverter
1
2
+
-
v
Vdc
g
A
B
C
pwm
3
4
5


EV_system12 ▸ Measurement
sig
1/z
Iabc
<Rotor speed (wm)>
N
Rotor speed (w/m)
<Electromagnetic torque Te (N*m)>
Te
Electromagenetic Torque Te (N*m)
Ibat
Ibat
Iref_bat
Iref_bat
Vbat
Vbat
Ve
Ve
Vdc
Vdc
Iabc
Iabc
N
-K-
N
Tref
Tref
Te
Te
Bsoc
Bsoc
[Nref]
-K-
Nref
[Wmot]
Wmot
Veref
Veref
Pedal
Pedal


EV_system12 ▸ Motor Mechanical ▸
0
sig
Tm
1
2
3
A
B
C
m
<Electromagnetic torque Te (N*m)>
1
Vehicle System


EV_system12 ▸ Motor Mechanical ▸ Vehicle System
3.6
Ve
H
V
W
NR
NF
beta
f(x) = 0
N
S
A
H
RL
FL
1
B
F
RR
FR

APPENDIX E Turnitin Result



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