MONITORING OF HIGH-VOLTAGE BATTERY OPERATIONS USING OBD DIAGNOSTICS DEVICE IN HYBRID VEHICLE

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (AUTOMOTIVE) WITH HONOURS

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DEDICATION

To my parents, Norhayati Binti Hassan and Khairunsam Bin Kamis, thank you for unwavering support and endless encouragement have been the foundation of all my endeavours. Your love, sacrifices, and belief in my potential have guided me through every challenge in my life. My loves for both of you cannot be described by everything stands in this world, even though I could not say it properly. I love you, ibu and ayah. Thank you.

ABSTRACT

Hybrid Electric Vehicles (HEVs) rely in high-voltage batteries to optimize performance and sustainability. Effective monitoring of these batteries is crucial for maintaining safety, efficiency, and longevity. The On-Board Diagnostic II (OBD-II) system offers real-time data for analysing vehicle components, including high-voltage batteries. Despite advancements in OBD-II technology, its application in comprehensive monitoring of high-voltage batteries remains unexploited. This limitation leads to inadequate battery health insights, premature failures, and inefficient maintenance strategies. This study employs an OBD-II device integrated with the Hybrid Assistant application to monitor the high-voltage battery of a Toyota Prius 3. Key parameters such as temperature, state of charge (SOC), and charge/discharge current limits were assessed under different modes and conditions, including ECO and SPORT modes. Findings reveal that battery performance and thermal stability vary significantly between driving modes. ECO mode prioritizes energy efficiency, while SPORT mode emphasized performance, with distinct impacts on SOC and temperature parameters. These observations underscore the critical role of adaptive monitoring in optimizing battery health. The integration of OBD-II devices with data analysis tools enables real-time insights into high-voltage battery behaviour, enhancing operational efficiency and lifespan. Future improvements in diagnostic systems could further refine battery management for HEVs, promoting cost-effective and reliable performance.

ABSTRAK

Kenderaan Elektrik Hibrid (Hybrid Electric Vehicles, HEVs) bergantung pada bateri voltan tinggi untuk mengoptimumkan prestasi dan kelestarian. Pemantauan yang berkesan terhadap bateri ini adalah penting untuk memastikan keselamatan, kecekapan, dan ketahanan. Sistem Diagnostik Dalam Kenderaan II (On-Board Diagnostic II, OBD-II) menyediakan data masa nyata untuk menganalisis komponen kenderaan, termasuk bateri voltan tinggi. Walaupun terdapat kemajuan dalam teknologi OBD-II, aplikasinya dalam pemantauan komprehensif bateri voltan tinggi masih belum dimanfaatkan sepenuhnya. Kekurangan ini menyebabkan kekurangan maklumat tentang kesihatan bateri, kegagalan awal, dan strategi penyelenggaraan yang tidak cekap. Kajian ini menggunakan peranti OBD-II yang diintegrasikan dengan aplikasi Hybrid Assistant untuk memantau bateri voltan tinggi Toyota Prius 3. Parameter utama seperti suhu, tahap cas (State of Charge, SOC), dan had cas/nyahcas dinilai di bawah mod dan keadaan yang berbeza, termasuk mod ECO dan SPORT. Penemuan menunjukkan bahawa prestasi bateri dan kestabilan haba berbeza dengan ketara antara mod pemanduan. Mod ECO mengutamakan kecekapan tenaga, manakala mod SPORT menekankan prestasi, dengan kesan yang berbeza terhadap parameter SOC dan suhu. Pemerhatian ini menekankan peranan penting pemantauan adaptif dalam mengoptimumkan kesihatan bateri. Integrasi peranti OBD-II dengan alat analisis data membolehkan pandangan masa nyata terhadap tingkah laku bateri voltan tinggi, sekaligus meningkatkan kecekapan operasi dan jangka hayat. Penambahbaikan lanjut dalam sistem diagnostik pada masa depan dapat memperhalusi lagi pengurusan bateri untuk HEV, menyokong prestasi yang cekap kos dan boleh dipercayai.

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In the name of Allah, the Most Gracious, the Most Merciful, I am deeply grateful for the strength and guidance bestowed upon me throughout this journey.

First and foremost, I would like to express my heartfelt gratitude to myself for the perseverance, dedication, and hard work that enabled me to complete this project. This journey has been a test of patience and resilience, and I am proud of the progress I have made.

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To my friends and peers, thank you for your support, motivation, and for making this journey more memorable and fulfilling. Your encouragement has been a source of great strength.

Lastly, I would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for providing me with the platform and resources to undertake this project. I am truly grateful for the opportunity to grow and learn during my time here.

I reflect on the wisdom of the Qur'an, which has always been my guiding light.

Surah Al-Ikhlas (112):
"Say, He is Allah, [who is] One,
Allah, the Eternal Refuge.
He neither begets nor is born,
Nor is there to Him any equivalent."

Surah Al-Asr (103):
"By time,
Indeed, mankind is in loss,
Except for those who have believed and done righteous deeds
and advised each other to truth
and advised each other to be patient."

Alhamdulillah, this milestone was achieved not only through my efforts but also the support and prayers of many. May Allah bless all of you abundantly.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	-	Percentage
A	-	Ampere
Ah	-	Ampere-hour
AI	-	Artificial Intelligence
BEV	-	Battery Electric Vehicle
BMS	-	Battery Management System
CAN	-	Controller Area Network
CD	-	Charge Depletion
CS	-	Charge Sustaining
CVT	-	Continuously Variable Transmission
ECU	-	Electronic Control Unit
EM	-	Electric Motor
EPA	-	Environmental Protection Agency
HEV	-	Hybrid Electric Vehicle
ICE	-	Internal Combustion Engine
km	-	Kilometre
KM/H	-	Kilometre per Hour
Kw	-	Kilowatt
kWh	-	Kilowatt-hour
LIB	-	Lithium-Ion Battery
ML	-	Machine Learning
MPC	-	Model Predictive Control
NiMH	-	Nickel-Metal Hydride
OBD-II	-	On-Board Diagnostics II
PHEV	-	Plug-in Hybrid Electric Vehicle
PIDs	-	Parameter IDs
PNG	-	Portable Network Graphic
PSD	-	Power Split Device
RUL	-	Remaining Useful Life
SAE	-	Society of Automotive Engineers
SOC	-	State of Charge
SOH	-	State of Health
V	-	Volts

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CHAPTER 1

INTRODUCTION

1.1 Background Study

A hybrid electric vehicle (HEVs) is one that uses both an internal-combustion engine and an electric motor for drive. HEVs have small high-voltage batteries to ignite their electric motors, but with no external source. With no external power source, electricity for the motor is receive from braking in a process called regenerative braking. The regen system does not replace the traditional brakes but instead works as an important alternative source. Electrical energy collected through this process is saved in the battery for immediate reuse in the next orientation (*What Is a Hybrid Car and How Do They Work?*, n.d.).

