EVALUATION OF AN ELECTRIC VEHICLE (EV) DISPOSAL PROCESS AND BENCHMARKING ON THE EV TECHNOLOGY

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Mechatronics Engineering with Honours

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"EVALUATION OF AN ELECTRIC VEHICLE (EV) DISPOSAL PROCESS AND BENCHMARKING ON THE EV TECHNOLOGY"** was prepared by **CHOY JIA QI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Mechatronics Engineering with Honours at Universiti Tunku Abdul Rahman.

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ABSTRACT

The global shift towards electric vehicles (EVs) as an eco-friendly transportation solution has accelerated, driven by environmental awareness and climate change concerns. However, EV sustainability poses multifaceted challenges surrounding the end-of-life disposal issues, and questions surrounding long-term performance. This research aims to explore the current vehicle disposal process and benchmark the EV technology. The outcome of this aim will evaluate the disposal process as well as the performance of modern electric vehicles. It includes a literature review of current EV disposal methods, encompassing recycling and component reuse, alongside hands-on disassembly of an aging EV conversion project vehicle. Additionally, computer software simulations will benchmark EV technology, offering insights into its performance in the transportation sector. The research revealed severe battery deterioration in the aging EV conversion project vehicle, and the project vehicle was sustainably disposed. The performance of modern electric vehicles has improved significantly over the decade, making them a viable zero emissions transportation solution. Simulations demonstrated a 4.48% of range loss when electric vehicles are driven on 0.6 mm water film thickness at 30 km/h speeds. Additionally, an average of 2.66% range loss per 100 kg increase in loading was recorded. A case study regarding the number of trips that can be completed between UTAR Sg Long and MRT Bukit Dukung has shown that modern electric vehicles can meet the daily needs of daily commuters while producing zero emissions. Lastly, a reduction of 38.77% in gear ratio enhanced the range of the 2015 Volkswagen e-Golf simulation model by 8.62% at higher speeds. The findings from this research contribute valuable insights for future improvements and sustainability initiatives within the EV industry. In a summary, current electric vehicle disposal processes were found to be manual intensive, which leads to opportunities for more automation in this sector. Electric vehicle technology has also improved and is able to meet the daily needs of a city commuter. In the future, the research can be improved by incorporating new electric vehicle technology such as solid-state batteries and sodium ion batteries into the simulator.

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LIST OF SYMBOLS / ABBREVIATIONS

e^{-}	electron ion
Fe	iron
$Fe(OH)_3$	iron hydroxide
O_2	oxygen
H^{+}	hydrogen cation
H_2O	water
Pb	lead
Pb^{2+}	lead (II) ion
$PbSO_4$	lead sulphate
HSO_4^{-}	hydrogen sulphate
SO_4^{2-}	sulphate ion

ASRs	auto shredder residues
ADVISOR	Advanced Vehicle Simulator
BMS	battery management system
EOL	end-of-life
EV	electric vehicle
ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
LFP	lithium iron phosphate
LIBs	lithium-ion batteries
NEDC	New European Driving Cycle
NREL	National Renewable Energy Laboratory
PMSM	permanent magnet synchronous motor
SOC	state-of-charge
SOH	state-of-health
SUV	sport utility vehicle

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The popularity of electric vehicles (EV) in the transportation sector has been growing steadily as environmental health and climate change awareness spreads across the globe. Conventional combustion vehicles in the transportation sector have long been a heavy contributor to global greenhouse gas emissions. The absence of dirty tailpipe emissions in clean electric vehicles makes them an enticing mobility prospect to governments and climate organisations alike, so much so that the European Union was set to ban the sale of new combustion engine cars by 2035 – until the recent deal with Germany to make an exception for combustion engine vehicles powered by synthetic fuels known as e-fuels (Frost, 2023).

Nevertheless, the uptake of electric vehicles in the transportation sector is sure to rise steadily, with a slew of new electric vehicle models launched by traditional and new manufacturers annually. Just in the year 2021, 6.6 million car sales are electric vehicles, a figure that is twice the amount from the previous year. However, these electric vehicles are set to deteriorate in terms of their condition and performance as time goes by. The life span of an electric vehicle is generally associated with the life span of the energy storage system, which are primarily batteries. As far as sustainable development is concerned, the attention to the sustainability of electric vehicles in their life cycle is of relevance to current resource woes. The rare earth minerals, such as nickel, lithium, and cobalt needed to manufacture the batteries are limited in global supply and unevenly distributed. This subjects electric vehicles to risks of supply shortages and disruptions. Besides that, electric vehicles at the end of their life span still contain high contents of rare earth minerals that may be an environmental hazard if not properly disposed of. Then, there is the question on the performance deterioration of electric vehicles at the end of their life span.

This research aims to evaluate the current electric vehicle disposal process and benchmark the EV technology to identify areas for improvement. The research will explore the current disposal methods, including recycling and reusing the components. To supplement this research, hands-on work will be conducted on the EV conversion project vehicle that has been completed by previous batches of Universiti Tunku Abdul Rahman engineering students as part of their Final Year Project. The electric vehicle, which is based on the Lancer-based Proton Wira, was completed almost a decade ago and is marked for disposal.

Additionally, this research will benchmark electric vehicle technology with computer software simulation. This analysis will help to determine the long-term sustainability of electric vehicles as a viable solution for reducing greenhouse gas emissions in the transportation sector.

Overall, this research will provide a comprehensive evaluation of the electric vehicle disposal process and benchmark the EV technology to provide insights for future improvements and sustainability efforts in the transportation sector.

1.2 Importance of the Study

The result of this research has significant importance in multiple areas. First, the outcome of the study will have importance in terms of environmental impact. As mentioned previously, the transportation sector is a large contributor to global greenhouse gas emissions. This study will provide actionable insights on the end-of-life disposal process of electric vehicles and determine the overall environmental impact of the processes involved, increasing the sustainability of the electric vehicle sector.

Next, the study will be of importance in terms of resource management. As mentioned previously, the manufacturing of electric vehicles is very costly in terms of resources. It requires the fabrication of high-power electrical components such as motors and batteries which require rare earth minerals. Rare earth minerals are already not in abundance in reserves, but they are continuously mined due to their superb properties in the manufacturing of these technologies, Hence, it is highly important to evaluate the course of actions involved when handling electric vehicles in their end-of-life to ensure that these materials can be salvaged and recycled for further use, reducing waste.

Moreover, the research will be of particular importance when it comes to evaluating the current state of technological advancements. The research will evaluate the performance of emerging electric vehicle technologies, reviewing the development and innovations of the technologies, and thus providing a guideline to the electric vehicle sector to pursue innovations.

Lastly, the research will be of importance to regulatory compliance. Car companies will have to abide by the policies set by governments in their attempt to revert climate change. The research will provide ideas for the electric vehicle sector to develop sustainability strategies and policies, thus encouraging healthy development.

1.3 Problem Statement

The annual exponential increase in electric vehicle sales will bring an influx of new energy vehicles on the streets of the world. Electric vehicles are undoubtedly environmentally friendly and efficient in the sense that they do emit harmful by-products during their operation as well as their efficient transformation of energy. However, the demand for rare earth minerals to produce electric vehicles will undoubtedly increase at the same time. There will be a day when these vehicles will reach the end of their life cycle. The pressing issue here is the lack of in-depth evaluation of the electric vehicle disposal process and management of these materials. Any unsuitable measures will lead to unnecessary wastage of these materials as these materials will be lost to the environment.

In addition to wastage, these materials may pose a serious hazard to the environment. While the radioactive properties of these materials give them the important characteristics required in the conduction and storage of energy, they are extremely toxic to living organisms. They can contaminate sources of water, air and even soil when improperly disposed of. Besides that, reaction of rare earth metals with air and water may lead to acidification of water and soil, which may lead to the slippery slope effects of ecology disturbance.

Next, while there is a significant push for electric vehicle sales by governments across the world in the form of subsidies, incentives and outright banning of internal combustion engine vehicle sales, there is still a gap in the formation of policies and regulations that sets standard for the management of these vehicles at the end of their life cycle. Compliance with regulatory requirements is one of the efficient ways to ensure that good disposal methods are practised from the grassroots level.

Lastly, there is a concern from large car manufacturers such as BMW, Porsche, and Toyota regarding the total replacement of ICE vehicles to electrified mobility. This is largely due to the huge energy investment costs to manufacture a single electric vehicle when compared to conventional vehicles. There is a concern on whether the electric vehicles can be properly used throughout their life cycle in a way that the initial investment costs can be offset and surpassed in benefits. The world's largest car manufacturer, Toyota, believes that electric vehicles must be driven for 100,000 KM for it to see any benefits in environmental impact when compared to conventional vehicles. Hence, the question regarding the efficiency of an electric vehicle throughout its life cycle and well to wheel is always debatable.

In a nutshell, the insufficiency of comprehensive evaluation of electric vehicle disposal process and benchmarking of EV technology represents a significant problem that needs to be addressed to ensure the sustainable development of the transportation sector.

1.4 Aim and Objectives

This research aims to explore the current vehicle disposal process and benchmark the EV technology. The outcome of this aim will evaluate the sustainability aspects of the disposal process as well as the viability of electric vehicles for reducing greenhouse gas emission in the transportation sector. The following objectives are to be completed to achieve the aim:

(i) Measure the current performance of the EV conversion project vehicle.
(ii) Disassemble and dispose the EV conversion project vehicle.
(iii) Develop electric vehicle models within a simulation software.
(iv) Conduct comparison and evaluation of the model.

1.5 Scope and Limitation of the Study

This research will be conducting a hands-on disassembly and disposal process of an electric vehicle conversion project. However, since the electric vehicle conversion project utilises a lead-acid battery pack, the preliminary results collected may not be of relevance to lithium-ion equipped electric vehicles that are more common in the current market. Additionally, the benchmarking of electric vehicle technologies will be conducted with the MATLAB Advanced Vehicle Simulator (ADVISOR) tool. The tool was developed and released to the public 1998 and may not be having the latest models that can better simulate emerging technologies. However, it can be linked with newer software packages to provide it with new models and data sufficient to complete this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review aims to research on the topic of EV disposal process and current EV technologies. This research will present an overview of the current practises, difficulties, and prospects for development in the EV disposal process and EV technologies by reviewing the existing literature on this topic.

2.2 Current Disposal Processes of Electric Vehicles

The usage of Electric Vehicles has been popularized with increasing market share of the global automotive market. One of the mainstream and popular Electric Vehicle in the market, the Nissan Leaf, was launched in the year 2010. A decade of service of mainstream Electric Vehicles and their ever-growing popularity begs the question as to what needs to be done when these vehicles reach their End-of-life. Current disposal processes of Electric Vehicles can be classified into three stages:

(i) Disassembly of Electric Vehicle.
(ii) Recycling of Electric Vehicle (reuse of batteries).
(iii) Remanufacturing of Electric Vehicle.

2.2.1 Disassembly of Electric Vehicle

Dismantling process of Electric Vehicles comes first before recycling can be conducted. This stage is of high value for car dismantlers, especially when disassembled components in satisfactory conditions possess high value in the secondary spare parts market. In general, the focus of the disassembly is mainly on the power electronics, electric motors, and batteries (D'Adamo and Rosa, 2019). Typical dismantling process of Electric Vehicles are completed manually due to the variation of components and lack of OEM training in the car dismantling industry.

Disassembly of power electronics have been investigated by researchers, who have formulated a novel approach to disassemble and extract

Strategically Important Materials (SIMs) from EV components with the utilization of a robotic system (Li, Barwood and Rahimifard, 2018). This process increases the SIMs concentration prior to recycling and refining processes. Basic metals such as aluminium, copper and steel which typically represent a huge proportion of weight (>70%) of vehicles, are the focus of current vehicle recycling processes employing automated fragmentation and separation processes. However, the usage of lightweight materials such as high-strength steel, polymer composites and carbon fibre have been increasing in modern vehicles, implying the need for a shift in focus towards light materials recovery.

Modern dismantling process of EV is similar to the processes that typical end-of-life vehicles go through. The vehicles marked for dismantling are gathered and brought to a facility that is permitted to treat them. De-pollution, which takes place in the first step, requires that hazardous materials including tyres, fluids, lubricants and batteries be removed. Manual disassembly is conducted to salvage or remanufacture easily accessible, valuable components. Then, before delivering to the shredding facility, the hulks are compressed. Huge hammers are implemented by the shredders to break up hulks inside a drum. The materials are then sorted and divided into several classes, which includes non-ferrous and ferrous metals (Ferrão and Amaral, 2006).

In the material sorting stage, magnetic separation is carried out first to separate the non-ferrous materials from the ferrous materials. The ferrous materials are metals that consist of iron and steel. The following step is to separate remaining non-metallic materials and non-ferrous metals. In the industry, the non-metallic components are known as light auto shredder residues (ASRs). The separation processes consist of air separation, dense media separation, and eddy current separation. Dense media separation refers to the separation of steel and aluminium by “heavy media” and “light media” characteristics (Jody et al., 2011). This is essentially the sink-and-float separation method, whereby gravity and fluids of various density are used to separate heavy and light metals.

On the other hand, metals of with differing physical properties can be separated by “image processing” methods, whereby the properties such as colour and reflection index are used as input parameters in algorithms that classifies metal types. The remaining materials with recyclable properties such as paper, glass, and wood are then extracted for that purpose. The leftovers that are not extracted are then disposed at landfill as ASR or used for energy recovery.

There is a need for specialised end-of-life (EOL) management procedures and technologies for electric vehicles. Researchers have explored various automated approaches to disassembly and concentration of valuable materials, such as the use of robotic technologies and flexible disassembly and recovery lines (Michalos et al., 2010). They have also proposed the idea of a cognitive robotic system that can disassemble LCD displays and TVs (Vongbunyong, Kara and Pagnucco, 2013). Additionally, some academics have advocated the employment of robots to disassemble the batteries in hybrid vehicles. Other ideas presented includes a computer-aided design evaluation to determine whether the designs are recyclable during the early stages of EOL management (Papakostas, Pintzos and Triantafyllou, 2015).

2.2.2 Reuse of Electric Vehicle Batteries

A significant number of retired lithium-ion batteries (LIBs) with deteriorated performance are a result of the rapid scaling up of electric vehicles in the market. Recovery and recycling are among the various end-of-life (EOL) methods being explored. However, there is an increasing confidence among stakeholders that outdated batteries might be utilised in less-demanding applications like stationary energy storage system, which could open up new streams in the transportation and energy sectors (Zhu et al., 2021).

2.2.3 Important Considerations of End-of-life

Electric vehicle batteries experience a tough environment for operation. Over the course of 5 to 10 years, electric vehicle batteries usually experienced more than 1,000 incomplete cycles of discharging and charging (Zhao, 2017). Furthermore, they are subject to wide range of operating temperatures between -20°C and 70°C, depending on the local climate (Waldmann et al., 2014). Under these circumstances, electric vehicle batteries must experience high discharging and charging rates as well as an increased discharge depth (DOD).

When the electric vehicle battery pack has deteriorated to the point where it is unable to support the usage demands of EVs, it is usually disposed or recycled, signifying the end of its life cycle. The United States Advanced Battery Consortium (USABC) has first introduced a popular battery retirement criterion in 1996. The criterion advises that a battery with a 80% metric state-of-health (SOH) should be retired. While the criterion has served well for the past few decades, its relevance in current battery technology must be investigated.

Developments in battery technology has significantly improved the maximum battery capacity and thus improving the maximum range of EVs. The U.S. Environmental Protection Agency (EPA) has given the Tesla's Model S Long Range Plus a rating of 647 kilometres of range. This range is more than the four times the highest range from 20 years ago. Hence, there is a larger tolerance threshold to the degradation of battery capacity, whereby a battery with 80% state-of-health (SOH) may still fulfil the typical use cases of an EV.

Besides that, the threshold value to which a battery should retire is dependent on the battery chemistry. Additionally, economic feasibility and the vehicle condition should also be considered in the determination of this threshold value. Some parameters that can be considered are the potential earnings from battery early retirement and the second-life battery performance requirements in the market. In a nutshell, the demand and supply balance in the revolving economy system should be researched to help with the determination of battery retirement threshold (Zhu et al., 2021).

2.2.4 End-of-life Options

Figure 2.1 presents the retirement possibilities in the form of a waste management hierarchy (Harper et al., 2019). Beginning from the highest level, reduction or prevention can be understood as to changing industrial production to reduce critical material usage and hazardous waste in the design. This method is important in economic terms but runs a risk of disrupting the supply chain. The next level is reuse, whereby the batteries are reconditioned for different, less-demanding second life applications like stationary energy storage. The next level is restoring, whereby the cathode materials are restored (Chen et al., 2019). The next level is recycling, whereby the valuable materials are extracted and processed. The fifth level is incineration, whereby part of the battery materials is used as fuel for other purposes. Lastly, the disposal process simply refers to sending the batteries to a landfill.