On-Board Diagnostic II (OBD-II) is the second generation of self-diagnostic equipment requirements for light- and medium-duty vehicles. On-board diagnostic capabilities have been built into the hardware and software of a vehicle's on-board computer, allowing it to monitor nearly every component that might affect vehicle performance. Diagnostic procedures are used to ensure that all parts function correctly. If a flaw is identified, the OBD II system lights a warning light on the vehicle's instrument panel, which regularly says, "Check Engine" or "Service Engine Soon," and is frequently accompanied by an engine symbol. Furthermore, the system saves vital details regarding the problem, allowing repair professionals to accurately identify and solve the issue (*On-Board Diagnostic II (OBD II) Systems Fact Sheet | California Air Resources Board*, n.d.).

The OBD-II port allows telematics devices to quietly analyse data such as engine cycles, vehicle speed, trouble codes, fuel consumption, and more. The telematics device may then make use of this data to figure out trip start and finish times, over accelerating, speeding, excessive idling, fuel consumption, and other parameters. All this information is sent to a software interface, which allows fleet managers to monitor vehicle usage and performance. With numerous OBD regulations, not all telematics systems are meant to function with all the car types that exist today. Geotab telematics tackles this difficulty by understanding car diagnostic codes from various manufacturers and types, including electric vehicles (*What Is OBDII? History of On-Board Diagnostics (OBD) | Geotab*, n.d.).

The electric motor in hybrid electric vehicles (HEVs) is powered by electricity obtained from battery packs. The battery pack is made up of numerous small, low-voltage batteries known as cells, which are stacked on top of one another to form a bigger high-voltage (HV) stick. The sticks are then linked to form a single high-voltage battery module. Most hybrids employ a nickel-metal hydride (NiMH) battery pack capable of both giving and receiving electricity; when recharging, it supplies power to the electric motor while also receiving power from the generator. Two most prolific hybrid manufacturers on the market, Toyota and Honda, each have battery packs with around 100 to 200 volts. In the case of the 2010 Toyota Prius, however, the voltage sent to the electric motor can be boosted up to 600 volts through a voltage converter. Since the battery packs used by most hybrids produce around 100 to 300 volts of electricity, they are considered "high voltage" and must be labelled as such on the parts of the vehicle through which this voltage flows (*How Much Voltage Does a Hybrid Car Produce? | HowStuffWorks*, n.d.).

1.2 Problem Statement

The application of high-voltage batteries in Hybrid Electric Vehicles (HEVs) creates potential and difficulties in terms of efficiency, performance, and lifetime. These batteries are essential for the smooth operation of HEVs, but their health and operating state have significant consequences on total vehicle performance, safety, and environmental advantages. Monitoring the life and condition of these high-voltage batteries is crucial for ensuring optimal performance and eliminating possible problems.

Currently, there is an inadequate number of extensive, real-time monitoring systems capable of properly tracking and analysing the operating characteristics of high-voltage batteries in HEV. While On-Board Diagnostic II (OBD II) devices provide a common platform for vehicle diagnostics, its ability to monitor high-voltage battery life has yet to be considerably investigated or used. This gap leads to insufficient understanding of battery performance, premature battery failures, and inappropriate maintenance plans, all of which have an impact on HEV reliability and cost-effectiveness.

The complicated structure of high-voltage battery systems, along with the need for precise and reliable data to make informed maintenance and operational decisions, worsens the problem. Without sufficient monitoring and diagnostic tools, car owners and technicians have considerable challenges in keeping the health of high-voltage batteries, resulting in increased downtime, higher maintenance costs, and a shorter vehicle life.

1.3 Research Objective

The objectives of this project are:

a) To test the High-Voltage Battery using vehicle various mode and driving speed.

b) To monitoring and analyse the temperature, state-of-charge, and current limits of High-Voltage Battery.

1.4 Scope of Research

The following are the scope of projects:

a. Toyota Prius 3 will be used.

b. An OBD-II's wireless adapter will be use.

c. "Hybrid Assistant" application will be installed.

d. Life monitoring using Toyota Prius will be conducted.

e. Monitoring the high-voltage battery parameters.

1.5 Summary

The research on the life monitoring of high-voltage battery operations using an OBD-II device in a hybrid electric vehicle features five chapters, each discussing an individual sort of problem. Each topic will have separate names, such as Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion. Below is a full description of each chapter's thesis outline:

Chapter 1: Introduction. This section of the report presents a basic overview of project categories. This section will explain the project's desired outcomes. The project requirements will also be provided in this section of the report.

Chapter 2: Literature Review. This section will go over the preparation for high-voltage battery monitoring in detail. This chapter will offer an expanded explanation of the project title, supported by previous studies. This section will expand on the theoretical and conceptual concepts of battery management systems.

Chapter 3: Methodology. In this section several methods will be proposed to run the life monitoring. Preliminary results are also mentioned in this section.

Chapter 4: Result and Discussion. This chapter will be discussed about the parameters obtained through the life monitoring session. The result will be analysed and compared.

Chapter 5: Conclusion. This chapter will focus on achievements, practicalities, and future suggestions for improvement. At last, the project's conclusion will be presented in this part.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, the evolution of hybrid and electric vehicles keep increasing day by day (*Electric and Hybrid Vehicles*, n.d.). It is important to ensure the best performance and endurance of the high-voltage batteries in both hybrid and electric vehicles. These batteries functioning as the heart of the hybrid vehicles, must provide enough energy to keep the vehicles' system active. However, these batteries tend to lose their power source and health, lead to effect on the vehicle's safety and efficiency (Arun et al., 2022).

The aim of this chapter is to study earlier research related to life monitoring of high-voltage battery operations using On-Board Diagnostics II (OBD-II) devices. By examining the past five years case study, aiming to discover point of view and methodologies, which can help the development of effective battery management strategies.

2.2 Hybrid Electric Vehicles (HEVs)

Hybrid electric vehicles combine the power of internal combustion engines with the zero-emission characteristics of electric cars. HEVs have better fuel economy compared to conventional vehicles, and they always operate in charge-sustaining mode, which keeps the SOC of the battery constant during a trip. Plug-in HEVs were developed to overcome the CS mode problem that relies mostly on regenerative braking and petrol for effective charging. Unlike HEVs, PHEVs can be charged from the outside by power outlets (K. V. Singh et al., 2019).

In PHEV, the electric motor is the main power source, and backup is given by the ICE. If the SOC of the battery exceeds the threshold value, then the PHEV behaves like a conventional HEV and the main source of power is the ICE. PHEVs work in charge depletion mode, where the SOC drops down to a threshold level. PHEVs offer improved electric range, improved air quality, and grid connection (K. V. Singh et al., 2019).