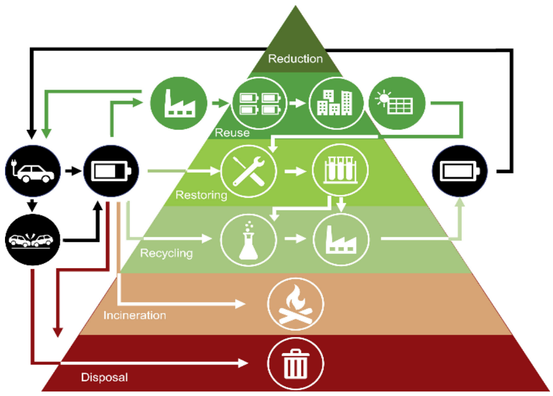

Figure 2.1: Electric Vehicle Lithium-ion Batteries Life Cycle.

All but reuse of the five retirement possibilities marks the end of the battery life. While being the least energy-efficient, disposal is frequently required since the other choices might expose employees to electrolyte leakage and dangerous chemical leaching (Harper et al., 2019). There is a chance that incineration, which in this context exclusively refers to burning battery components as fuel for other operations, may release air-polluting hazardous gases(Neuhaus, 2018). The alternative that has likely been examined the most in the open literature is recycling. Advanced technologies in valuable material extraction from batteries have been developed. The advancement in these technologies is typically stimulated and encouraged by government policies. Some of these technologies include physical materials separation, direct recycling, and recovery by pyrometallurgical means (Chen et al., 2019; Harper et al., 2019; Fan et al., 2020). In addition to recycling and reuse, restoring recovers the cathode materials for use in new battery production (Chen et al., 2019; Xu et al., 2020).

Reuse provides the retired battery packs a second chance at life, as opposed to the previous four possibilities. Reuse technically refers to a variety of meanings and processes, depending on whether the old batteries are repaired or utilised directly for vehicle or other applications (Gifford and Lee, 2020). It is important to note that while the precise needs and requirements for the second-life batteries varied, the core technologies are the same for different approaches.

Second-life batteries will eventually reach the end of their useful lives, at which point they will almost certainly be recycled by removing the raw materials to make new batteries. However, because reuse extends the life cycle of the materials, it is preferable from a financial and environmental standpoint to recycling (Chen et al., 2019; Harper et al., 2019; Fan et al., 2020). The practical industrial option is largely reliant on both its technological and economic viability, as was already mentioned before (Zhu et al., 2021).

2.3 Modern Technology of Electric Vehicle

The market for EVs and hybrid electric vehicles (HEVs) is expanding non-stop. Automobile manufacturers have continued to look for technology that increase efficiency under the stimulus of governmental policies and market demand. To allow the widespread market adoption of EVs and HEVs in the future, ongoing research and development are necessary. Power electronics, traction motor, and energy storage systems are three key areas where current research is focused on enhancing the vehicle (Sarlioglu et al., 2017).

2.3.1 Motor

This literature review investigates direct current motor, switched reluctance motor, induction motor and permanent magnet motor. In the late ninetieth century, due to its straightforward speed regulation, direct current motors were frequently utilized as the traction motor in early electric cars and prototypes (Cai et al., 2021). However, due to shortcomings of the direct current motor such as lackluster reliability, heavy mass, and bad efficiency, its viability for high-speed electric vehicles diminished. It is only used in low-speed EVs, such as logistical carts in factories.

The switching reluctance motor does not have permanent magnets, windings, or slip rings on the rotor like other types of motors do (Cai et al., 2021). Simple focused windings are arranged on the stator. The switching reluctance motor is strong, easy to use, economical, and able to operate at high speeds due to its configuration. In addition, short circuit faults is prevented due to the inverter’s reliable topological structure (Yang et al., 2015). Nevertheless, because of their jarring vibrations, loud noises, and unpredictable torque changes, switching reluctance motors have not yet become a typical traction motor in electric cars. However, its lack of permanent magnet makes it a prospective choice for electric vehicles due to current world events, and research is still being conducted on its feasibility.

Squirrel-cage induction motors are widely used, although the first two motors have yet to be utilized in mass-produced electric cars (Cai et al., 2021). The stator and rotor are made of laminated silicon steel sheets, and three-phase windings are put into the stator lamination stack and rotor slots. Induction motors are inexpensive, have a strong and simple construction, little torque ripple, require minimal maintenance, and produce little noise. These elements enable the induction motor to operate at 15,000 rpm at high speeds with a broad constant power range. However, because of their complex control circuit and the growing popularity of permanent magnet motors, which offer superior efficiency and power density, in the market for electric vehicles, induction motor utilization is diminishing.

Permanent magnets are used to excite the magnetic field in permanent magnet motors. The frequency drive and the motor operate in synchronism. They may also be broken down into permanent magnet hybrid excitation motor, permanent magnet brushless DC motor, permanent magnet synchronous motor, and permanent magnet direct current motor (Cai et al., 2021). The permanent magnet synchronous motor (PMSM) is the one that is utilized in electric vehicles more frequently. Apart from permanent magnets in place of the excitation winding, the stator of a PMSM with three-phase windings is identical to an induction motor or synchronous motor. The two subcategories of permanent magnet motors are interior embedded type and surface-mounted permanent magnet synchronous motor. High efficiency, high reluctance torque, low heat production, high power factor, low noise, and tiny packaging are among the characteristics of interior embedded type PMSM. Interior embedded type PMSMs have taken over as the most popular traction motor type for electric vehicles because of these benefits and the development of sophisticated power electronics control strategies. Due to its completely enclosed design, it is also maintenance-free and does not contribute significantly to wind friction losses.

Table 2.1 shows the performance comparison of the electric vehicle motor types.

Table 2.1: Performance Comparison of EV Motor Types.

Index	Direct Current Motor	Switched Reluctance Motor	Induction Motor	Interior Embedded Type PMSM
Control Simplicity	Good	Medium	Medium	Poor
Efficiency	Poor	Poor	Medium	Good
Performance	Poor	Medium	Medium	Good
Reliability	Poor	Good	Medium	Good
Size	Poor	Medium	Medium	Good
Speed	Poor	Good	Good	Medium

(Modified from source: Cai et al. 2021, p. 6).

High power density, high efficiency, fast speed, low noise and vibration, cheap cost, and greater electromagnetic compatibility are important considerations for the development of electric cars in the future (Cai et al., 2021). The US Department of Energy has put up a roadmap for the development of electric vehicles (EVs) that calls for electric motors to have a 97% efficiency rating, 50 kW/L of power density, and a cost of 3.3 dollars per kW.

2.3.2 Battery Technology

Batteries are the most popular choice of energy storage solution in power systems. Nickel-based batteries, lead-acid batteries, and lithium-based (Li-based) batteries are the main battery types that are appropriate for road vehicle use. Additionally, there are three uncommon battery types: flow batteries, metal-air batteries, and sodium sulphur (NaS) batteries (Li, Khajepour and Song, 2019).

Lead-acid batteries are the pioneer rechargeable electrochemical devices for use in the industry and household environments. Lead-acid batteries offer the following benefits: high energy efficiency (63%-90%), low initial prices (60-200 $/kW h), and quick reaction times. Lead-acid batteries also have modest self-discharge rates, by which it will only discharge 2% of the rated capacity each month under room temperature conditions. However, lead-acid batteries have the following drawbacks. It has a weak specific energy density (25–50 Wh/kg) and a short cycle life (500–1500 cycles). Additionally, both the fabrication and disposal process of these batteries are actually harmful to the environment. The more widespread commercial deployment of lead-acid batteries is restricted by these unfavourable characteristics (Chen et al., 2009; Hadjipaschalis, Poullikkas and Efthimiou, 2009; Aneke and Wang, 2016).

There are four different types of nickel-based batteries. They are nickel-zinc (NiZn), nickel-iron, nickel-metal hydride (NiMH), and nickel-cadmium (NiCd). Comparing the nickel-iron battery to other nickel-based batteries reveals that it is more stable, has a longer lifespan, and is significantly less expensive. However, there are disadvantages to the nickel-iron battery as well, including high maintenance costs, high self-discharge rate, heavy weight, and low power density. The NiCd battery charges quickly, is resistant to overcharging and overdischarging, and has strong temperature range adaptation. The NiCd battery, however, suffers from a memory effect during discharging and charging process as well as environmental issues brought on by its poisonous elements, making it all but obsolete in the use of digital electric gadgets.

In comparison to other nickel-based batteries, the NiMH battery has a faster rate of discharge and a bigger energy density, but it also heats up during charging. The NiZn battery is safe and favourable to the environment, but at the moment its main drawback is its short cycle life, which severely restricts its commercial use. In 2018, it was revealed that scientists from Dalian University of Technology had discovered a breakthrough in the cathode material used in NiZn batteries, allowing for a tenfold improvement in cycle life to reach 10,000 cycles. Overall, nickel-based batteries outperform lead-acid batteries due to their better cycle life and energy density. However, they are costly, costing between $100 and $300 per kWh, and have lower energy efficiency of under 80% (Hadjipaschalis, Poullikkas and Efthimiou, 2009; Tie and Tan, 2013).

Due to its benefits, including their high energy density, lack of environmental issues, lack of memory effect, and light weight, lithium-based batteries are quickly becoming the most well-liked storage systems. There are four primary types of lithium-based batteries, the lithium-ion, lithium iron phosphate, lithium iron sulphide, and lithium-ion polymer. The lithium iron phosphate battery is the costliest of these batteries, but it also has the highest power density (2-4.5 kW/kg) and longest cycle life (more than 2000 cycles). The Li-iron sulphide battery is lighter and has a larger energy capacity, however it only has a 1000+ cycle life. Although the Li-ion polymer is durable and reliable, it has poor conductivity and a lower power density than other materials. With its excellent specific energy density (up to 250 Wh/kg), resistance to self-discharge, good power density (0.5-2 kW/kg), reasonable cost, extended lives, and superb energy efficiency (90-100%), the Li-ion battery is the greatest option for cost performance. Although a protection circuit is necessary to ensure safe operation, there is a possibility that the lifetime of the Li-ion battery can be abruptly reduced as it is susceptible to deep discharge operation and high temperature conditions (Hadjipaschalis, Poullikkas and Efthimiou, 2009; Tie and Tan, 2013; Aneke and Wang, 2016; Hannan et al., 2017).

The rare batteries may be succinctly explained as follows. The NaS batteries include characteristics like high energy density (150–300 Wh/L), a good energy efficiency (89–92%), a long cycle life (2500 cycles at 90% depth of drain), and a high pulse power capability with quick and accurate responses. However, in order to guarantee the operating temperature for the NaS batteries, an additional system is needed. They are only appropriate for large-scale stationary applications due to their relatively high operational expenses per year (Luo et al., 2015; Aneke and Wang, 2016). Metal-air batteries produce energy by electrochemically coupling atmospheric oxygen with an electropositive metal, such as aluminium or zinc. These batteries are small and inexpensive, but they have poor energy efficiency of just 50%, short cycle lives of only a few hundred cycles, and narrow temperature working ranges (Aneke and Wang, 2016). The electrolytes are kept in the independently sealed tanks, giving the flow batteries which may be divided into redox flow batteries and hybrid flow batteries, an intrinsic strength of extremely little self-discharge. However, they have drawbacks that prevent them from being used in commercial settings, such as complicated system structures, high capital, and poor performance (Luo et al., 2015).

2.4 Modern Charging Technologies

Modern charging technologies can be classified into 2 types, namely wired charging (contact charging) and wireless charging (contactless charging) (Ahmad and Derrible, 2018; Niu et al., 2019). An alternative to charging that is present in today's market is battery swapping, a hallmark of the Chinese NIO Electric Vehicle Company. Figure 2.2 below shows the various classification of Battery Electric Vehicle charging technologies.

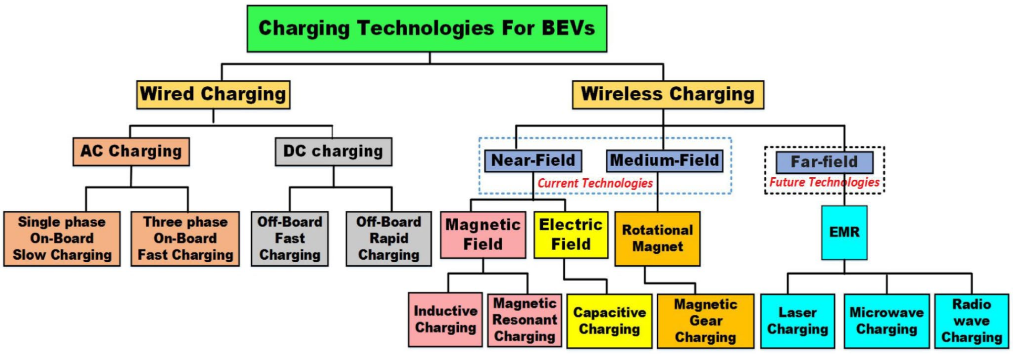

Figure 2.2: Battery Electric Vehicles Charging Technology Classification.

2.4.1 Wired Charging

Wired Charging is the most common charging method in the electric vehicle market. It is primarily achieved with two methods, namely AC Charging and DC Charging. To employ AC Charging, a converter that converts AC power to DC is built inside the vehicle. It is more commonly known as an "onboard charger" and is the most popular way of charging electric vehicles currently. In the domain AC Charging, there exists also fast charging and slow charging. Fast charging is made possible by three-phase AC Charging, while slow charging is provided by single-phase AC Charging (Barrero-González et al., 2019; Sayed, Ali and Aldhaifallah, 2020). Three-phase AC power provides power delivery higher than single-phase AC power, due to the fact that three sets of alternating current are being delivered simultaneously. The voltage and current levels are not limited to the capacity of a single conductor. As voltage and current flow are delivered in sine waves, having it distributed across three conductors offset by one-third of a cycle. Hence, three-phase AC power is able to deliver more power per unit time, rapidly charging the Energy Storage System in the Electric Vehicle.

In the domain of DC Charging, there exists off-board fast charging and off-board rapid charger (Adil et al., 2020). As mentioned in the name, AC to DC conversion is completed before the energy flows to the vehicle and is primarily deployed at electric vehicle charging stations. High voltage DC power bypasses the onboard charger and directly flows to the energy storage system that exists on the Electric Vehicle. Fast charging stations commonly employ DC Charging, because it is quicker and more powerful. However, since DC Charging requires specialized equipment usually available at fast charging stations, AC Charging tends to be more cost effective and more widely available. Table 2.2 shows a list of popular wired charging methods with their manufacturer.

Table 2.2: List of Wired Charging Methods.

BEV Model	**Battery Type and DC Voltage (V) / Capacity (kWh)**	**Charging Criteria**			
		Power (kW)	**Charging Duration**	**Available Charging Speed**	**Charging Type**
Nissan Leaf	Li-ion (~360)/40	3~100	3 h with 22 kW (32 A)	Fast	3 ϕ on-board fast charging
Hyundai IoniqEV	Li-ion Polymer (240~360)/28	3~50	5.5 h with 7 kW (30 A)	Fast and slow	3 ϕ on-board fast charging
Tesla Model 3	Li-ion (230~350)/75	3~120	55 min with 50 kW (100 A)	Fast and slow	3 ϕ off-board fast charging
BMW i3	Li-ion (~352)/33	3~50	45 min with 50 kW	Fast	3 ϕ off-board fast charging

Table 2.2 (Continued)

Kia Soul EV	Li-ion polymer (230~350)/30	2~100	50 min with 50 kW (125 A)	Fast and slow	3 ϕ off-board fast charging
			11 h with 2.3 kW (10 A)		1 ϕ on-board slow charging

(Modified from source: Bharathidasan et al. 2022, p. 9673).

2.4.2 Battery Swapping

Electric vehicle (EV) owners can replace their exhausted batteries for fully charged ones at approved swap stations thanks to the ground-breaking concept of battery swapping. This technology has been around for a while, and it has a number of advantages that make it a desirable choice for EV drivers.

The ability of battery switching to dramatically shorten EV charging times is one of its key benefits. The exhausted battery may be rapidly changed out for a fully charged one in a matter of minutes rather than having to wait for the car to charge for hours. Because drivers can rapidly swap out their batteries at authorized sites along their route, long-distance driving becomes more feasible for EVs.

Furthermore, battery changing can eventually lower the cost of EV ownership. When an old battery begins to fail, drivers can easily swap it out for a fully functional one at a much lower price than buying a new one. As a result, the EV may last longer and be a more cost-effective option for drivers.

Overall, battery switching is a promising technology that provides EV owners with several advantages. Even if there are still certain issues to be solved, like the cost and complexity of constructing and maintaining a battery swapping infrastructure, it has the potential to make EVs a more useful and affordable option for consumers.