2.2.1 Parallel HEVs

In parallel HEVs, the ICE and the MG are both mechanically coupled to the output shaft in such a way that they can simultaneously provide power to the vehicle. The available MG is utilized to adjust the operating points of the engine towards a higher efficiency region. It acts like a generator when the power demand is low and as a motor when the power consumption is high. This enables the engine to be more efficient than in conventional vehicles. Parallel hybrids also require a transmission capable of supporting high engine speed coupled with low vehicle speed (Zhuang et al., 2020).

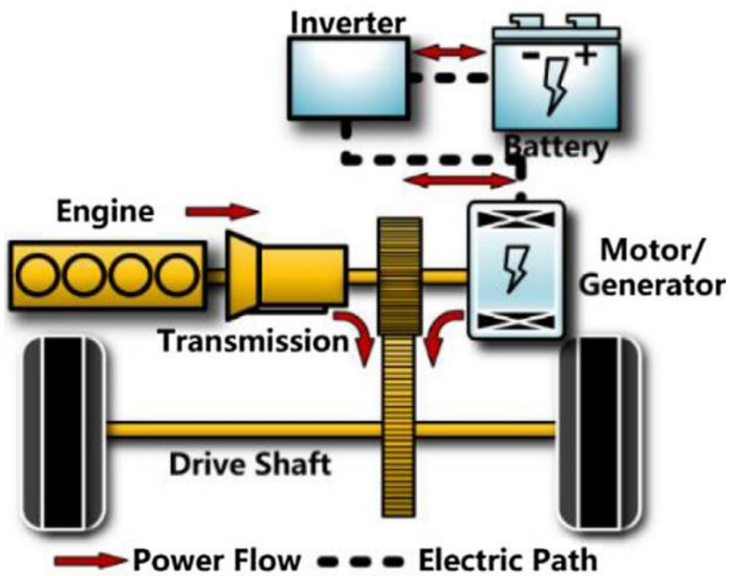

Figure 2.1 Configuration of Parallel HEV (Zhuang et al., 2020).

Parallel HEVs are effective in city congestion. However, this configuration may not be the most efficient due to the mechanical connection between the ICE and output shaft. Furthermore, because the MG cannot charge the battery while also running the combustion engine, the power aid and EV duties must be carefully regulated to minimise battery depletion. During city driving, constant start-stops may drain battery energy, forcing the engine to pump out power in low efficiency areas. Because of these disadvantages, parallel HEVs have a lower market share percentage, even if range of variants are now available (Zhuang et al., 2020).

2.2.2 Series HEVs

Series HEVs generally use motors for propulsion to power the vehicle, whereas ICEs require a generator. The motors are powered by the battery and generator and may be put on both the front and rear axles to provide electric all-wheel drive (Figure x). Because there is no mechanical link between the ICE and the vehicle's drive axle, the ICE can function in its most efficient mode independent of the vehicle speed or power demanded by the driver (Zhuang et al., 2020).

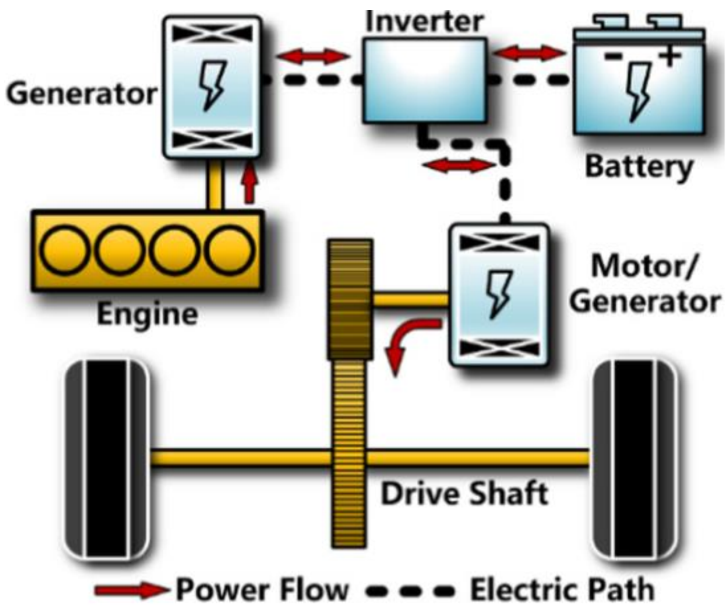

Figure 2.2 Configuration of Series HEV(Zhuang et al., 2020).

The traction motor surpasses the internal combustion engine (ICE) in terms of operating range and performance. As a result, while transmissions are needed in conventional vehicles, they may not be needed in series HEVs. As a result, the series hybrid powertrain is straightforward than other types, including setup and energy management (Zhuang et al., 2020).

2.2.3 Series-Parallel HEVs

With the Accord plug-in hybrid's intelligent Multi Mode Drive (i-MMD) technology, Honda first debuted the series-parallel variant in 2014. This configuration has two MGs, one completely integrated with the ICE and the other directly connected to the motor shaft as shown in Figure x. A clutch is used to disconnect the connection between the ICE and the output shaft, allowing three operating modes: EV, series, and parallel. The mode shift method reduces unnecessary engine operating (Zhuang et al., 2020).

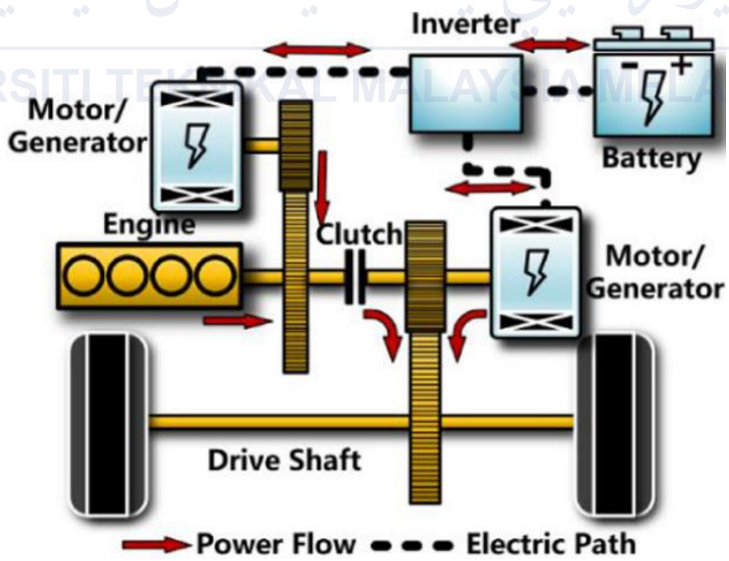

Figure 2.3 Configuration of Series-Parallel HEV (Zhuang et al., 2020).

The EV mode is activated when the battery's state of charge is high, while the series and parallel modes are utilised only at low and high speeds, respectively. A standard drivetrain is no longer needed to decrease powertrain expenses. Because a mechanical link occurs between the ICE and the output shaft in parallel mode, the ICE cannot run in its most efficient behaviour at all vehicle speeds (Zhuang et al., 2020).

2.3 Batteries for Hybrid Electric Vehicles

Battery energy is only needed for a limited time. The HEV battery rarely undergoes full charge-discharge cycles, which are common in electric vehicles. Most HEV batteries have an assurance for eight years. To achieve this long-lasting service life, the cells are designed for durability instead of high specific energy, as in everyday products. The battery manufacturer does this in part by utilising a thicker, more durable separator. To decrease stress, the battery operates at 30-80% state-of-charge (SoC), or around 3.5-4.0V per cell for Li-ion, rather than the standard 3.0-4.20V per cell (BU-1002a: Hybrid Electric Vehicles and the Battery, 2022).

Instead of using long, continuous discharges to accelerate, like EV batteries do, HEV batteries act briefly and resemble starter batteries. A hybrid electric vehicle's battery might hardly ever drop to a limited 20% state of charge (SoC). In typical operation, a parallel HEV uses less than 2% of the available battery capacity each mile (1.6km). Battery capacity fade is undetectable, and a HEV battery still performs effectively with less than half of its initial capacity (BU-1002a: Hybrid Electric Vehicles and the Battery, 2022).

2.3.1 Lithium-Ion Batteries

Lithium-ion batteries are the most popular type used in electric cars. Many portable electronic devices, including mobile phones and personal computers, use this type of battery. Lithium-ion batteries have a high power-to-weight ratio and good high-temperature resistance.

As this type of batteries are used in electric vehicles, it means that the batteries can store a large quantity of energy at a low cost, which is important because lighter vehicles can go longer trip on a single charge. It is also worth noting that lithium-ion batteries have a lower "self-discharge" rate than conventional batteries, allowing them to hold a charge for longer time. Beyond being reusable, lithium-ion battery parts are also eco-friendly (Arun et al., 2022b).

2.3.2 Nickel-Metal Hydride Batteries

Rechargeable nickel-metal hydride batteries, often known as NiMH or Ni-MH batteries, happen to be the best on the market. They achieve the best chemical reaction using nickel oxide hydroxide, which is identical to that of a metal cell (NiCd) (NiOOH). Instead of cadmium, the negative electrodes are made of a hydrogen-absorbing alloy. NiMH batteries have almost twice the amount of capacity of NiCd batteries and far higher energy efficiency than lithium-ion batteries (Arun et al., 2022b).

Although both hybrid and all-electric vehicles might use nickel-metal hydride batteries, hybrids are more likely to do so. Hybrid-electric vehicles are not considered to be as electric vehicles since they do not utilise a plug-in source of power and rather recharge their batteries with petrol. Nickel-metal hydride batteries have several disadvantages, including excessive cost, strong self-rate, and high heat output at hot temperatures (Arun et al., 2022b).

2.3.3 Lead-Acid Batteries

Lead-acid batteries are used to complement other battery cells in electric vehicles. Even though these batteries are very reliable, inexpensive, safe, and have a short annual life, their poor performance in cold temperatures makes them problematic to employ in electric automobiles. High-capacity lead-acid batteries that can store a huge amount of energy are currently being developed, but exclusively for commercial vehicles. (Arun et al., 2022b).

Lead-Acid batteries are quite typical rechargeable batteries with high-capacity. They are widely used because they are both dependable and cost-effective per watt. Furthermore, few other types of batteries provide bulk power at the same cost as Lead-acid batteries, making it an affordable choice for automobiles, EVs, forklifts, boats, and Uninterruptible Power Supplies (UPS) (Mohammadi & Saif, 2023).

Lead-acid batteries are simple to build, dependable, and can withstand overcharging. Furthermore, they are accessible in a wide variety of brands, prices, and sizes. Although there are few advantages to using lead-acid batteries, environmental issues, corrosion difficulties, acid smells, and sulfation have been significant disadvantages to using such batteries in recent years (Mohammadi & Saif, 2023).

2.4 Battery Degradation Mechanisms

Research for literature review is conducted to understand the different mechanisms responsible for battery degradation. They distil current knowledge into simpler forms, emphasizing the relationships between different mechanisms. They also focused on finding and supervising degradation mechanisms using physical and chemical procedures. This required monitoring observable consequences at the cell level (modes) and operational effects, such as capacity or power fade (Edge et al., 2021).

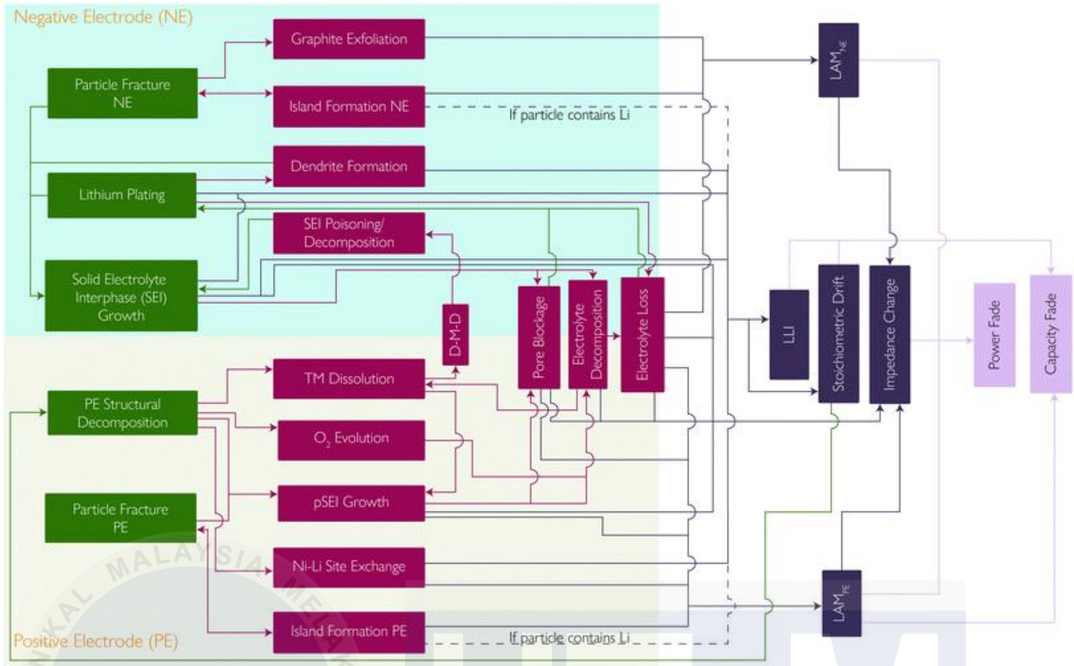

Figure 2.4 Mechanisms to be the cause of battery degradation (Edge et al., 2021).

Figure 2.4 showed five principal and thirteen secondary mechanisms in general hold to be the cause of degradation during normal operation of the battery. Through this mechanism procedure, five noticeable modes can be detected, which show the results of battery degradation. A flowchart summarizes the feedback loop that combined diverse types of degradation, highlighting the unified of these mechanisms. A table is introduced to emphasizing experimental state probably trigger specific battery degradation mechanisms (Edge et al., 2021).