2.5 Electric Vehicle Simulation Tools and Comparison

While researching the various technologies that are available in current electric vehicles, it is important to be able to benchmark the technologies such that better understanding of the strengths and weaknesses can be gained. By doing this, manufacturers and consumers alike can make informed choices on which technology to adopt and pursue based on their requirement.

An electric vehicle system comprises various components, such as the energy storage system (battery), motor and power electronics. With the degree of complexity involved, designing, and optimizing electric vehicles is becoming a challenge to developers and researchers alike. To address this challenge, various computer software simulation tools have been created to model and analyse the performance of electric vehicle design.

In this context, it is crucial to compare and contrast the tools to determine the tool that is most suitable in this research. The comparison should take into consideration factors like modelling precision, user-friendliness, simulation speed, and price. Two popular electric vehicle simulation tools, namely MATLAB Advanced Vehicle Simulator (ADVISOR) and AVL Cruise have been selected for comparison.

2.5.1 Advanced Vehicle Simulator

The National Renewable Energy Laboratory (NREL) wrote the Advanced Vehicle Simulator (ADVISOR) in the MATLAB/Simulink environment. It was first released for public use via the Internet in 1998. For sophisticated vehicle modelling, ADVISOR offers automotive engineers an adaptable, user-friendly, supported and rigorous analysis tool. It is mainly used to measure fuel efficiency, emissions and performance of vehicles powered by alternative technologies. Electric motors, batteries, fuel cells, and hybrid (multiple power source) designs make up some of the alternative technologies that are present currently. It is superb at computing the anticipated relative change in comparison to a reference situation (Markel et al., 2002)

It uses a novel hybrid backward/forward modelling methodology. This method eliminates the requirement for iteration that other models require, allowing ADVISOR to accurately describe vehicle function under a variety of operating scenarios. ADVISOR is a great option for automotive system optimisation studies due to its fast solution speed (on the order of 1/75th real time).

The modular and open nature of ADVISOR enables the ability to integrate with intricate, dynamic, and proprietary models when detailed component models are required. This is largely due to the fact that it is written within the MATLAB environment, as it can utilise Simulink to integrate external software packages. Intellectual property can even be preserved through the linking and compilation of proprietary models to Simulink. Current versions of ADVISOR contain a variety of battery and fuel cell models with differing levels of complexity.

Furthermore, while ADVISOR alone is not designed to measure oscillation of electric field, mechanical vibrations and the multitude of fast dynamics, it can be successfully integrated with other tools such ADAMS/CAR and Saber for such dynamics analysis. ADAMS/CAR is a software tool that is primarily used for the study of vehicle dynamics. It implements a multibody dynamics technique, which mimics the interaction and motion of multiple rigid bodies. Maharun M., Baharom M.B. and Mohd M.S. have created a co-simulation environment with MATLAB Simulink and ADAMS/Car for their research on their HEV model and controllers (Maharun, Bin Baharom and Syaifuddin Mohd, 2013).

On the other hand, Saber is a software tool developed by Synopsys for the study of intricate electronic and electrical systems. Saber's unique points is that it is excellent at power electronics systems simulation while considering the influence of factors like electromagnetic interference (EMI) and thermal properties. It has a library roster of capacitors, diodes, and transistors models for the simulation of inverters, motor drives, and converters. Johnson V.H. states that ADVISOR and Saber co-simulation was created as a joint project with Delphi Automotive (Johnson, 2002). This co-simulation enabled ADVISOR to utilise the lead acid battery model present in Saber.

ADVISOR even includes over 40 drive cycles, captured using on-board data gathering equipment under actual driving conditions. One of these drive cycles is the Colorado driving cycle (CYC_NREL2VAIL), which can be used to mimic realistic driving conditions on the Continental Divide interstate highway for the verification of the model's performance. Figure 2.3 shows the Colorado driving cycle.

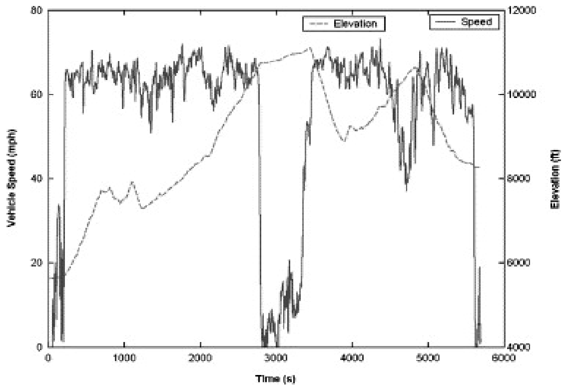

Figure 2.3: Colorado Driving Cycle (CYC_NREL2VAIL).

2.5.2 Anstalt für Verbrennungskraftmaschinen List Cruise

AVL Cruise is a powerful software programme for simulating and analysing vehicle dynamics (Iorga, 2016). AVL Cruise was created by AVL List GmbH, a well-known engineering firm in the automotive industry. AVL Cruise is utilized extensively by automotive manufacturers, suppliers, and research organizations around the world.

The capability of AVL Cruise to model how vehicle components behave under a variety of circumstances, including braking, full acceleration, cornering, and uneven road surfaces, is one of its main advantages. The tool mimics the interaction and motion of several rigid bodies in a system using a multibody dynamics technique. This enables engineers to precisely simulate the intricate connections between various vehicle components and forecast the impact of these interactions on the vehicle's overall performance.

AVL Cruise has a wide range of libraries and models for simulating vehicle components, such as steering, tires, and platform. It also includes tools for analyzing the results of simulations, such as animations, graphs, and charts. These tools make it easy for engineers to visualize and interpret the behavior of vehicle systems and to optimize their design for improved performance and efficiency.

The user-friendly interface of AVL Cruise is one of its main advantages. Engineers may easily set up and run simulations, as well as analyse and explain the findings, thanks to the software's well-designed and simple user interface. Engineers may customise the programme to meet their own needs thanks to the interface's numerous customization possibilities.

AVL Cruise has a variety of optimisation and parameterization tools in addition to its simulation capabilities. Engineers may use these technologies to automatically optimise the design of a vehicle's systems for increased functionality, effectiveness, and safety. Engineers may construct and change models using the software's parameterization tools, which are based on data and observations from the actual world.

The high cost of AVL Cruise is one factor that can make it less affordable for smaller businesses and organisations. However, larger organisations and research institutions that need a complete toolset for vehicle dynamics simulation and analysis will find the software to be an excellent choice due to its advanced features and capabilities.

2.6 Standards

Electric vehicle disassembly and disposal are crucial procedures that call for great attention to environmental and safety issues. A number of international standards have been created to address these concerns. These international standards provide instructions on safe handling, transportation, storage and disposal of electrical components safely. These standards aim to ensure that the disassembly and disposal procedures are conducted in a manner that reduces the possibility of accidents and safeguards the environment. The standards cover a variety of subjects, such as hazard identification and evaluation, electric vehicle batteries' safety requirement, electric vehicles operational safety, as well as the electric vehicle components testing and evaluation.

2.6.1 International Organization for Standardization

The International Organization for Standardization (ISO) is a non-governmental organisation that creates and disseminates international standards for a variety of sectors and disciplines. ISO was founded in 1947 and is made up of national standards organisations from more than 160 nations that collaborate to create standards based on consensus that advance efficiency, quality and safety across different industries. Globally recognised, ISO is practised by enterprises, governmental bodies, and other organisations (Craig and Yates, 2009). This is largely because the standards give organisations a uniform operating and communication framework, simplifying commerce and enhancing the quality and safety of services and goods. In the context of electric vehicles, ISO provides the following standards.

The first one is ISO 6469-1:2019 that outlines the safety standards for the conception, development, and operation of electric vehicles of up to 1,500 V DC. It covers a host of issues pertaining to safety, such as thermal safety, electrical safety, and functional safety. The standard offers recommendations for the safe design of electrical components of high voltage. The standard also mitigates accidents by defining safety regulations for mechanical systems, such as steering and brakes. Additionally, the standard offers safe instructions on electric vehicle operation, which includes driver education and the usage of safety features like reverse alarms. The standard also offers advice for the service and maintenance of electric vehicles to ensure safe operational conditions (International Organization for Standardization, 2019).

The second one is ISO 6469-2:2022 that outlines the safety standards for electric vehicle operation and measures against failures. The standard covers the development, fabrication, and testing of electric vehicles to ensure safe use. A host of safety features, such as suspension system, braking system, and even electric shock protection are covered by the standard. Occupant and other road users' safety are also highlighted in terms of fire safety and crashworthiness (International Organization for Standardization, 2022).

2.6.2 International Electrotechnical Commission

International standards for the electronics and electrical sectors are created and published by the International Electrotechnical Commission (IEC), a nonprofit organisation. The IEC was established in 1906 and consists of national committees from more than 80 nations. These committees collaborate to create standards based on consensus that support dependability, safety, and efficiency in the design, manufacture, integration, and utilisation of electrical equipment and systems. The IEC standards cover a wide scope, such as information technology, electric vehicles, renewable energy, and power generation and distribution. A framework is established by the standards for guaranteeing the efficiency, interoperability, and safety of electronic and electrical systems and products used by organisations worldwide. Overall, sustainability and innovation are heavily promoted by the IEC, addressing challenges in the topics of cybersecurity, power use, and environmental friendliness (Brouder and Tietje, 2009). In the context of electrical vehicles, IEC provides the following standards (Craig and Yates, 2009).

The first one is IEC 62660-1:2018 that outlines electric vehicle traction lithium-ion battery performance and testing specifications. The testing specifications cover a range of parameters, from storage life, power density, cycle life, to energy density. Additionally, battery management systems (BMS) specifications are also offered as guidelines for use in the design. All these efforts are to ensure the safety and dependability of lithium-ion batteries used in electric cars (International Electrotechnical Commission, 2018a).

The second one is IEC 62660-2:2018 that outlines methods of testing to measure the dependability and abuse behaviour of lithium-ion cells that are used in electric vehicle propulsion. Similar to the IEC 62660-1:2018, the classification of test results serves to become a guideline for use in the development of batteries (International Electrotechnical Commission, 2018b).

2.7 Summary

In summary, there is a need to evaluate the overall efficiency of an electric vehicle's life cycle. The selection of EV technology in the design stages and the disposal process in the end-of-life stages greatly influence the vehicle's overall efficiency. However, the disposal processes currently employed may no longer be suitable for extracting the high-value rare minerals used in electric vehicle manufacturing. Researchers have proposed novel approaches, often with the use of automation or machine vision, that need to be further researched for adoption on a larger scale.

End-of-life policies for vehicles also require revision to accommodate the ongoing innovations of electric vehicle technologies. The determination of the battery state-of-health (SOH) threshold must be revised, possibly by manufacturers, before a standard can be implemented. Furthermore, emerging electric vehicle technologies need to be benchmarked to determine their viability based on metrics such as efficiency, performance, and battery life.

Overall, parameters considered satisfactory five years ago need to be reevaluated based on current innovations and environmental requirements.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The problem that this research intended to solve is the insufficient evaluation of electric vehicle disposal process as well as the benchmarking of electric vehicle technologies, such that sustainability of these technologies is ensured. To address this issue, the research was conducted in a blended approach of quantitative and qualitative methods.

The qualitative research method required the gathering of data through interviews, observation, and other methods that are non-numerical to achieve the interpretation of a phenomenon. In the first stage of the research, preliminary observation on the conditions of the Universiti Tunku Abdul Rahman electric vehicle was conducted, with emphasis on the physical status of the body, interior, lead-acid battery pack, electric motor, and various mechanical components. The observations were then documented for further interpretation in Chapter 4. Hands-on methods were also required to disassemble the electric vehicle components before disposal.

The quantitative research method required the gathering of numerical data and analysis through the utilisation of statistical methods to generate interpretations. The data collected from the revival process of the lead-acid batteries as well as the software simulation used to benchmark EV technologies was classified as quantitative research methods.

Hence, the research was conducted in a blended approach of both methods to provide a more extensive and thorough understanding of the electric vehicle disposal process and benchmarking of the electric vehicle technology.

3.2 Physical Observations of UTAR Electric Vehicle

The UTAR Electric Vehicle conversion project was the culmination of the efforts of multiple batches of final year engineering students as part of their capstone project. The project involves the conversion of a conventional Mitsubishi Lancer-based Proton Wira into an electric vehicle through the removal of the internal combustion engine and relevant components. The manual 5-speed gearbox was still retained and was coupled to an electric motor, complemented with a control system, battery management system, 144 V Lead-acid battery pack, and relevant power electronics component.

After the UTAR Electric Vehicle has been transferred to the Universiti Tunku Abdul Rahman Sungai Long campus, it was left idling at the basement parking garage for almost a decade. As part of the disposal process, it is important to observe the possible decaying condition of the electric vehicle. Potential rusting, rat bite marks of cabling and other potential hazards should be taken note of so that necessary precautions can be taken to ensure safety.

In the case when there is rusting, the parts where there are exposed metals may pose risk of cuts and puncture wounds. Additionally, bacteria and other harmful microorganisms may find rusty metals a haven for breeding. They may cause nasty infection, such as tetanus, when they come in contact with mucous membranes and wounds. Proper care should be taken when operating around these rust spots, and it would be better to treat the rust spots with some sanding or covering with duct tape at the very least.

In the case that there are rat bite marks of cabling, the relevant cable must be traced to the source and disconnected when necessary. Even if each of the twelve series connected 12 V lead-acid batteries still retain 50% of their voltages, that is 6 V, it would amount to a sum of 72 V in the system, which is potentially lethal. Besides that, the exposed wires may be a potential fire hazard as it may cause electric shorts and trigger combustion of flammable materials. Hence, proper handling of these exposed wires should be taken for safety. In the case where the wires cannot be traced, the exposed end of the cable should be sealed off with an electrical tape. Before any work around the vehicle is conducted, runaway currents were ensured to be not leaking to the surrounding body of metals. This was accomplished by testing for electrical continuity with a multimeter or test pen.

All in all, proper attire was worn at all times when conducting work on the electric vehicle. Long pants and gloves provided protection to the exposed body parts and serve as an insulation. Safety boots were also worn as they provided excellent ground insulation to prevent electric shocks, besides protecting the feet from punctures and impacts.

3.3 Revival and Recycling of Lead-Acid Batteries

The neglected condition of the UTAR electric vehicle serves as an excellent opportunity for research on the real-world performance of a neglected battery electric vehicle. Before starting the revival process, voltage and current measurements were conducted on the lead-acid batteries to calculate the state of charge (SOC) and state of health (SOH).

The state of charge (SOC) refers to the amount of charge contained within a battery at a given time. As the battery is charged and discharged, the SOC changes accordingly. State of health (SOH) on the other hand measures the ageing level of batteries (Li et al., 2019). It is an indication of the battery’s ability to hold and provide energy compared to when it is still new. In mathematical context, it is simply the actual cell capacity/resistance to the initial value ratio.

Initial voltage measurements of the 12 V auxiliary lead-acid battery were also taken. Out of the twelve Trojan T-1275 Deep Cycle lead-acid batteries, the batteries with the highest charge will were selected for charging and discharging as an attempt to revive or restore their functionality. The voltages of the charging curves were taken periodically with the use of a Tenma 72-14625 multimeter equipped with USB connectivity. The USB connectivity allowed data logging on the 72-14525 Interface Program at customisable intervals, which then can be saved as an Extensible Markup Language (XML) file for graph plotting. Figure 3.1 shows the user interface of the data logging software.

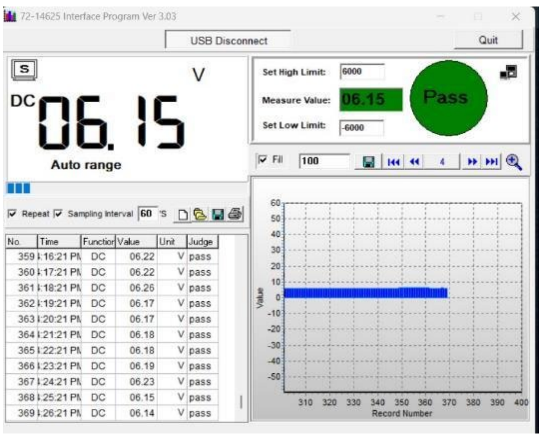

Figure 3.1: User Interface of the 72-14625 Interface Program.

In the event of the possibility that the batteries can be restored to operating conditions, relevant performance data pertaining to the condition of the power electronics components can be measured. The maximum distance that can be travelled by the electric vehicle on a full SOC shall be measured and benchmarked against its range in the beginning of its life cycle.

However, in the event of the possibility that the batteries cannot be restored to operating conditions, the batteries shall be deemed as inoperable and marked for disposal. Due to the technological maturity of lead-acid batteries in the market, there exists a closed loop for lead-acid batteries, whereby 99% of lead-acid batteries are recycled in Europe (Karden, 2017). A point of contact will be determined to recycle the lead-acid batteries as part of sustainability efforts.