The basic principles of Lithium-ion batteries (LIBs) are described and numerous aspects that be partly responsible for the battery's degradation is studied. They then go through into the specific analysis of degradation mechanisms of Li-rich cathodes, which are a different type of electrode material. Newly discovered techniques are considered for recognizing degradation mechanisms, which cover spectroscopy, microscopy, and other analytical methods. Diverse theoretical imitations are presented to understand and guess the processes withing LIBs (A. N. Singh et al., 2023).

A comprehensive of LIBs degradation mechanisms' understanding is achieved through the study of the basic principles of Lithium-ion batteries (LIBs). It further underlines that the degradation is not merely a result of charge-discharge cycling but also synthesis-induced stress, which also plays a very important role in catalysing degradation. Further studies on advanced battery substances which can replace traditional layered cathodes, directing the upgrade of battery life and performance (A. N. Singh et al., 2023).

Research employed an electrochemical model in studying the degradation mechanisms of batteries in electric vehicles for some real case scenarios. The work developed a methodology that segregates and isolates aging mechanisms in batteries from electric vehicles with different mileages, independent of the use history. They also established a sound correlation between the model parameters and noticeable degradation processes. (Abhishek Appana et al., 2024).

The procedures used, allowed the discovery and evaluation of the influence of each degradation mechanism on the battery's parameters. The report also highlighted the helpfulness of identifying, separating, and quantifying the effects of battery degradation in real case scenarios. These methods are a notable development in the non-contact analysis of battery health, offering valuable understanding of the maintenance and durability of electric vehicles (EVs) batteries (Abhishek Appana et al., 2024).

2.5 OBD II Technology and Battery Monitoring

A Raspberry Pi Zero W and other supporting components are installed in two Hyundai Ioniq battery electric cars through this experimentation. The electric cars and the Raspberry Pi are communicated through the OBD-II port. A Python manuscript or coding is thrived to request vehicle data from time to time by inputting various Parameter IDs to the vehicles. The raw response data obtained then is gathered. A website is developed to process the hexadecimal-encoded data and display it on a dashboard (Ramai et al., 2022).

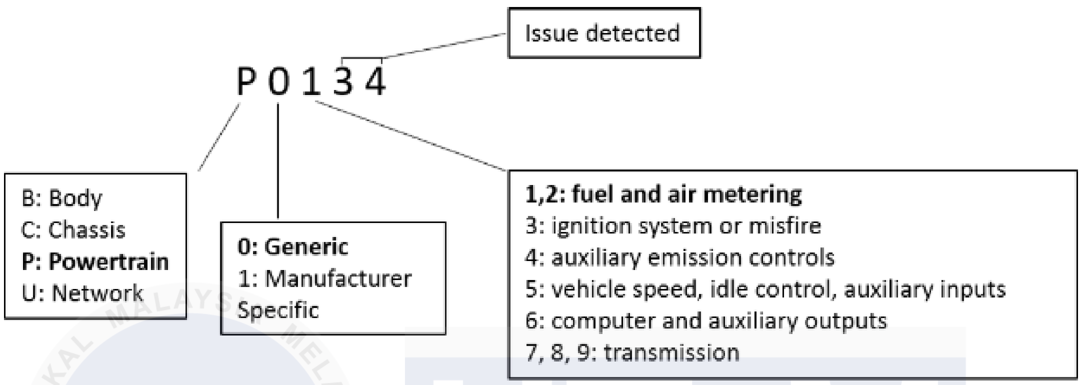

Figure 2.5 Breakdown of OBD-II diagnostic trouble code (Ramai et al., 2022).

Essential parameters such as battery state of health (SOH), state of charge (SOC), battery temperature, cell voltages, and cumulative energy consumption are flourishingly captured and recorded. These obtained data ease way for battery problems' check. The recorded data also can be used for forthcoming alliance with quick chargers to help united charging. This groundwork produces a low-cost quick fix for battery electric vehicles' (BEVs) life monitoring using OBD II technology, allowing real-time data collection and diagnostics (Ramai et al., 2022).

Table 2.1 Parameters data obtained from the OBD-II

Parameter	PID Response Location	CAN hex	Dec.	Scale Factor	Value	Unit
Battery Max Temperature	21 7	1F	31	1	31	°C
Battery Min Temperature	22 1	1E	30	1	30	°C
Battery Module 6 Temperature	21 6	1F	31	1	31	°C
Battery Module 7 Temperature	22 2	1F	31	1	31	°C
Battery Module 8 Temperature	22 3	1E	30	1	30	°C
Battery Module 9 Temperature	22 4	1E	30	1	30	°C
Battery Module 10 Temperature	22 5	1E	30	1	30	°C
Available Charge Power	22 6:7	2648	9800	0.01	98	kW
Available Discharge Power	23 1:2	2648	9800	0.01	98	kW
Battery Cell Voltage Deviation	23 3	0	0	-	0	V

Parameter	PID Response Location	CAN hex	Dec.	Scale Factor	Value	Unit
Quick Charge Normal Status	23 4	1	1	-	1	-
Airbag H/wire Duty	23 5	50	80	1	80	%
Battery Heater Temp 1	23 6	0	0	1	-	°C
Battery Heater Temp 2	23 7	0	0	1	-	°C
State of Health (SOH)/Max Deterioration	24 1:2	3E8	1000	0.1	100	%
Max Deterioration Cell no.	24 3	2E	46	1	46	-
Min Deterioration	24 4:5	3E8	1000	0.1	100	%
Min Deterioration Cell no.	24 6	1	1	1	1	-
State of Charge (SOC) Display	24 7	A5	165	0.5	82.5	%

The use of On-Board Diagnostic tools to figure out any faults occurred on the vehicle are debated. A comparison between OBD-I and OBD-II are made, resulting the restriction of OBD-I and the betterment of OBD-II. Various modes of PIDs are managed by OBD-II to connect data from the vehicle's Electronic Control Units (ECUs) over the Controller Are Network (CAN) bus. They then analyse the SAE J1850 protocols, which are part of the OBD-II accepted for vehicle connection. The study also watches how OBD-II runs specific information to request and retrieve data from vehicles using different PIDs and modes (Saibannavar et al., 2021).

The endorsement of OBD-II devices has enhanced the satisfaction and performance of diagnosing vehicle's problems. Investing a better diagnostics system of OBD-II grants an overall health of the vehicle and securing the safety of the driver and passenger in the vehicle. The maintenance process has been up to date via the uses of OBD-II, simultaneously reducing the time and complicatedness while diagnosing the vehicle's faults (Saibannavar et al., 2021).

A direct measurement method is used to measure the battery's terminal voltage, current, and temperature, developing a real-time data about the battery's condition and performance. Through this method, the status of Li-ion batteries and manage cell operation within the battery pack can be check. An analysis-based method is conducted to figure out data from the battery to predict its ability. The battery capacity prediction of the battery can be found based on the battery's performance (Peng et al., 2022a).

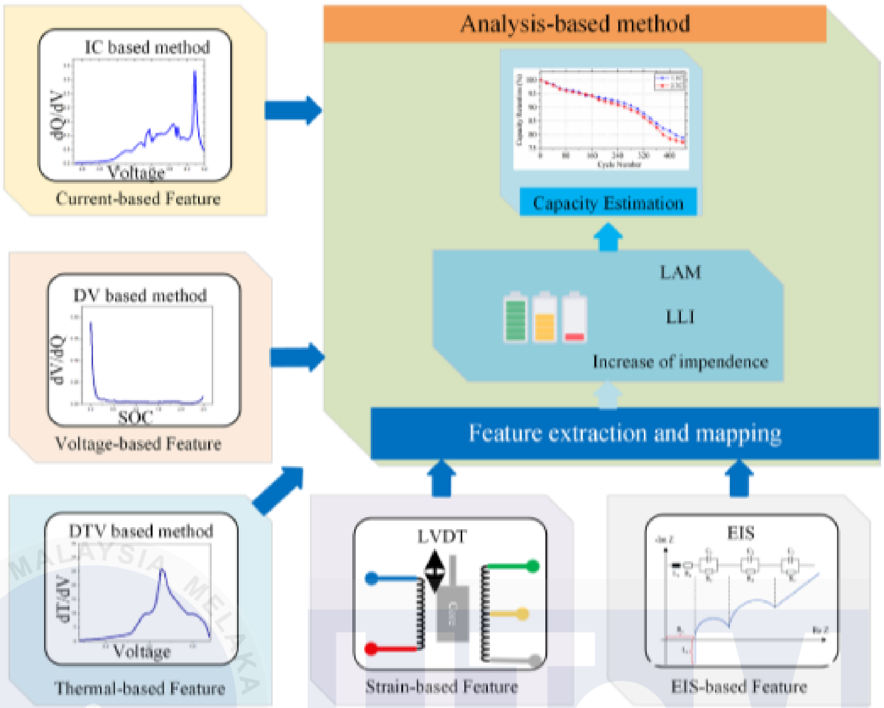

Figure 2.6 Schematic of Analysis-based Method (Peng et al., 2022b).

State-of-Charge (SOC) evaluation method helps decide the remaining capacity of the battery and is essential for control strategies. An over discharge can be preventing and enhances simultaneously protect the battery life, by obtaining an exact SOC estimation through this method. The study also uses a data-driven methods, which referring to earlier or historical data to predict the capacity. This procedure proposes higher accuracy and increase capacity estimation under different situations (Peng et al., 2022b).

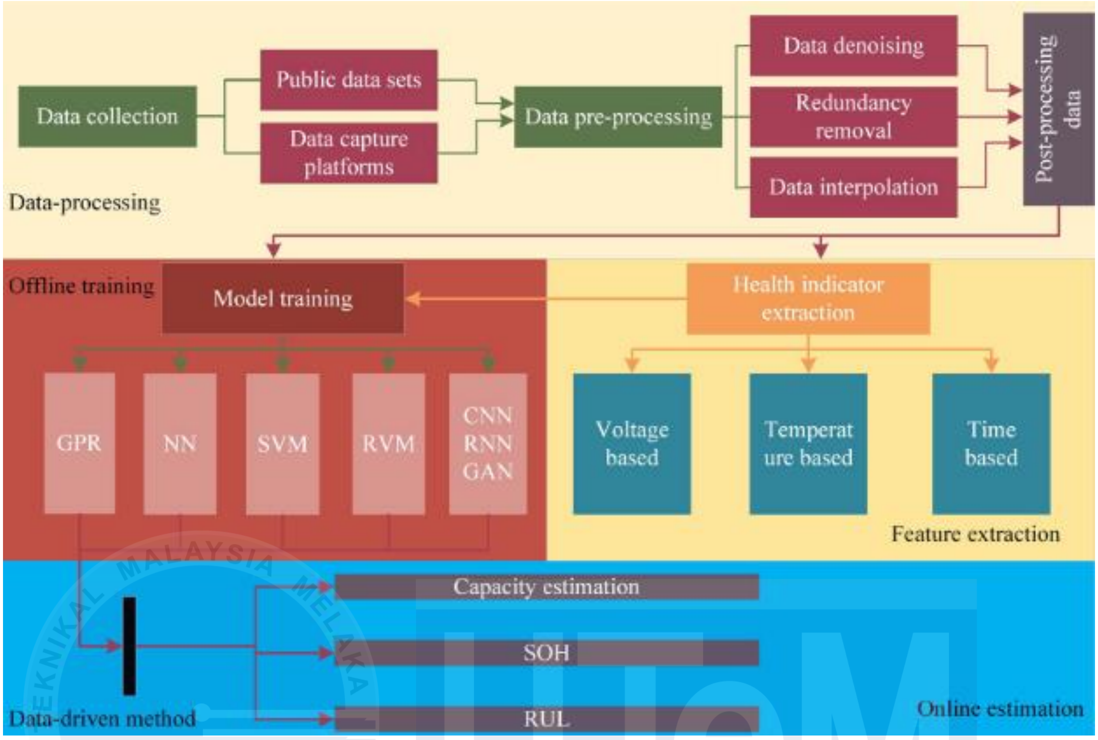

Figure 2.7 Battery's SOH and RUL calculation process using data-driven method (Peng et al., 2022b).

2.6 State-of-the-art (Modern) Battery Diagnostic Algorithms

State-of-the-art battery diagnostic algorithms influence advanced technologies such as machine learning, artificial intelligence, and deep learning to improve the precision and reliability of battery management systems (BMS). These algorithms are created to estimate battery state-of-charge (SOC), state-of-health (SOH), and remaining useful life (RUL), securing efficient battery performance and safety. They merge data-driven models with physics-based approaches to diagnose faults, manage thermal conditions, and optimize energy usage in real-time (Batteries, n.d.).

A broad analysis of machine learning (ML) technique is presented and is applied to electric vehicle (EV) battery management, specifically focus on condition guess and ageing problem. The plan concern evaluating, coordinating, and applying multiple ML algorithms to estimate the State of Health (SOH) and Remaining Useful Life (RUL) of lithium-ion batteries. The research also points out that the non-linear performance of battery health estimation and the challenges it gives to industry in this field (Das & Kumar, 2023).