3.4 Disassembly of Electric Power Components

Once the revival and recycling process of the lead-acid batteries were concluded, disassembly of electric power components commenced. The electric power components to be removed include the traction motor, motor controller, and the battery charger. Just these three components alone weigh 64.52 kg, with their individual weights shown in Table 3.1. It is wasteful to dispose of these components without attempting to salvage the materials that constitute these components. Hence, these components were disassembled from the electric vehicle and returned to the university authority for further use.

Table 3.1: The Weights of the Traction Motor, Motor Controller and Battery Charger.

Component	Model Name	Weight (kg)	Quantity
Three phase induction motor	AC51-26.26.2	52.00	1
Motor controller	HPEVS Curtis 1239-8501	5.45	1
2,000 kW lead-acid battery charger	Elcon TCCH-120-15	7.07	1

WD40 anti-rust lubricant, rubber mallet, car jacks, wrenches, spanners of various sizes, and screwdrivers were prepared for use in the disassembly process. Figure 3.2 shows some of the equipment prepared.

Figure 3.2: Spanners, Wrench, Pliers, Testpens, Screwdrivers and Multimeter.

3.5 Disposal of Base Vehicle

With all the electrical components removed from the vehicle, the remainder of the vehicle will be disposed of. According to the Malaysia Department of Environment, scheduled wastes can be classified into 77 categories. The automotive industry is among the highest contributors to these wastes (Amelia et al., 2009). However, a research has identified that Malaysia has not implemented an End-of-life policy for vehicles (Harun et al., 2021). Malaysia does not mandate vehicle inspections for private vehicles, unless the road tax has expired for over one year. Hence, there is no check system for non-roadworthy vehicles to undergo disposal. Vehicle disposal in Malaysia is usually carried out voluntarily by the owners or when abandoned at a public space for long periods of time.

In terms of the typical vehicle disposal process in Malaysia, the process involves multiple agencies such as the Road Transport Department (JPJ), customs, and companies that actively engage in such activities. The process to be taken is to deregister the vehicle in the Road Transport Department (JPJ) database. Next, the vehicle will go through a series of dismantling processes. Liquids such as the brake fluid, hydraulic fluid, and gas coolant will be drained and recycled. Next, components that can be recycled such as the tyres and batteries will be dismantled. Lastly, reusable parts such as the alternator and radiator will typically be dismantled and sold as spare parts.

The base vehicle of the UTAR electric vehicle will undergo a similar process. A contact in the industry that engages in the vehicle disposal process will be determined.

3.6 Developing Electric Vehicle Model in Simulation Software

Once the disposal process of the UTAR electric vehicle has concluded, the next step is to develop an electric vehicle model in a simulation software. The purpose of this simulation is to determine the performance and efficiencies between the UTAR electric vehicle and the latest emerging technologies, so as to understand the technological breakthroughs. The simulation software selected is MATLAB Advanced Vehicle Simulator (ADVISOR) based on cost, modelling accuracy and user-friendliness.

The primary factor is due to cost. When compared with GT-Suite and AVL Cruise, ADVISOR is free to use for academic research. GT-Suite and AVL Cruise are commercial software with licensing fees. The second factor is due to modelling accuracy. Despite the fact that ADVISOR is free to use, its programming in the MATLAB environment gives it versatility to link with various add-ons and simulation software such as Simulink and Saber. This gives ADVISOR added benefits of extending its models and simulation libraries, giving the latest representation of the latest technologies and real-world use cases. The use of quality input data will certainly produce a result of high accuracy. Additionally, the user-friendly interface of ADVISOR within the MATLAB environment is easy to learn for users with programming experience. Figure 3.3 shows the user interface of ADVISOR for the setting up of the electric vehicle models.

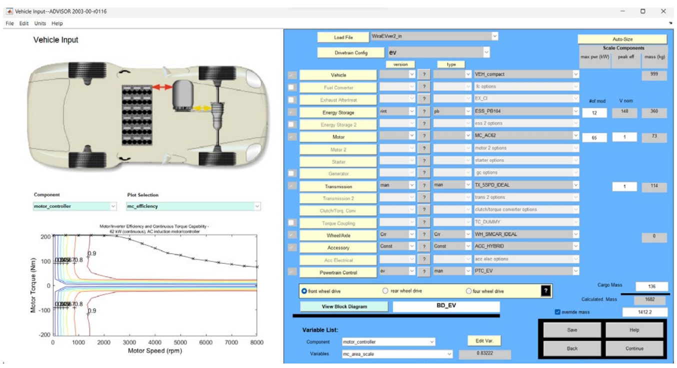

Figure 3.3: Vehicle Model Set Up Interface of ADVISOR.

3.7 Inter-comparisons of Electric Vehicle Technologies in Simulation Software

Once the simulation model has been completed, comparisons will be drawn among other simulation models representing the new electric vehicle technologies. The parameters and aspects that can be compared are energy efficiency, performance, battery life, range, and emissions. To standardize the testing and evaluation of the electric vehicle models, the New European Driving Cycle (NEDC) was selected. The New European Driving Cycle is a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars. Figure 3.4 and Table 3.2 shows the details of the NEDC cycle.

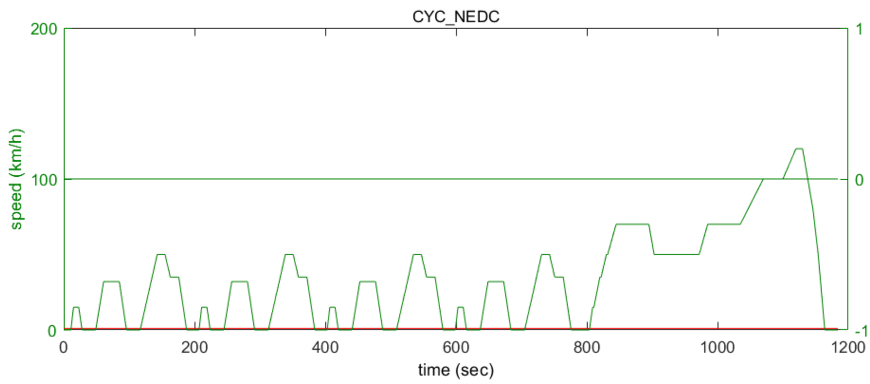

Figure 3.4: Speed Profile of NEDC Cycle Against Time.

Table 3.2: Details of the NEDC Cycle.

Parameters	Value
Time	1184 seconds
Distance	10.93 km
Max Speed	120 km/h
Average Speed	33.21 km/h
Maximum Acceleration	1.06 m/s^2
Maximum Deceleration	-1.39 m/s^2
Average Acceleration	0.54 m/s^2
Average Deceleration	-0.79 m/s^2
Idle Time	298 seconds
Number of Stops	13
Maximum Upwards Grade	0 %
Average Upwards Grade	0 %
Maximum Downwards Grade	0%
Average Downwards Grade	0 %

By examining elements like motor efficiency, regenerative braking, and battery capacity, MATLAB Advanced Vehicle Simulator (ADVISOR) can simulate the energy efficiency of various electric vehicle systems. The research can identify which electric vehicle technologies are more energy efficient and, thus, more cost-effective by comparing their energy usage. Next, variables like motor power and torque can allow ADVISOR to simulate the maximum velocity, acceleration, and other performance parameters of various electric vehicle systems.

Moreover, by using variables like vehicle weight, life cycles, battery size, and road conditions, ADVISOR can simulate the range of various electric vehicle systems. The research can then identify which electric vehicle technologies are better suited for various driving circumstances and user demands by analysing the driving range results.

3.8 Planning and Managing of Project Activities

This section explains the research planning and managing. As shown in Table 3.3, Final Year Project 1 involves problem formulation and project planning, preliminary observations and testing, data collection of lead-acid batteries performance, electric vehicle disassembly, recycling of lead-acid batteries, and report writing and presentation. Table 3.4 shows that the Final Year Project 2 involves project planning and research, gearbox dismantling, simulation of electric vehicle models, arranging of towing of Wira EV for scraping, and report writing and presentation preparation.

Table 3.3: Gantt Chart of Final Year Project Part I.

Gantt Chart Part-1															
No.	**Project Activities**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
M1	Problem formulation & Project planning														
M2	Preliminary observation and testing														
M3	Data Collection of Lead-acid Batteries Performance														
M4	Electric vehicle disassembly														
M5	Recycling of Lead-acid Batteries														
M6	Report writing & presentation preparation														

Table 3.4: Gantt Chart of Final Year Project Part II.

Gantt Chart Part-2															
No.	**Project Activities**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
M1	Project planning and research														
M2	Gearbox dismantling														
M3	Simulation of Wira EV with lead-acid battery, 2015 Volkswagen e-Golf, 2017 Volkswagen e-Golf, 2021 Mercedes-Benz EQA 250, 2020 Smart EQ Fortwo, 2023 Tesla Model Y, and 2023 BYD Atto 3														
M4	Arranging towing of Wira EV for scraping														
M5	Report writing & presentation preparation														

3.9 Requirement/ Specification/ Standards

According to the Occupational Safety and Health Administration (OSHA), several types of hazards that may be associated with the disposal of electric vehicles have been identified. The first is electrical hazards, due to the presence of high-voltage batteries that may pose risks of electrocution, electric shocks, and fires. The next is chemical hazard, due to the presence of chemicals in the lead-acid batteries. The presence of lead sulphate crystals is dangerous to humans as they are deemed as carcinogens, components that may cause cancer under prolonged exposure. The following hazard is fire hazards, as the ageing lead-acid batteries have risk of explosion and fire. Moreover, physical hazards are present when handling the components of the vehicle, as there may rusting metal parts which may cause injuries and bacterial infection. Lastly, environmental hazards can arise if the electric vehicle components and chemicals are improperly disposed.

Under the International Organization for Standardization (ISO), there is at least two standards to follow for the safe handling and disposal of the electric conversion vehicle. The first is ISO 14001:2015. ISO 14001:2015 has provided the framework for an environmental management system that can be utilised to manage environmental impact, including during the disposal of materials and waste. The disposal processes were ensured to be environmentally responsible and compliant with regulations by following ISO 14001 (International Organization for Standardization, 2015).

The next standard under ISO to be followed is ISO 26262-1:2018. This standard addresses the hazard risks that are associated with faulty safety-related electrical and electronic systems. The disposal processes were ensured to be safe with regards to the electrical and electronic systems by following ISO 26262-1:2018(International Organization for Standardization, 2018).

Under the International Electrotechnical Commission (IEC), there is at least one standard to follow for the safe handling and disposal of the electric conversion vehicle, IEC61508-2:2010. The standard has provided the framework for the functional safety of safety related electronic and electrical systems. The electric vehicle components were ensured to be safely disassembled and disposed of according to safety requirements (International Electrotechnical Commission, 2010).

Safety boots, long pants or jeans, and gloves are required to be worn when work was conducted on the electric vehicle.

3.10 Summary

In summary, the process of the research is as follows. The research started with the disposal process of the UTAR Electric Vehicle. The process began with the physical observation of the UTAR Electric Vehicle, followed by the revival and recycling of lead-acid batteries, then the power components were disassembled, and the base vehicle can be sent for disposal.

The research will then transition to the benchmarking of electric vehicle technologies with MATLAB ADVISOR simulation software. The electric vehicle model will be created in the software first. Then, the relevant results will be recorded, and the inter-comparisons of electric vehicle technologies can then be conducted.

Adherence to the ISO and IEC standards ensure safe management and disposal process. The completion of these steps will help to achieve the aim of this research, that is to explore the current vehicle disposal process and benchmark the EV technology.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter shows the findings of the UTAR electric vehicle disposal process. The physical observations of UTAR Electric Vehicle, revival and recycling of lead-acid batteries, disassembly of electric power components and interior parts, disassembly and recycling of lead-acid battery pack and copper cable were completed. The chapter then proceeds to show the findings of the electric vehicle benchmarking process. The development of seven electric vehicle simulation models, performance recording of the electric vehicle models under different loading, increased rolling resistance due to wet surface, and real-life route simulation were completed.

4.2 Physical Observations of UTAR Electric Vehicle

The physical conditions of the UTAR Electric Vehicle were taken note of during the early stages of the project. As mentioned in Chapter 3.2, observation on the physical conditions is extremely important in the identification of hazards. Once the identification of hazards was completed, proper measures can be taken to mitigate potential injuries.

From initial observations, there was no obvious rusting on the external body of the vehicle. There was only accumulation of dust over the years, but all in all the car is in good shape, as shown in Figure 4.1.

Figure 4.1: The External Condition of the UTAR Electric Vehicle.

Moving on to the rear of the vehicle, the Trojan T-1275 Deep Cycle Lead-acid Batteries were observed to be held in their respective positions by their brackets. A total of eight lead-acid batteries were found in the trunk, whereas four were found in the cabin. Observations on the lead-acid batteries were conducted. All the lead-acid batteries have signs of swelling at the sides. Lead-acid batteries are designed as recombinant batteries, meaning that they will release and absorb gases. The gases are mainly hydrogen and oxygen gases that are the result of electrolysis, which are then dissolved into the battery water again. Over time as the condition of batteries degraded, the process became unbalanced and there is a build-up of gases within the batteries, leading to the swelling observed. Additionally, on almost all the lead-acid batteries, white crystal solids were found to have deposited on the vent ports of their caps, as shown in Figure 4.2.

Figure 4.2: White Crystal Solids Deposited on the Vent Cap of Lead-acid Battery.

These white crystal solids are most likely to be lead sulphate precipitation, typically associated with the high rate discharging of lead-acid batteries (Lam and Furukawa, 2009). Typically, the formation of lead sulphate is due discharging and charging at a high rate. As demonstrated by the reaction 4.1, HSO_4^- ions interact with the negative plate sponge lead to form lead sulphate ($PbSO_4$). The rate of reaction is so rapid to the point where the consumption rate of HSO_4^- in the plate interior surpasses the rate of diffusion of HSO_4^- in the majority of the solution.

$$Pb + HSO_4^- \xrightarrow{Dissolution} Pb^{2+} + SO_4^{2-} + H^+ + 2e^- \qquad (4.1)$$

where

Pb = lead

HSO_4^-= hydrogen sulphate

Pb^{2+}= lead (II) ion

SO_4^{2-}= sulphate ion

H^+= hydrogen cation

$2e^-$= 2 electron ions

The result of this reaction is a supersaturation of Pb^{2+} ions. The precipitation of lead sulphate will then occur rapidly on any surface, with the reaction denoted by reaction 4.2.

$$Pb^{2+} + SO_4^{2-} \xrightarrow{Deposition} PbSO_4 \qquad (4.2)$$

where

Pb^{2+} = lead (II) ion

SO_4^{2-}= sulphate ion

$PbSO_4$= lead sulphate

Moving on to the engine compartment of the vehicle, the accumulation of rust dust was found at the surface of metals, as shown in Figure 4.3. This is not uncommon in vehicles that are above more than ten years old. The formation of rust is typically attributed to a reaction between iron and oxygen, shown by reaction 4.3. The rust dust is particularly prevalent in the engine bay since there are more moving mechanical parts, hence insulation or protective layers of the metal parts such as paint have likely been chipped, leaving the metal parts exposed.

$$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3 \qquad (4.3)$$

where

Fe= iron

O_2= oxygen

H_2O= water

$Fe(OH)_3$= iron hydroxide

Figure 4.3: Rust Dust was Accumulating on the Surface of Metals.

Besides that, it can be noted that the absorber mountings on both sides were cracked as shown in Figure 4.4, due to the hardening of the rubber material over the years. Mould growth can also be found on the surface of the rubber hose of the brake reservoir, as shown in Figure 4.5. The dark and relatively cold conditions of the basement made the car a perfect environment for growth.

Figure 4.4: Cracks can be Observed on the Mounting Bushing.

Figure 4.5: Mould Growth Found on the Surface of Rubber Hose.

All in all, the electric vehicle physical condition was found to be in a good condition relative to a vehicle of the same age that is actively used on the road. The conditions above were not of great hazardous concern, however, lead sulphate is known to be carcinogenic to humans. Hence, care should be taken when handling the lead acid batteries and mask was worn.

4.3 Revival and Recycling of Lead-Acid Batteries

Before the revival and recycling of lead-acid batteries can be conducted, the initial voltages of the batteries were measured. The findings were tabulated before analysis was conducted and presented in a chronological order.

The electric vehicle was fitted with a 12 V auxiliary battery to power the auxiliary systems such as the infotainment system. The 12 V auxiliary battery was charged with a 12 V Teletron TC-1207A battery charger, rated at 7 A. The result of the first attempt at charging it was recorded in Table 4.1. The duration of the first charging attempt was 2 hours 25 minutes. The result of the second attempt at charging the 12 V battery again was recorded in Table 4.2. The duration of the second charging attempt was 2 hours 44 minutes.

Table 4.1: Voltage and Current Measurement of 12 V Auxiliary Battery from First Charge.

	Before Charging	**After 2-hour 25-minute Charging**
Voltage	1.557 V	9.95 V

Table 4.2: Voltage and Current Measurement of 12 V Auxiliary Battery from Second Charge.

	Before Charging	**After 2-hour 25-minute Charging**
Voltage	9.77 V	7.79 V

The voltage of the 12 V auxiliary battery was found to have dropped drastically after being charged for the second time. The period between the 2 charges was 16 hours 30 minutes. Next, the initial voltage of each deep cycle lead-acid battery was measured and recorded in Table 4.3.

Table 4.3: Initial Voltage of Each Deep Cycle Battery Measured in Parallel with Multimeter.

Battery No.	**Voltage (V)**
1	3.390
2	0.908
3	1.777
4	1.903
5	2.888
6	1.544
7	2.334
8	2.819
9	3.264
10	3.336
11	3.036
12	2.877

The lead-acid battery pack was charged for 2 hours 51 minutes through the original TCCH-120-15 charger. The voltage of the battery pack hardly changed from its initial voltage of 30.2 V to 30.4 V. A closer inspection showed that the TCCH-120-15 charger was blinking green and red, indicating that it was disconnected from the battery. However, there was no visible cuts to the connectivity of the circuit. An initial assumption was made that the cumulative voltage of the battery pack was lower than the rated battery voltage that can be charged by the charger, which caused the error to occur. This assumption was confirmed by the customer service of the charger manufacturer, ELCON, after an inquiry was sent. Each of the 12 V lead-acid batteries may need to be charged to 10 V minimum for the TCCH-120-15 charger to start charging.

The subsequent step taken was to charge the electric vehicle batteries individually. Battery number 8 was first selected to be charged with Teletron TC-1207A battery charger. The battery was disconnected from the battery pack before it was charged. The voltage of the battery while charging was recorded in intervals of 60 seconds with a data logging software and plotted as a charging curve in Figure 4.6. Before charging, the battery number 8 was measured to be 3.298 V. The smooth line between the 250th to 400th interval is due to the closure of the data logging software. Its straight line begins from the last recorded value in the software and final recorded value on the multimeter before charging was stopped. The final voltage was measured to be 3.841 V.

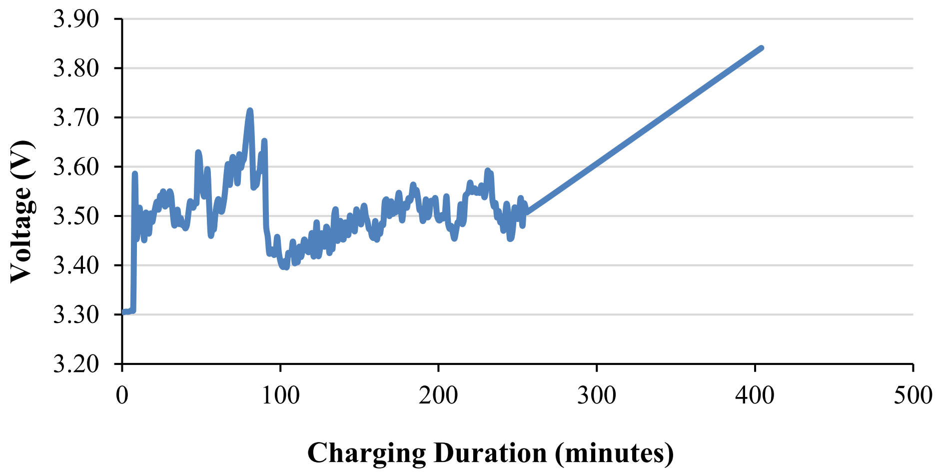

Figure 4.6: Graph of Battery 8 Voltage against Charging Duration.

The next battery selected for the charging process is battery number 1. The charging process was repeated with a Teletron TC-1207A battery charger and a data logger software. The charging setup was as shown in Figure 4.7. The voltage while charging was logged at 60 seconds intervals and plotted as a charging curve in Figure 4.8. Before charging, battery number 1 was measured to be 5.529 V, a spike from 3.39 V measured two days prior.

Figure 4.7: Charging Setup of Battery 1.

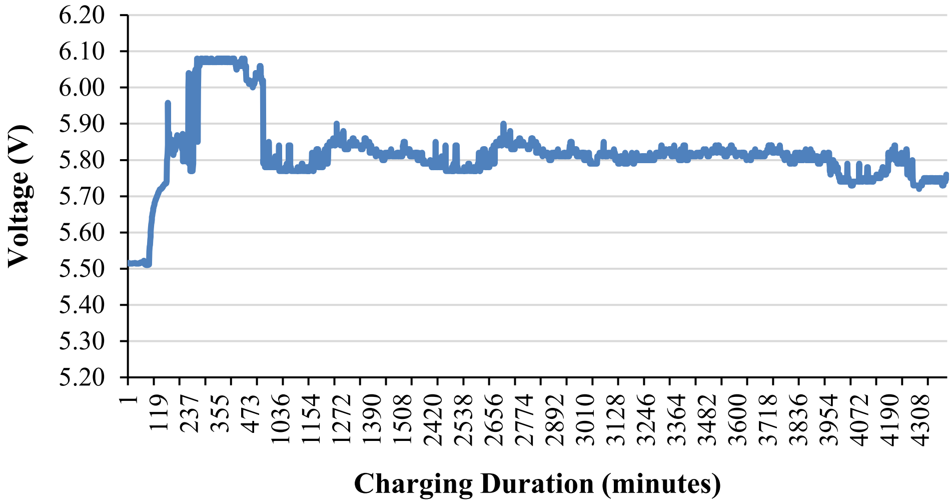

Figure 4.8: Graph of Battery 1 Voltage against Charging Duration.

Battery number 10 was selected to measure the load current. It was connected in series with a 7 ohm power resistor and multimeter. The current dropped rapidly from 603 µA to 480 µA within the first 3 minutes. Battery 10 is selected to be next battery to be charged. The charging process was repeated with a Teletron TC-1207A battery charger and a data logger software. The voltage while charging was logged at 60 seconds intervals and plotted as a charging curve in Figure 4.9. Before charging, battery number 10 was measured to be 5.70 V.

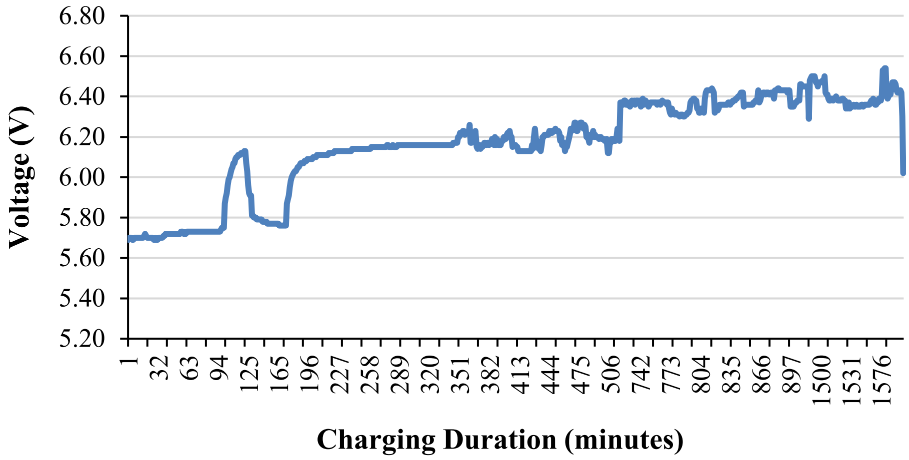

Figure 4.9: Battery 10 Voltage against Charging Duration.

Based on the measurements recorded in Table 4.3, battery 2 was deemed the weakest and was replaced with another battery of similar condition that was in storage. The battery that took the place of battery 2 was recorded as battery 13, and was measured to have 3.86 V. On the 27th of February 2023, an experimental charger was brought to revive the 12 lead-acid battery pack. The experimental charger is a switching (AC/DC) to generator (DC/AC) to rectifier (AC/DC) type of charger. The switching power supply takes in 230 V AC 50 Hz of energy from the domestic power port. Then, it outputs 48 V DC, from a range of 3 A to 17 A to the Variable Speed Drive (VSD) generator. The one driver, two generator design outputs into two channels, each carrying 123 V AC. Due to the motor generator, 3,000 Hz to 13 MHz of energy can be generated. Then, the AC power goes into a rectifier, which converts 123 V AC into a maximum output of 67 V DC.

With the specifications set, the objective of the charging is to increase the average battery voltage of each lead-acid battery in the battery pack to a minimum of 10 V so that charging with the original on-board TCCH-120-15 charger can commence. The initial voltage levels of each battery in the battery pack were recorded in Table 4.4. The overall voltage of the battery pack was recorded at 33.3 V, verified with two multimeters. The average battery voltage was around 3 V.

Table 4.4: Initial Voltage of Each Deep Cycle Battery Measured in Parallel with Multimeter before Charging with Experimental Charger.

Battery No.	Voltage (V)
1	3.810
3	2.100
4	2.170
5	2.790
6	1.360
7	2.500
8	2.860
9	3.011
10	3.110
11	2.713
12	2.999
13	3.622
Total Voltage	33.010

According to Mr David, the inventor of the experimental charger, the experimental charger is currently tested to be one of the few chargers that will not cause heating in the batteries. Heating is an important concern for fast charging methods, which tends to be more damaging to the batteries. Care must be taken on the possibility that the battery might combust or explode with fast charging methods. The exothermic chemical reactions within the battery will cause heating, leading to potential risk of explosions. David's opinion to the reason of absence of heating phenomenon with the charger is related to the frequency, as the charger can provide frequencies in the Mhz range, far exceeding the 50 Hz and 60 Hz standard used worldwide. However, in the industry, pulse charging is the popular practice to restore the capacity of batteries.

The voltage charging graph is given in Figure 4.10. It was found that the battery pack voltage was dropping at a fast rate when charging was stopped. After closer inspection, it was found that the batteries were dry inside and needed battery acid to facilitate the required reactions. After 24 hours, the voltage of each individual battery and overall voltage of the battery pack was recorded in Table 4.5.

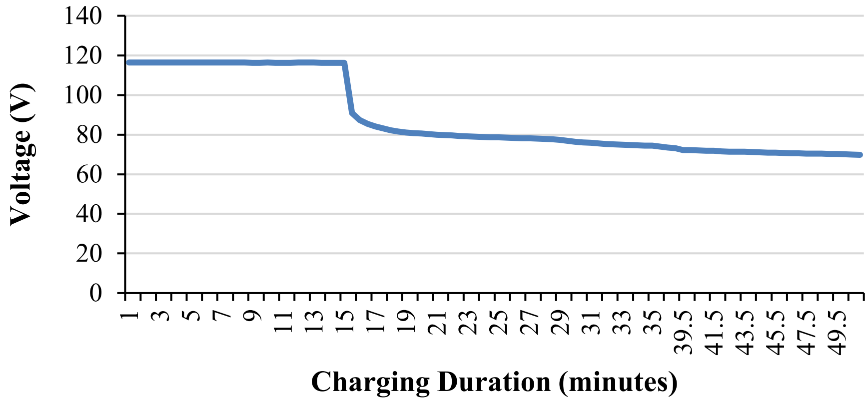

Figure 4.10: Battery Pack Voltage against Charging Duration.

Table 4.5: Voltage of Each Deep Cycle Battery Measured in Parallel with Multimeter 24-hour after Charging with Experimental Charger.

Battery No.	Voltage (V)
1	6.590
3	2.934
4	3.348
5	2.090
6	2.557
7	3.112
8	3.526
9	3.930
10	6.390
11	5.140
12	3.930
13	4.390
Total Voltage	47.900

The next step would be to refill the lead-acid batteries with battery water. Diluted water was purchased for an experiment to revitalise the lead-acid batteries. Battery 1 was selected to be filled with diluted water first and charged with Teletron TC-1207A battery charger. Filling battery 1 required two litres of distilled water. During the filling process, no physical reaction can be observed within the battery. The initial voltage was 6.59 V. The voltage charging graph was given in Figure 4.11. There was no change in the voltage after 54 minutes of charging.

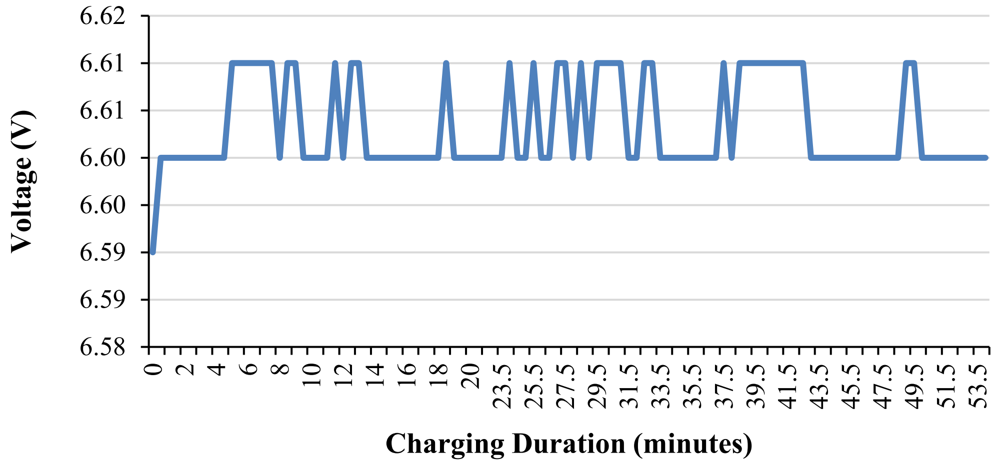

Figure 4.11: Distilled Water Refilled Battery 1 Voltage against Charging Duration.

Since white crystal solids can be observed in the lead-acid batteries as shown in Figure 4.12, it was deduced that the lead sulphate deposition may have caused the deacidification of the battery water. The existing sulphuric acid may have been lost to these lead sulphate deposition, and sulphuric acid concentration must be compensated to revitalise the batteries.

Figure 4.12: Crystal Solids Observed in the Interior of Battery 10.

Diluted sulphuric acid water was purchased for the filling of the lead-acid batteries. Battery 10 was selected for the experiment to be conducted. The voltage of the battery increased from 5.81 V to 6.13 V after adding distilled water and 20 ml of diluted sulphuric into each of the battery cells. Then, battery 10 was charged with a Teletron TC-1207A battery charger and a data logger software. The voltage while charging was logged at 60 seconds intervals and plotted as a charging curve in Figure 4.13.

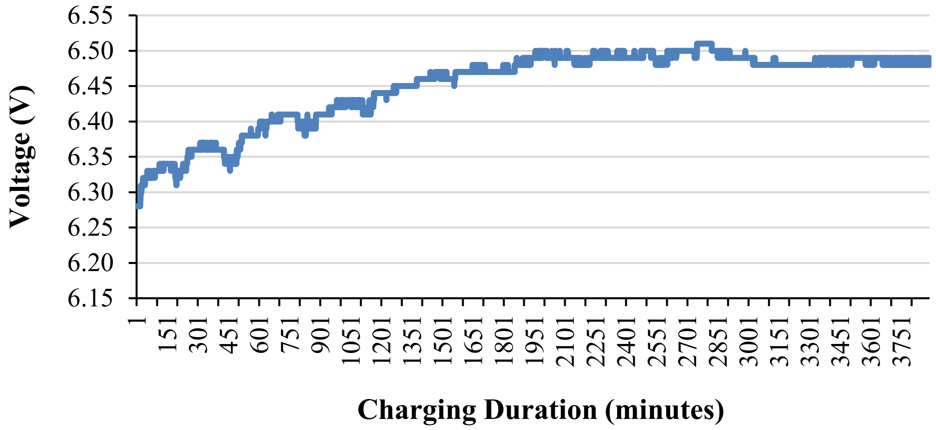

Figure 4.13: 20 ml Diluted Sulphuric Acid and Distilled Water Refilled Battery 10 Voltage against Charging Duration.

The experiment was conducted again but with 60 ml of diluted sulphuric added into each of the battery cells. Battery 11 was selected for the experiment to be conducted. The charging of the battery was conducted by having two discontinuous charging sessions, followed by a discharging and charging, and followed by another recording of the discharging a day after the charge. Battery 11 was connected in series with a 7 ohm power resistor and multimeter during discharging.