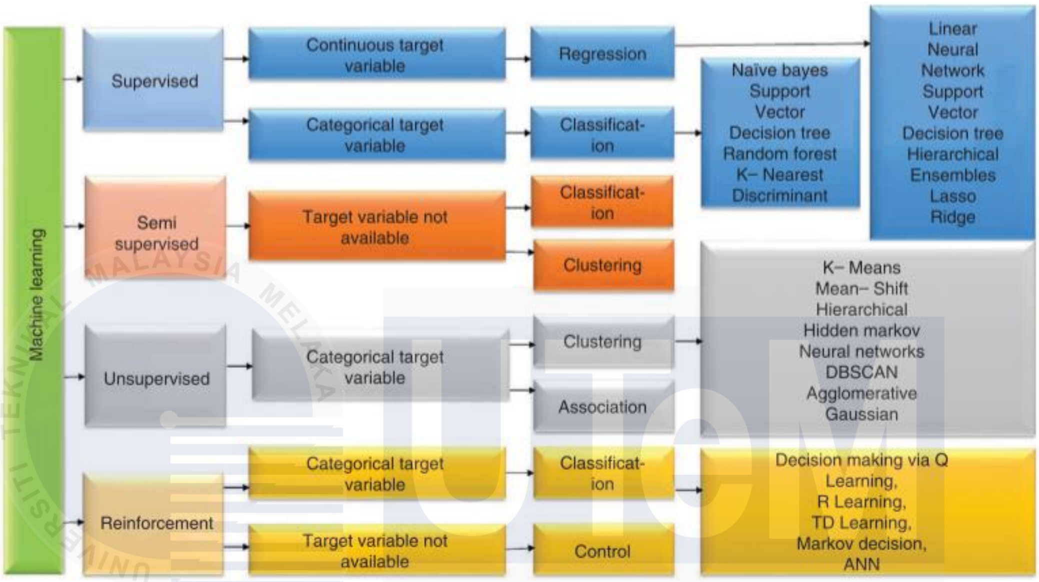

Figure 2.8 Different Machine Learning methods to estimate SOH (Das & Kumar, 2023).

The potential of ML acknowledging the frequent challenges faced in battery management systems is highlighted. The behaviour of lithium-ion batteries, the approach to SOH evaluation, the upper hand, and the obstacles of using ML for different conditions estimations are discussed throughout the study. They also outline the future enhancements in battery management systems via the implementation of ML, offering a positive supervision for time ahead research and development in this area of activity (Das & Kumar, 2023).

The research leads off with collecting and preliminary processing data from 14 individual Nickel Manganese Cobalt-Lithium Cobalt Oxide (NMC-LCO) batteries that encounter over 1000 cycles. Then, proper features and cutting outliers are decided on to boost the predictive model's exactness. Numbers of machine learning (ML) models such as, XGBoost, BaggingRegressor, LightGBM, CatBoost, and ExtraTreesRegressor are engaged throughout this study (Karthick et al., 2024).

Table 2.2 Comparison between before and after outlier removal.

Feature	Before Outlier Removal (15,064 Instances)		After Removal of the Outliers (14,445 Instances)	
	Skew	Kurtosis	Skew	Kurtosis
Discharge Time (s)	16.300	339.993	−0.154	−1.170
Decrement 3.6–3.4 V (s)	9.986	253.344	0.241	−0.899
Max. Voltage Discharge (V)	−0.530	11.564	−0.079	−0.966
Min. Voltage Charging (V)	0.329	1.145	0.213	−0.235
Time at 4.15 V (s)	16.238	340.628	−0.106	−1.206
Time Constant Current (s)	24.723	696.544	−0.138	−1.171
Charging Time (s)	22.770	587.790	−0.125	−0.654
RUL (Cycles)	0.006	−1.208	−0.012	−1.202

Crucial analysis such as critical parameters that affect battery health and lifetime can be achieved through the improvement of machine learning models. Statistical evaluations also proves that there are no lost nor same data collected, and the model's exactness can be upgraded by removing the outlier. They also find out that among all involved learning machine models, XGBoost appeared to be the most competent algorithm, producing almost-perfect RUL projections (Karthick et al., 2024).

The study emphasizes on AI methods to strengthen the battery management system (BMS) in electric vehicles (EVs). These techniques are applied in precise battery health diagnostics, fault analysis, and thermal management. An in-depth statistical analysis is also being conducted based on 78 most relevant publications from 2014 to 2023. Parameters estimated include present research trends, keywords, publishers, research classifications, republic analysis, authorship, and collaboration. The research strictly discusses state-of-art AI proposition in the context of EVs BMS. These methods are evaluated about their aims, contributions, advantages, and disadvantages (Lipu et al., 2023).

Figure 2.9 Number of relevant manuscripts in AI-integrated BMS for EV applications between 2014 and 2023 (Lipu et al., 2023).

2.7 Predictive Maintenance Strategies

In this research, Fiber Bragg grating (FBG) sensors are engaged to record real-time data on crucial EV components such as battery, electric motor, and power electronics. These sensors provide advantages such as resistance to electromagnetic interference, high sensitivity, and multiplexing potential. They also used a quantum-enhances machine learning algorithm to process obtained data. Quantum evaluating is attached to manage large-scale data sets and upgrade prediction accuracy (Rao et al., 2023).

The paper also says that an AI model is trained for predictive maintenance by examining data from the FBG sensors, so that the model can project any possible failures before it happens. Then, by increasing parts' lifespan and minimizing downtime, the suggested method provides to efficient and sustainable EV operation (Rao et al., 2023).

In this research paper, they use the identification the importance of combining energy storage such as battery energy storage systems into the electric grid infrastructure. The grid improves in managing the intermittency root by sustainable energy sources and enhance overall reliability. They also tried decreasing the cost of Li-ion batteries to manage the escalation in battery energy storage systems (BESSs) deployment. Through this method, BESSs become more economically applicable and widespread promotion of BESSs due to affordability (Fioravanti et al., 2020).

Table 2.3 Safety-focused Failure Mode and Effects Analysis (FMEA) for a BESS (Fioravanti et al., 2020).

System or Component	Failure Mode	Hazard Effect	Consequence	Prevent	Detect	Probability; Severity	Value for Risk
BMS	System does not operate safely through normally expected temperature operating range	Fire	Safety incident	BMS testing	Independent temperature sensor	3; 10	30
Battery cell	Group of failures	Fire	Safety incident	Abuse testing	Fire alarm	3; 9	27
Battery pack	Group of failures	Fire	Safety incident	Abuse testing	Fire alarm	2; 10	20
BMS	Battery damage due to BMS malfunction	Fire or loss of functionality	Safety incident	Fusing, inverter protection	EMS fault on BMS behavior	2; 7	14
Inverter	Inverter fails to detect/ react to overtemperature in insulated-gate bipolar transistors	Loss of functionality	Power output derating	Reliance on supplier	EMS fault on inverter temperature rise or inverter fault	3; 4	12

Table 2.3 shows the systems or components failures, its hazard effect, the consequences that might happen, which actuator to detect the failure and the risk value of the failure.