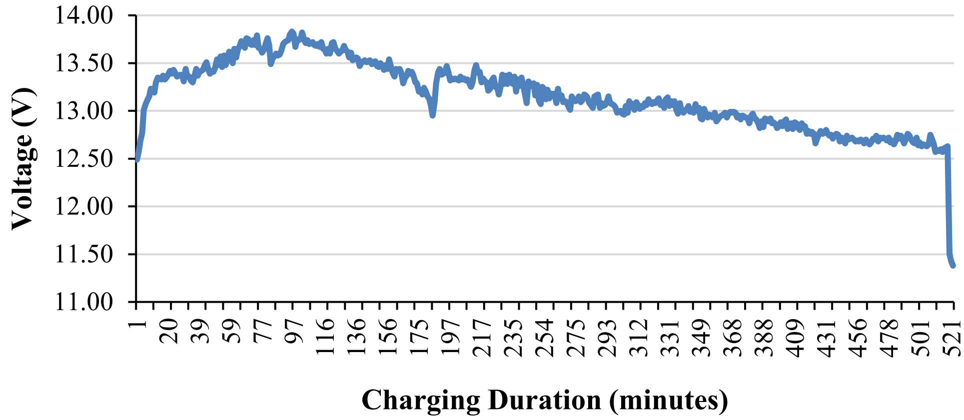

Figure 4.14: 60 ml Diluted Sulphuric Acid and Distilled Water Refilled Battery 11 Voltage against First Charging Duration.

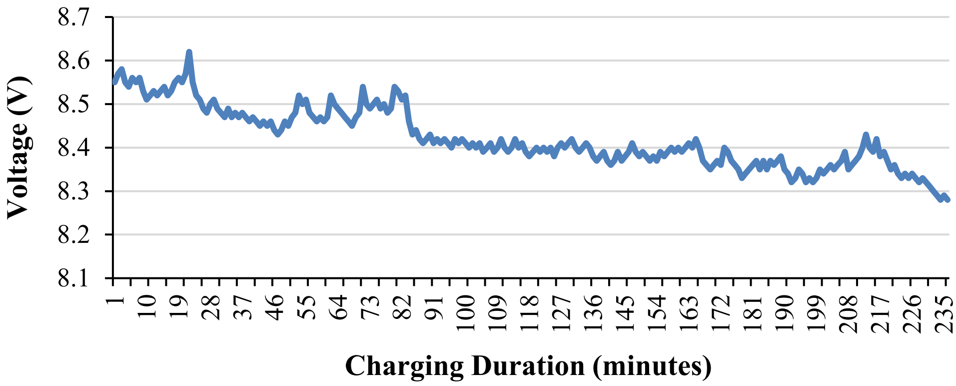

Figure 4.15: 60 ml Diluted Sulphuric Acid and Distilled Water Refilled Battery 11 Voltage against Second Charging Duration.

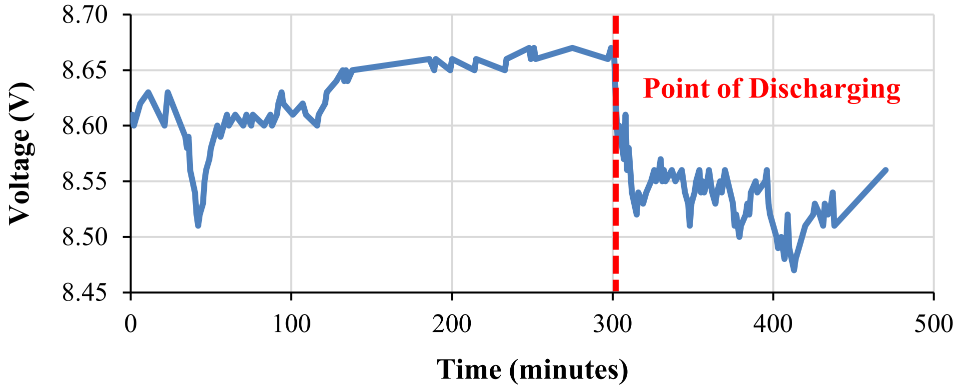

Figure 4.16: 60 ml Diluted Sulphuric Acid and Distilled Water Refilled Battery 11 Voltage against Charging and Discharging Time.

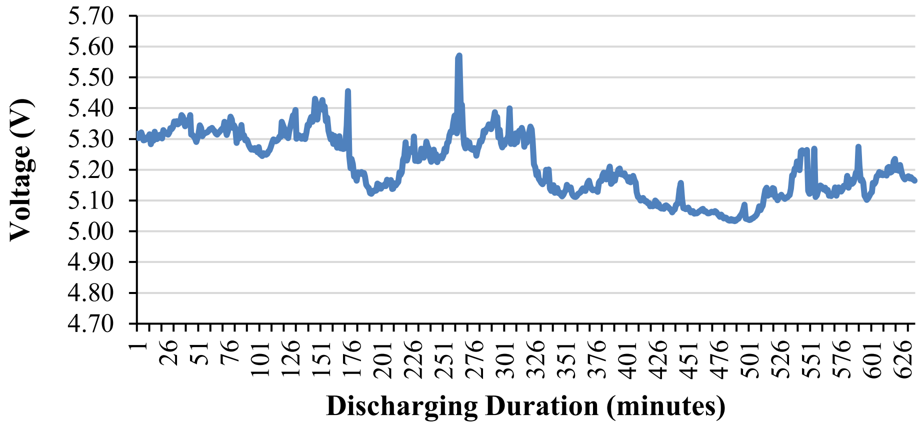

Figure 4.17: 60 ml Diluted Sulphuric Acid and Distilled Water Refilled Battery 11 Voltage against Discharging Duration.

On 18th March 2023, the initial voltage of Battery 11 was measured at 5.273 V, which spiked to 12.44 V during the first charge session. Figure 4.14 shows the voltage of Battery 11 during this charge session. On 25th March 2023, the initial voltage was lower at 8.55 V during the second charge session. There was a gap of one week so there has been some self-discharging within the battery. Figure 4.15 shows the voltage of Battery 11 during this charge session. However, the longer the charging in session two, the lower the voltage. On 26th March 2023, during the third charging session, the battery voltage remains unchanged at 8.61 V and discharged to 8.56 V when charging was stopped. Figure 4.16 shows the voltage of Battery 11 during this charge and discharging session. Battery was discharged again on the 10th April 2023 with the use of 7 ohm power resistor. Battery voltage dropped from 5.3 V to 5.18 V, as shown in Figure 4.17.

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4.4 Disassembly of Electric Power Components and Interior Parts

The disassembly of electric power components was conducted on the 28/3/2023. The removed power components were listed in Table 4.6. The removed power components were returned to the supervisor, Ts. Dr. Chew Kuew Wai from the Department of Electrical and Electronic Engineering.

Table 4.6: Electric Power Components Removed.

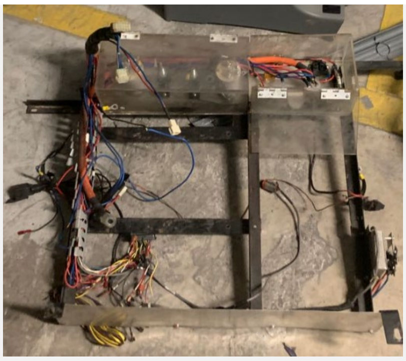
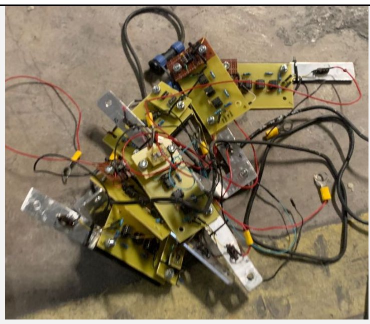
Model	Quantity	Picture
Motor Controller Curtis 1239-8501	1	
DC to DC Converter TDC-96-12EGC	1	
Battery Charger TCCH-120-15	1	
Voltage Regulator Circuit	1	

Table 4.6 (Continued)

Voltmeter	1	
Ammeter	1	
Battery Indicator	2	

Table 4.6 (Continued)

Power Balancing Components	12	

Besides removing the power components, the interior components were also removed as shown in the Figure 4.18. The interior components include the car seats and interior plastics.

Figure 4.18: Power Electronics and Interior Components Removed from Electric Vehicle.

Before the removal of the traction motor, a survey on the mounting points of the traction motor was conducted and at least three jackscrews were determined to be required for supporting the traction motor during disassembly. On the 25/4/2023, the traction motor AC51-26.26.2 was removed from the vehicle and passed to Ts. Dr. Chew Kuew Wai. The removed motor is shown in Figure 4.19. The engine bay before disassembly and after disassembly of electric vehicle components is shown in Figure 4.20 and Figure 4.21.

Figure 4.19: Traction Motor AC51-26.26.2 Removed.

Figure 4.20: Engine Bay before Disassembly of Electric Vehicle Components.

Figure 4.21: Engine Bay after Disassembly of Electric Vehicle Components.

4.4.1 Disassembly and Recycling of Lead-acid Battery Pack and Copper Cable, as well as Vehicle Disposal

The twelve 12 V Trojan T-1275 Deep Cycle Lead-acid Batteries have been removed from the electric vehicle. Including four 12 V Trojan T-1275 Deep Cycle Lead-acid Batteries in storage, a total of sixteen 12 V Trojan T-1275 Deep Cycle Lead-acid Batteries and three 12 V lead-acid auxiliary batteries were marked for recycling.

The quoted payment from Syarikat Perniagaan Hup Ek, a car battery shop, was RM95 per Trojan T-1275 battery, and RM40 for the three auxiliary batteries. A total of RM1560 was received for selling the batteries to the contractor, who will bring the batteries to a recycling centre for the extraction of lead from the batteries. Typically, lead is sold for 2.15 USD per Kg. Figure

4.22 shows the banner of the shop located in Klang. The receipt for the selling of batteries is shown in Figure 4.23.

Figure 4.22: Banner of Syarikat Perniagaan Hup Ek in Klang.

Figure 4.23: Transaction Receipt for RM 1,560 Earned from Selling the Batteries.

To transport the batteries, a Lalamove van was contracted to transport the batteries to the battery shop. The total cost of the van was RM 166.50. The Lalamove order page is shown in Figure 4.24. Figure 4.25 shows the batteries loaded into the cargo van.

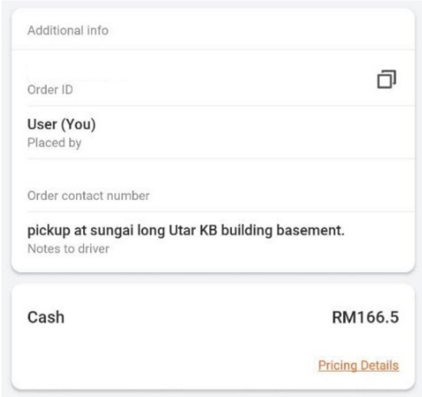


Figure 4.24: Lalamove Order Page Showing the Price for the Transportation of Batteries.

Figure 4.25: The Lead-acid Batteries Loaded into the Cargo Van.

Additionally, the power cables used in the connection of batteries of the battery pack were stripped for the copper. A total of 7 Kg of copper were extracted and sold for a total of RM196 for recycling. Figure 4.26 shows the power cables that were removed from the electric vehicle.

Figure 4.26: The Power Cables Removed from the Electric Vehicle.

Finally, the base Proton Wira was towed away to Thanam Industry Sdn. Bhd., a scrap metal dealer in Kuala Lumpur. An amount of RM500 was received as the value of the vehicle, and RM200 was paid for the towing service. Figure 4.27 shows the Proton Wira EV towed by the towing service.

Figure 4.27: The Base Vehicle Towed by the Towing Service.

4.5 Formation of EV Simulation Models

To benchmark the performance of Electric Vehicle Technologies, simulation on the MATLAB ADVISOR was conducted. The EV selected must be representative of significant Electric Vehicle developments in the industry. In addition, a few success parameters were identified to verify the accuracy of the Electric Vehicle simulation models.

4.5.1 Success Parameters of the Electric Vehicle Simulation Models

Success parameters of the electric vehicle simulation models are based on comparing the simulation results with the official figures provided by the electric vehicle manufacturer. The parameters include the acceleration time from zero to a hundred km/h, the maximum achievable speed of the vehicle, as well as the maximum range of the electric vehicle. Generally, a percentage error of within twenty percent is acceptable.

When it comes to verifying the range of the electric vehicle, the New European Driving Cycle was selected to benchmark the electric vehicle models.

4.5.2 Proton Wira EV Simulation

Detailed specifications of the Proton Wira Electric Vehicle can be found in Table 4.7. The model year 2000 Proton Wira 1.5GL (M) was equipped with an engine codenamed 4G15F-GR0160 before it was converted.

The Proton Wira EV was equipped with twelve Trojan T-1275 Deep Cycle lead-acid batteries, with a combined voltage of 144 V and capacity of 150 Ah. The combined weight of the batteries was 468 kg. Traction motor was provided by an AC-51 DC 144 V. Max power of the motor is 65.99 kW or 88.09 hp, while the peak torque of the motor is 146.4 Nm. The traction motor weight is 73 kg. As an electric vehicle, the Proton Wira electric vehicle was rather unique as the electric motor was paired to the original 5 speed manual gearbox with a custom coupler. Codenamed the Mitsubishi F5M41, the 5-speed manual transmission has a final drive ratio of 3.722, with a weight of 44.4521 kg (Anon., n.d.).

Table 4.7: Specifications of Proton Wira EV.

Specifications	Value
EV Model	UTAR Proton Wira EV
Body Type	Sedan
Traction Motor Type	3 Phase AC Induction
Traction Motor Peak Power	65 kW
Traction Motor Peak Torque	155 Nm
Gearbox Type	5 Speed Manual
Gearbox Final Driver Ratio	3.722
Battery Type	Deep Cycle Lead Acid Battery
Battery Voltage	144 V
Battery Capacity	21.6 kWh
Kerb Weight	1412.2 kg
Drag Coefficient	0.330
Front Area	1.98237 m^2

Figure 4.28 shows the vehicle speed, energy storage state of charge, torque output and motor power loss of the Proton Wira Electric Vehicle in one New European Driving Cycle. During the first 800 seconds of the cycle, the vehicle was simulated to undergo a couple of short drives and stops. From the motor torque output graph, there was a spike of up to 100 Nm when there was increase in vehicle speed. However, the high torque output quickly drops back down to a low amount of less than 50 Nm whenever the desired speed of the vehicle was achieved.

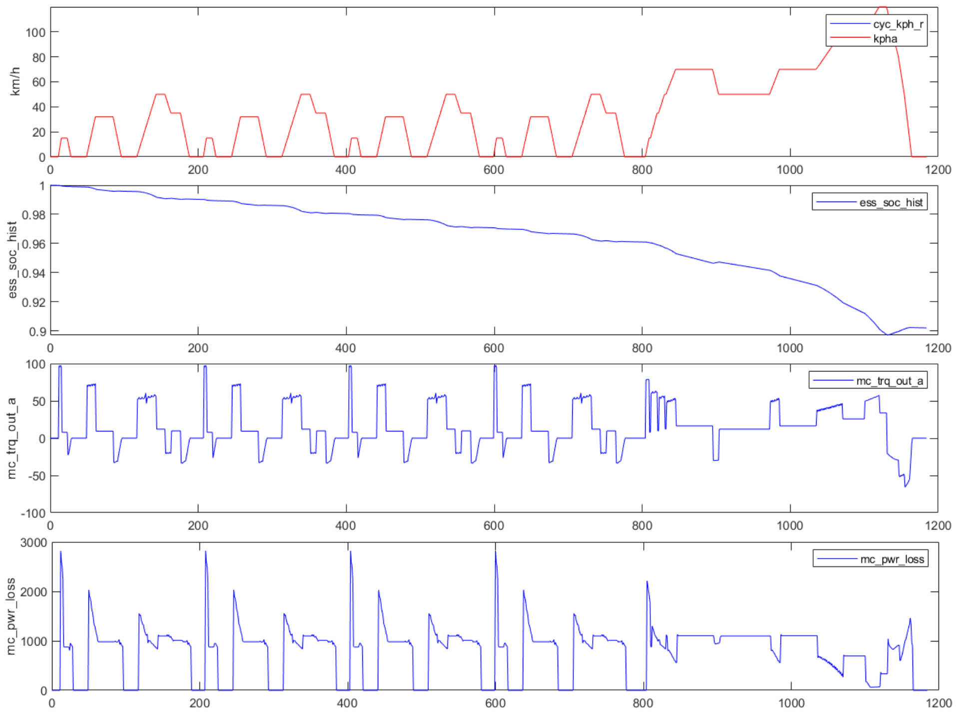


Figure 4.28: Graph of Vehicle Speed, State of Charge of Vehicle, Torque Output and Power Loss of Motor against Time (in one NEDC Cycle)

In fact, whenever there was a decrease in vehicle speed, there was a negative value in the torque output, indicating that the reduction of vehicle speed exerts energy back into the system. This energy recuperation is known as energy regeneration, evidently during the end of the driving cycle where the battery's state of charge increases as the vehicle experiences sharp deceleration to a stop.

The motor loss graph shows that the power loss is at the maximum when acceleration of the vehicle is at the maximum. In other words, the motor is highly inefficient when there was a sudden increase in vehicle speed. This result shows that aggressive throttle inputs can negatively impact on the efficiency of the electric vehicle.

Table 4.8: Comparison of Results of Wira EV Simulation.

	Data As Tested Originally	NEDC Simulation Result	Percentage Difference
Range (km)	120	106.7	11.08 %
0-100km/h Acceleration Time (s)	12	14.8	23.33 %
Top Speed (km/h)	150	169.9	13.27 %

The New European Driving Cycle was then repeated for 50 cycles to test the maximum range that the Proton Wira Electric Vehicle model can achieve. 0-100 km/h acceleration time and top speed at 0% gradient of the Proton Wira Electric Vehicle model was also obtained. The results were tabulated in Table 4.8. The model was able to achieve 106.7 km of maximum traveling range, an acceleration time of 12 seconds, and a top speed of 169.9 km/h. The respective percentage difference was 11.08%, 23.33%, and 13.27% respectively. The percentage differences were acceptable however the percentage difference for the acceleration time was at the high side.

The discrepancy of the acceleration time was likely attributed to the limitations of unable to specify the actual shift points of the 5-speed manual transmission that is equipped by the electric vehicle simulation model. The Proton Wira electric vehicle model was deemed to be completed.

4.5.3 Modern EV Simulation

A few modern electric vehicles were selected for the benchmarking of electric vehicle technology. The models were selected based on their technological representation, marking milestones in the electric vehicle development.

The selected electric vehicles were the 2015-2017 Volkswagen e-Golf, 2017 Volkswagen e-Golf, 2021 Mercedes-Benz EQA 250, 2020 Smart EQ Fortwo Coupe, 2023 Tesla Model Y Standard Range RWD and 2023 BYD Atto 3. With regards to the 2015-2017 Volkswagen e-Golf, it was selected due to its significance to the world's largest car manufacturer. It represents Volkswagen's entry to the electric vehicle market, part of Volkswagen's broader strategy to shift towards a more sustainable and eco-friendly mobility solution. The e-Golf was then further improved in 2017, featuring a larger lithium-ion battery and a more powerful traction motor. The larger lithium-ion battery provided a higher commute range for the e-Golf, addressing range anxiety, one of the key concerns for potential electric vehicle buyers.

The 2021 Mercedes-Benz EQA 250 was selected as it was equipped with an AC Induction Motor. The EQA 250 was also Mercedes-Benz's entry level electric vehicle SUV, a segment that is the fastest growing and most competitive in the automotive industry. This allowed Mercedes-Benz to capture a share of the market, increasing the commonality of electric vehicles. The 2020 Smart EQ Fortwo Coupe was chosen for its AC Separately Excited Synchronous motor. It is the lightest and smallest electric vehicle in the selection here. With a length of only 2695 mm and a width of 1663 mm, its compact size addresses the need for efficient and space-saving urban mobility solutions.

The 2023 Tesla Model Y Standard Range RWD was undoubtedly one of the most anticipated electric vehicles in the Malaysian market. At the world stage, the Tesla Model Y was the best-selling electric vehicle in 2022 and is the among the top five best-selling cars in the world. Additionally, the Tesla Model Y Standard Range RWD utilizes lithium iron phosphate (LFP) battery as its energy storage system, which is known the next big thing in electric vehicles. On the topic of lithium iron phosphate (LFP), the 2023 BYD Atto 3 is equipped with the revolutionary BYD Blade Battery that is based on similar chemistry. It is known for its exceptional safety, featuring a unique structural design that incorporates cells arranged in a blade-like shape, separated by fire-resistant materials. This makes the battery resistant to thermal runaway, thermal propagation, and fires, making it one of the safest lithium iron phosphate (LFP) battery designs. The range, acceleration, and top speed simulation results are shown in Table 4.10, Table 4.11, and Table 4.12 respectively. A summary of the specification parameters of the electric vehicles are shown in Table 4.9. Gearbox ratios that were unable to be found were assumed to be 10:1. Frontal area that was unable to be found were calculated by multiplying the vehicle's width with height and multiply by 0.85.

Table 4.9: Specifications of Modern EVs.

Brand	VW	VW	Smart	BYD	Tesla	Mercs-Benz
Model Name	e-Golf	e-Golf	EQ Fortwo	Atto 3	Model Y	EQA 250
Model Year	2015	2017	2020	2023	2023	2021
Body Type	Hatchback			SUV		
Traction Motor Type	AC Permanent Magnet Synchronous (PMS) Motor				AC PMS Reluctance Motor	AC Induction Motor
Traction Motor Peak Power	85 kW	100 kW	60 kW	150 kW	255 kW	140 kW
Traction Motor Peak Torque	270 Nm	290 Nm	160 Nm	310 Nm	420 Nm	375 Nm
Gearbox Type	Single speed					
Gearbox Final Drive Ratio	0.98	0.98	1.00	1.00	0.90	1.00
Battery Type	Lithium-ion			Lithium iron phosphate		Lithium-ion
Battery Voltage	323 V	323 V	400 V	403 V	345 V	420 V
Battery Capacity	24.2 kWh	35.8 kWh	17.6 kWh	62.0 kWh	62 kWh	66.5 kWh
Kerb Weight	1538 kg	1615 kg	1085 kg	1750 kg	1909 kg	2040 kg
Drag Coefficient	0.27	0.27	0.35	0.29	0.23	0.28
Frontal Area	2.22 m^2	2.22 m^2	2.00 m^2	2.57 m^2	2.65 m^2	2.47 m^2

(Source: evspecifications.com, ev-database.org, official manufacturer websites).

Table 4.10: Comparison of Range Results for Modern EVs.

EV Models	Official NEDC Range (km)	Simulated NEDC Range (km)	Percentage Difference
2015-2017 VW e-Golf	190	187.9	1.11 %
2017 VW e-Golf	300	265.6	11.47 %
2021 Mercedes-Benz EQA 250	486	481	1.03 %
2020 Smart EQ Fortwo	159	153.9	3.21 %
2023 Tesla Model Y	510	436.9	14.33 %
2023 BYD Atto 3	470	446	5.11 %

Table 4.11: Comparison of Acceleration Results for Modern EVs.

EV Models	Official 0-100 km/h Acceleration Time (s)	Simulated 0-100 km/h Acceleration Time (s)	Percentage Difference
2015-2017 VW e-Golf	10.4	9.9	4.81 %
2017 VW e-Golf	9.6	8.9	7.29 %
2021 Mercedes-Benz EQA 250	8.9	7.7	13.48 %
2020 Smart EQ Fortwo	11.5	11.3	1.74 %
2023 Tesla Model Y	6.9	7.2	4.35 %
2023 BYD Atto 3	7.3	7.7	5.48 %

Table 4.12: Comparison of Top Speed Results for Modern EVs.

EV Models	Official Top Speed (km/h)	Simulated Top Speed (km/h)	Percentage Difference
2015-2017 VW e-Golf	140	157.2	12.29 %
2017 VW e-Golf	150	157	4.67 %
2021 Mercedes-Benz EQA 250	160	155.3	2.94 %
2020 Smart EQ Fortwo	130	159.4	22.62 %
2023 Tesla Model Y	217	177.2	18.34 %
2023 BYD Atto 3	160	154.6	3.38 %

The average percentage error of all electric vehicle models in terms of their range, acceleration and top speed were calculated to be 6.04%, 6.19% and 10.7% respectively. The low percentage error shows that the simulation results are within the error margin, and that the electric vehicle models are acceptable for further benchmarking. However, some of the simulation results have a higher percentage difference. In the range simulation, the percentage difference for the 2017 Volkswagen e-Golf is 11.47% and 2023 Mercedes-Benz EQA 250 is 13.48%. In the top speed simulation, the percentage difference for the 2015 Volkswagen e-Golf is 12.29%, 2020 Smart EQ Fortwo is 22.62%, and 2023 Tesla Model Y is 18.34%.

The high range simulation difference of the 2023 Tesla Model Y can be attributed to lack of lithium iron phosphate model in the simulator. The lithium-ion model was used instead with the Tesla's battery capacity parameters inserted. Due to the difference in the discharge profiles, thermal properties, charging and discharging efficiency, the range, acceleration, and top speed was affected. Compared to lithium iron phosphate batteries, lithium-ion batteries exhibit more flat and stable discharge voltage profiles. It also has a higher charging and discharging efficiency, but a slightly worse thermal properties compared to lithium iron phosphate.

For other models, it is important to note that the discrepancies for the acceleration and top speed were likely due to the different control strategies employed by the electric vehicle manufacturers, which were not considered in the simulation. In fact, most electric vehicles have their top speed electronically limited for the purpose of preserving the battery and for safety reasons (Jones, 2023). Additionally, for the purpose of the simulation, the tyre rolling coefficients were standardised. Practically, the tire selection and tire pressure have an influence on both acceleration and range. Due to the lack of publicly available info regarding the gear ratio, the Smart EQ Fortwo, BYD Atto 3, and Mercedes-Benz EQA 250 were assumed to be 10:1. This decision may have impacted the accuracy of the results.

4.6 Benchmarking of EV Models

With the electric models verified, the following step was to benchmark the performance of the electric vehicles in different driving scenarios. The primary parameter to be gauged is the range of the electric vehicles. The tests to be conducted includes range testing under different loading conditions, range testing on wet surface, as well as a case study on the number of round trips to and from MRT Bukit Dukung and UTAR Sungai Long that can be completed by the electric vehicle models. In addition, the single gear ratio choice of electric vehicles has made it important to choose the right gear ratio that can balance efficiency, acceleration, and top speed. The effects of different gear ratios were investigated.

4.6.1 Range Testing under Different Loading Conditions

This test was carried out at four different loading conditions. The first being the vehicle at its kerb weight. The kerb weight can be understood as the weight of the vehicle with all liquids (such as coolant) at nominal tank capacity but without cargo and passengers. It is the closest to the actual weight of the vehicle. The test is then repeated with an additional 100 kg, the standard testing weight on the New European Testing Cycle. The additional weight represents the weight of a driver as well as the testing equipment. The experiment was then further repeated two times, adding another 100 kg each time. The payload of a

Tesla Model Y is 460 kg while the payload of a 2017 Volkswagen e-Golf is 405 kg. The results were tabulated in Table 4.13, Table 4.14, and Table 4.15.

Table 4.13: Range Comparison between Vehicle at Kerb Weight and Vehicle at Kerb Weight + 100 kg.

EV Model	Kerb Weight (kg)	Range at Kerb Weight (km)	Range at Kerb Weight + 100 kg (km)	Percentage Difference
Proton Wira EV	1512.2	111.4	107.9	3.14 %
2015 VW e-Golf	1538	193.1	187.9	2.69 %
2017 VW e-Golf	1615	274.3	265.6	3.17 %
2021 Mercedes EQA 250	2040	481.4	471.4	2.08 %
2020 Smart EQ Fortwo	1085	158	153.9	2.59 %
2023 Tesla Model Y	1909	448.1	436.9	2.50 %
2023 BYD Atto 3	1680	457.6	446	2.53 %

Table 4.14: Range Comparison between Vehicle at Kerb Weight + 100 kg and Vehicle at Kerb Weight + 200 kg.

EV Model	Kerb Weight (kg)	Range at Kerb Weight + 100 kg (km)	Range at Kerb Weight + 200 kg (km)	Percentage Difference
Proton Wira EV	1512.2	107.9	105	2.69 %
2015 VW e-Golf	1538	187.9	186.2	0.90 %
2017 VW e-Golf	1615	265.6	262.7	1.09 %

Table 4.14 (Continued)

2021 Mercedes EQA 250	2040	471.4	462.1	1.97 %
2020 Smart EQ Fortwo	1085	153.9	146.6	4.74 %
2023 Tesla Model Y	1909	436.9	426	2.49 %
2023 BYD Atto 3	1680	446	435.1	2.44 %

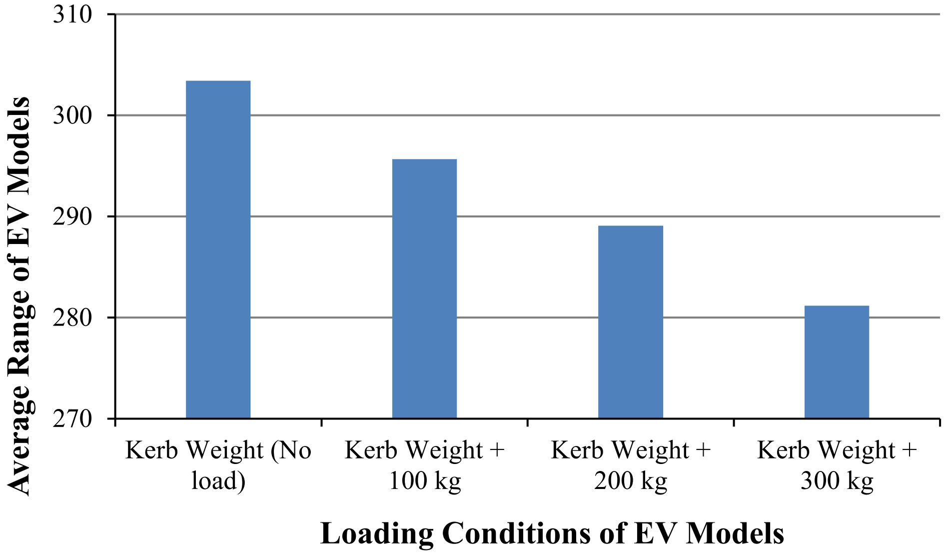


Figure 4.29: Graph of Average Range of EV Models against Loading Weight.

Table 4.15: Range Comparison between Vehicle at Kerb Weight + 200 kg and Vehicle at Kerb Weight + 300 kg.

EV Model	Kerb Weight (kg)	Range at Kerb Weight + 200 kg (km)	Range at Kerb Weight + 300 kg (km)	Percentage Difference
Proton Wira EV	1512.2	105	101.7	3.14 %
2015 VW e-Golf	1538	186.2	177.3	4.78 %
2017 VW e-Golf	1615	262.7	253.3	3.58 %

Table 4.15 (Continued)

2021 Mercedes EQA 250	2040	462.1	452.9	1.99 %
2020 Smart EQ Fortwo	1085	146.6	143.1	2.39 %
2023 Tesla Model Y	1909	426	415.2	2.54 %
2023 BYD Atto 3	1680	435.1	424.8	2.37 %

The average range of all electric vehicle models at each loading weight were calculated and reorganized into a graph in Figure 4.29. The range of electric vehicle models decreased 2.66% averagely with each additional 100 kg of load.

4.6.2 Range Testing on Wet Road Surface

A car must overcome rolling resistance to move, and rolling resistance is a result of the interaction between the road surface and tires. Macro texture and unevenness along the road are two of the characteristics of the road surface that are thought to be most significant contributors for rolling resistance. But the rolling resistance is also influenced by the presence of water on the road surface. Rain that is still falling on the road requires the wheels to be driven through, which results in a rise in resistance. Furthermore, water cools more quickly than air, which affects the tire behaviour as the viscoelastic characteristics of tires are dependent on temperature. Generally, at 30 km/h, rolling coefficient increases 20% at 0.6 mm water film thickness (Jerzy Ejsmont et al., 2015). The New European Driving Cycle test was repeated with the rolling coefficient of all vehicles increased 20% to observe the changes in their maximum range. The results were tabulated in Table 4.16.

Table 4.16: Range Comparison between Dry Road and Wet Road Simulation.

EV Models	Simulated Dry Road Range (km)	Simulated Wet Road Range (km)	Percentage Difference
Proton Wira EV	107.9	102.4	5.10 %
2015-2017 VW e-Golf	187.9	177.3	5.64 %
2017 VW e-Golf	265.6	252.8	4.82 %
2021 Mercedes-Benz EQA 250	471.4	454.6	3.56 %
2020 Smart EQ Fortwo	153.9	145.3	5.59 %
2023 Tesla Model Y	436.9	409.3	6.32 %
2023 BYD Atto 3	446	420.4	5.74 %

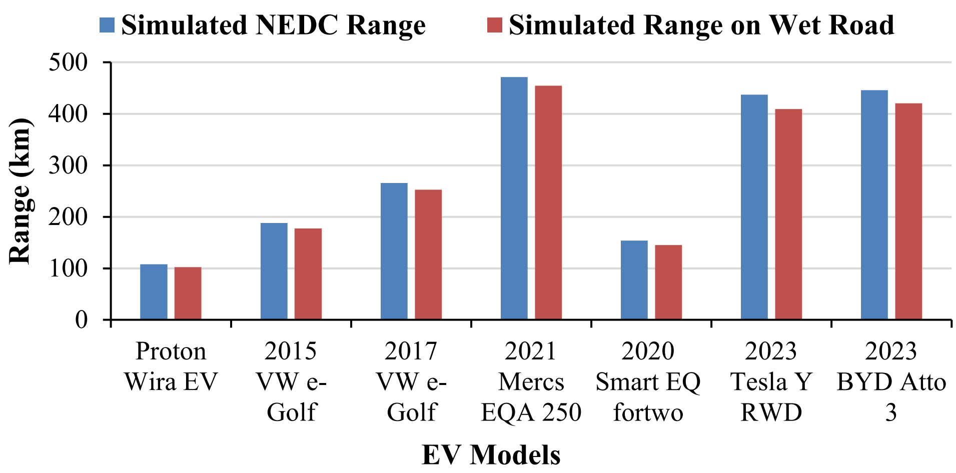


Figure 4.30: Graph of Range on Dry Road and Wet Road against EV Models.

For better visualization, the results were graphed in Figure 4.30. The average range loss when driving in the rain is 4.48%. The 2020 Smart EQ experienced the least difference in range, losing only 4.6 km in the process. However, the 2023 Tesla Model Y experienced the most difference in range, losing 26.6 km of range in the process. The factor to the big loss of range can be attributed to its larger vehicle mass. Equation 4.4 shows how the weight of a vehicle can increase the force of rolling resistance.

$$F = \mu_r mgcos(\theta) \tag{4.4}$$

where

F= force of rolling resistance

μ_r= coefficient of rolling resistance

$mgcos(\theta)$= normal weight of vehicle over axle

4.6.3 Round Trips from UTAR Sg Long to MRT Bukit Dukung Case Study

To investigate the efficiency of the electric vehicle models, a case study on the number of trips that can be completed by the electric vehicle models was conducted. The route selected was from Universiti Tunku Abdul Rahman Sungai Long Campus to MRT Bukit Dukung. A custom driving cycle consisting of a 1015 driving cycle, ECE driving cycle, and a Manhattan driving cycle was created through the MATLAB Advisor's trip builder. The 1015 driving cycle represents the morning drive commute to MRT Bukit Dukung. The ECE driving cycle and Manhattan driving cycle represents the peak hour commute from MRT Bukit Dukung back to Universiti Tunku Abdul Rahman Sungai Long Campus. The average speed and distance were compared to the values in Google Map and verified. Table 4.17 lists the details of the custom driving cycle representing the round trip.

Table 4.17: Details of The Custom Driving Cycle.

Parameters	Value
Time	1946 s
Distance	8.48 km
Max Speed	69.97 km/h
Average Speed	15.68 km/h
Maximum Acceleration	2.06 m/s^2
Maximum Deceleration	-2.5 m/s^2
Average Acceleration	0.56 m/s^2
Average Deceleration	-0.67 m/s^2
Idle Time	673 s
No. of stops	30

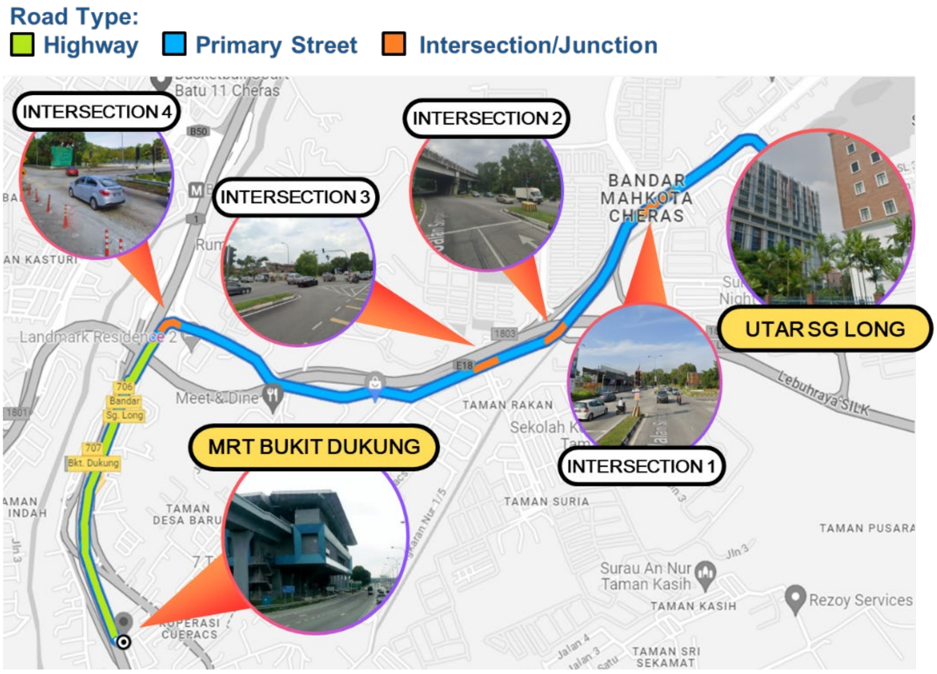


Figure 4.31: Map of the Route Between MRT Bukit Dukung and UTAR Sungai Long with Location of Junctions.

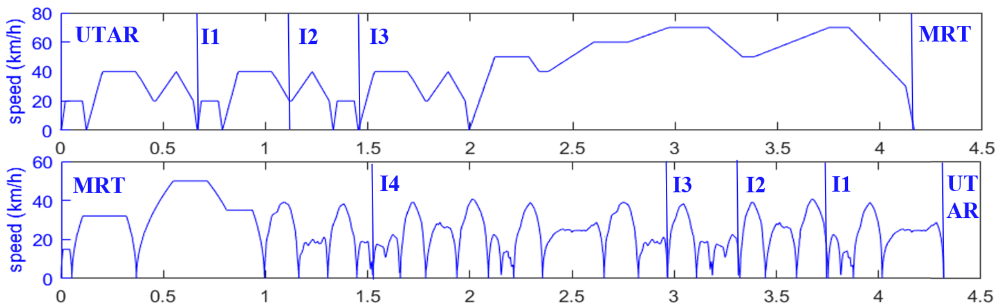


Figure 4.32: The Speed Profile of the Trip to MRT Bukit Dukung (Top) and The Speed Profile of the Trip to UTAR Sg Long (Bottom).

Figure 4.31 shows the map of the route between MRT Bukit Dukung and UTAR Sungai Long with the location of junctions. There are 4 intersections to pass in the selected route. Intersections 1 to 3 are situated on the primary street located between UTAR Sg Long and the highway. Intersection 4 serves as an exit from the highway into the primary street to UTAR Sg Long and will only be passed when heading back to UTAR Sg Long. Figure 4.32 shows the speed profile against distance of the trip to MRT Bukit Dukung as well as the speed profile against distance of the trip to UTAR Sg Long.

Table 4.18: Range Simulation Result of the Custom Driving Cycle.

Simulated EVs (km)	NEDC Range (km)	Commute Range (km)	Percentage Difference	No. of Round Trips
Proton Wira EV	106.7	83.2	22.02 %	9.81
2015-2017 VW e-Golf	187.9	156.8	16.55 %	18.49
2017 VW e-Golf	265.6	221.5	16.60 %	26.12
2021 Mercs-Benz EQA 250	481	364.2	24.29 %	42.95
2020 Smart EQ Fortwo	153.9	122.6	20.34 %	14.46
2023 Tesla Model Y	436.9	323.7	25.91 %	38.17
BYD Atto 3	446	355.8	20.22 %	41.96

The result of the case study simulation was tabulated in Table 4.18. An average of 20.58% reduction of range was calculate when compared with the simulated NEDC cycle range. This drop in range was due to the higher number of stops and idle time in the custom driving cycle, leading to more wasted energy in the process. The 2021 Mercedes-Benz EQA 250 simulation model performed the best in this experiment, where it was able to complete up to 42 round trips before needing to charge. The Proton Wira electric vehicle on the other hand could complete up to 9 round trips before needing to charge. This shows that the technology of electric vehicles has been evolving rapidly, with better performances and longer ranges to cope with the range anxiety.

4.6.4 Gear Ratio's Influence on Vehicle Efficiency

Table 4.8 showed that the Proton Wira EV was able to achieve a top speed of 169.9 km/h, higher than other modern electric vehicles' top speed shown in Table 4.12, even though it was equipped with the lowest rated traction motor of 65 kW and 155 Nm of torque. This was likely due to its final drive gear ratio of

3.722. This means that for every 3.722 revolutions of the engine, the wheels make one revolution.

Due to the broader torque curve and higher operating speeds of electric motors compared to internal combustion engines, modern electric car manufacturers have opted for a single gear reduction powertrain. The selection of the single gear reduction powertrain brings benefits of simplicity, smooth operation, lower cost, weight savings, reliability, and low noise and vibration. However, electric vehicles with this powertrain tend to have lower efficiency when driven at high speeds. To demonstrate this, simulation was conducted with the 2015 Volkswagen e-Golf model with gear ratios of 0.6, 0.8, 0.98, 1.2 and 1.4, at a constant speed of 72.42 km/h and at a constant speed of 96.56 km/h. The range and efficiency result were tabulated in Table 4.19.

Table 4.19: Range and Efficiency Simulation Result of Different Gear Ratios.

Gear Ratio	**Range (constant 72.42 km/h)**	**Efficiency (constant 72.42 km/h)**	**Range (constant 96.56 km/h)**	**Efficiency (constant 96.56 km/h)**
0.60	251.5 km	1.3 L/100 km	206.7 km	1.7 L/100 km
0.80	244.8 km	1.4 L/100 km	205.1 km	1.7 L/100 km
0.98	241.7 km	1.4 L/100 km	190.3 km	1.8 L/100 km
1.20	223.3 km	1.5 L/100 km	175.5 km	2.0 L/100 km
1.40	203.4 km	1.7 L/100 km	163.4 km	2.1 L/100 km

The 2015 Volkswagen e-Golf was equipped with a 0.98 gear ratio originally. At a constant speed of 72.42 km/h, it was able to achieve a gasoline equivalent efficiency of 1.4 L/100 km, and can achieve a maximum range of 241.7 km. On the other hand, at a constant speed of 96.56 km/h, the e-Golf model was able to achieve a gasoline equivalent efficiency of 1.8 L/100 km, and can achieve a maximum range of 190.3 km. To put into perspective, with a fixed gear ratio of 0.98, an increase of 33.33% of vehicle speed from 72.42 km/h results in a 21.27% loss of range and 28.57% loss of efficiency. At 96.56 km/h, the best performing model was equipped with a gear ratio of 0.6, achieving a range of 206.7 km and efficiency of 1.7 L/100 km. While the 0.6 gear ratio can achieve the best range of 251.5 km at the lower speed of 72.42 km/h, it is important to investigate the trade-offs and improvements of acceleration and top speed if a sole 0.6 gear ratio was selected. The acceleration and top speed simulation of the different gear ratios was tabulated in Table 4.20.

Table 4.20: Acceleration and Top Speed Simulation Result of Different Gear Ratios.

Gear Ratio	0 – 100 km/h Acceleration Time (s)	Maximum Speed (km/h)
0.60	11.2	206.8
0.80	10.2	197.0
0.98	9.9	160.4
1.20	9.9	130.6
1.40	10.0	111.6

From Table 4.20, the model with a gear ratio of 0.6 suffers a reduction in acceleration time by 13.13% when compared with the performance of the original gear ratio of 0.98. However, the gear ratio of 0.6 was able to provide the model with a higher top speed of 206.8 km/h, an improvement of 28.93% over the original model. Hypothetically, a pairing of a two-speed powertrain of first gear ratio of 0.98, and final gear ratio of 0.60 would result in 8.62% range and 5.56% efficiency improvements when driving at higher speeds, while achieving a higher maximum top speed. These improvements can be achieved with minimal losses to the acceleration capability of the model as the original, higher gear ratio was retained for lower speeds. Various research on multispeed transmission for electric vehicles have been conducted by Zhang et al. (2013), Ruan et al. (2018), and Roozegar and Angeles (2017). They have found that multispeed transmission is able to improve the energy consumption of electric vehicles.

4.7 Summary

In summary, all objectives have been completed. With regards to measuring the performance of the EV conversion project, the lead-acid batteries were deemed to be way degraded for revival. The deposition of lead sulphate within the lead-acid batteries was likely the hindering factor to the chemical reactions required in a lead acid battery. Not only the formation of lead sulphate crystals reduced the sulphuric acid concentration, but it has also formed a layer of insulation at the surface of the battery plates, thus reducing the chemical reactions.

Next, with regards to the disassembly and disposal of the electric vehicle conversion project, the electrical components were successfully removed and passed to the supervisor. The lead-acid batteries and copper wires were successfully sold for recycling. The remainder of the vehicle was successfully sold as scrap.

Finally, the Proton Wira EV and 6 popular modern EVs, 2015 Volkswagen e-Golf, 2017 Volkswagen e-Golf, 2021 Mercedes-Benz EQA 250, 2020 Smart EQ Fortwo, 2023 Tesla Model Y RWD, and 2023 BYD Atto 3 has been successfully modelled with 91.18% accuracy. Many factors influence the actual range of the electric vehicles when compared to the standard testing cycle, such as traffic conditions, loading weight, and road surface conditions. An average 4.48% of range loss was recorded when the rolling coefficient constant was increased due to rainwater. Aggressive throttle inputs can also lead to high power loss in the motor. Electric vehicle technology has been improving year on year, and while lithium-ion has higher energy density than lithium phosphate, as demonstrated by the higher performing 2021 Mercedes-Benz EQA 250, lithium phosphate that is equipped on the 2023 Tesla Model Y and 2023 BYD Atto 3 is safer and environment friendly. Lastly, a gear ratio of 0.6 could achieve 5.56% efficiency, 8.62% range and 28.93% top speed improvements of the 2015 Volkswagen e-Golf model. Minimal losses to the acceleration time can be achieved by retaining the original gear ratio of 0.98 in a 2-speed gearbox setup.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research aimed to explore the current vehicle disposal process and benchmark the electric vehicle technology. To achieve this, hands on work was conducted to dismantle the Proton Wira Electric Vehicle, as well as simulation of electric vehicles through MATLAB software. In terms of the sustainability aspects of the dismantling and recycling aspects, a high degree of sustainability can be achieved if proper disposal and recycling steps were conducted. The power components can be repurposed to be used in other applications or recycled to obtain their rare earth materials. The lead-acid batteries were recycled for their lead and could be further repurposed again for alternative applications.

Simulation was conducted using MATLAB Advanced Vehicle Simulator with a total of seven electric vehicle model successfully modelled with 91.18% accuracy in terms of the range, acceleration, and top speed. Simulation has found that an average of 2.66% of range was loss with every 100 kg increase in loading. Hence, the same can be said for range improvements through weight reduction. Development of electric vehicles can focus on weight reduction with new technology such as in-wheel traction motor that is compact and low weight. The actual range of the electric vehicles could be influenced by many factors, such as traffic conditions, loading weight, and road surface conditions. Wet surfaces could reduce range by 4.48%, so choosing the right tyre threads can help with mileage. The energy density of lithium-ion is higher than that of lithium phosphate, as shown by the more efficient Mercedes-Benz EQA 250, but lithium iron phosphate is also safer and more environmentally friendly. Electric car technology has been advancing year after year. With zero emissions and a higher energy efficiency than comparable combustion cars, electric vehicles offer smart and efficient transportation. Lastly, a multiple speed gearbox could increase the efficiency of electric vehicles by 5.56% at higher speeds.

5.2 Recommendations for future work

This research can be improved in many ways due to the diminished relevance of the Proton Wira Electric Vehicle's lead acid battery to the current market. Another real-life electric vehicle project can be carried out with a focus on modularity which allows for different electric vehicle technologies to be easily swapped. Sensors and instrumentation can be installed on this electric vehicle project to collect real life benchmarking data to compare with simulation data.

Another aspect that the research can be improved on is the MATLAB Advanced Vehicle Simulator's limitation. The MATLAB Advanced Vehicle Simulator do not have the latest lithium iron phosphate models, and hence even when similar specifications of battery capacity and voltage was set, a higher degree of percentage error was recorded in the simulation for Lithium Iron Phosphate vehicles. The thermal characteristics of the battery was based on the lithium-ion model. However, the flexibility of the MATLAB environment makes it possible to create and link a correct lithium iron phosphate battery model for further simulations.

The results of the range of the electric models are based on the New European Driving Cycle, which has been replaced by the Worldwide Harmonized Light Vehicles Test Procedure. It has a longer testing time, requiring the tested vehicles to run for 30 minutes, compared to the New European Driving Cycle test time of 20 minutes. It uses a profile that is more reflective to actual day-to-day usage, and hence may return with more accurate results of the vehicle range. The simulation can be repeated using the new cycle for new electric vehicle models moving forward. Additionally, the ambient temperature can be set to 25.7 °C, the average Malaysian temperature, instead of 20 °C, to better reflect the driving conditions in Malaysia.

Additionally, electric vehicle technology is advancing year by year. New technologies such as solid-state batteries and sodium ion batteries are being introduced to the market. It is of great interest to produce the models of these new technologies and simulate them in the MATLAB Advanced Vehicle Simulator environment to compare the efficiency and effectiveness with current technologies. Lastly, further optimization of multiple speed gearboxes can improve the efficiency of electric vehicles, especially at higher speeds.

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