2.8 Safety Considerations and Fault Detection

Battery management system (BMS) productively checks main electrical parameters of a battery pack system, including voltage, current, and temperature. This is because battery management system (BMS) is a crucial role in safeguarding battery cells which connected in high-voltage systems. In this research paper they also use the battery management system of the hybrid electric vehicles (HEVs) to conduct safety measures to enhance battery performance and confirm safe operation. By holding to functional safety principles, the battery management system (BMS) will aid prevent failures that might affect the environment, people, and the vehicle itself (See et al., 2022).

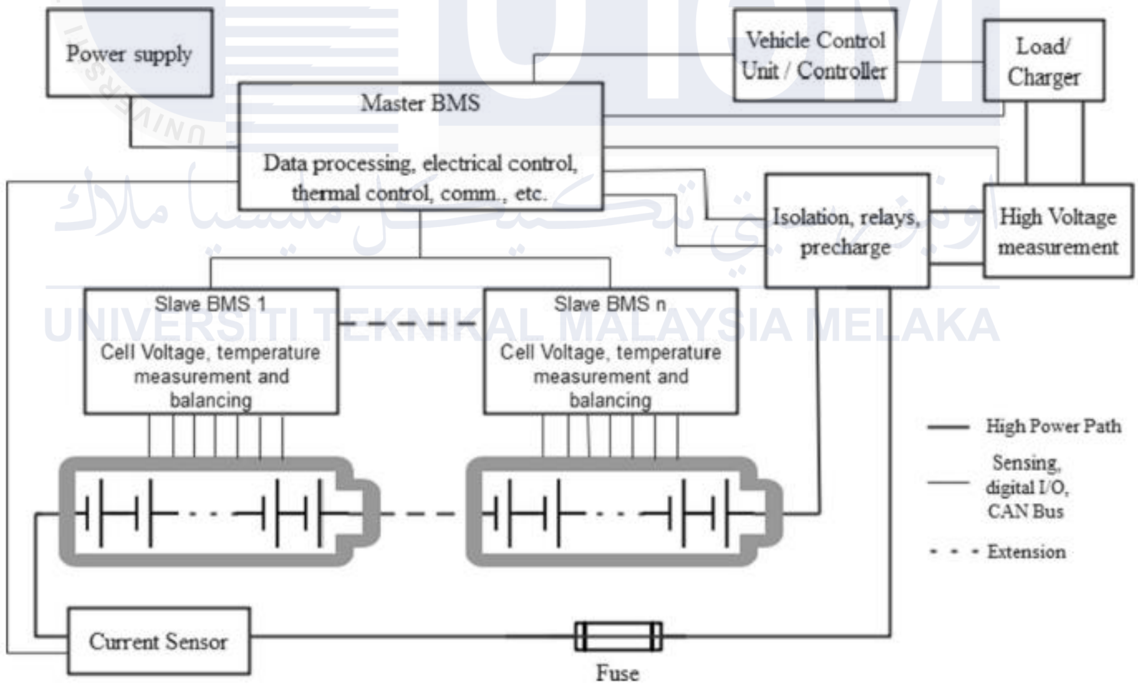

Figure 2.10 Example of basic BMS architecture and the functional safety concept (See et al., 2022).

The paper also highlights functional safety, which implicates automatic protection mechanisms, such as risk assessment, hazard analysis, and compliance with relevant industrial standards. The comprehensive consideration covers components, architecture, risk depletion methods, and failure mode analysis specific to battery management system (BMS) operation (See et al., 2022).

The paper uses 1-D wavelet signal analysis on MATLAB Software (Figure 2.11) to detect faults in the battery management system (BMS) of hybrid electric vehicles (HEVs). A wavelet transforms are applied to input-output signals gathered from both healthy and faulty battery systems. The aim is to spot sensor failures related to current, voltage, and temperature measurements within rechargeable HEV batteries. The method used is then compared to conventional Kalman filtering estimation techniques (Tudoroiu et al., 2020).

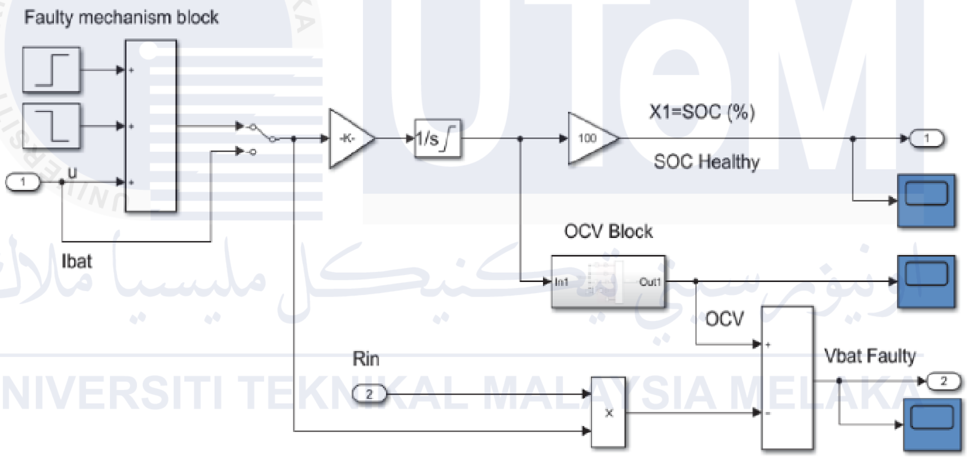

Figure 2.11 Simulink diagram of battery fault detection model setup.

From the methods used, they obtained a high detection accuracy, which is accurately recognizing faults in the battery management system. The process is computationally well organized, making it acceptable for real-time applications. They also reveal robustness against measurement uncertainty, performing well even when faced with uncertainties in sensor readings (Tudoroiu et al., 2020).

2.9 Integration with Vehicle Control Systems

A vehicle has few control mechanisms that cannot be fully run by humans. These systems must also be present in the vehicle for it to be easily controlled. The control system consists of three components: a sensor, control, and actuators. The Electronic Control Unit (ECU) is the sensor's principal control mechanism. The sensor incorporates the following components: engine speed, temperature, load, wheel speed, and steering angle. It also covers road speed, acceleration, and more systems, all of which are controlled by the ECU. The actuators include fuel control, automatic transmission, traction control, ABS, and more. (Peachyessay, 2021).

A two-level cooperative control method is used to integrate traffic signal control, vehicle speed control, and energy consumption management. This method is seen at two levels which are traffic level and vehicle level. Traffic level test is represented to lessen the total travel time and fuel consumption of all types of HEVs. A dynamic programming is used to raise traffic signal timings based on arrival time and better information of vehicles (Chen et al., 2020).

While as for vehicle level testing, a hierarchical control architecture and model predictive control (MPC) are involved to perfect speed trajectories and powertrain of HEVs. A These methods of test impressively decreasing travel time compared to fixed-time and cycle-based signal control strategies. By integrating traffic signal control and vehicle speed control, both traffic flow and fuel efficiency are enhanced with the fuel consumption is reduced by up to 24% (Chen et al., 2020).

2.10 High-Voltage Battery's Temperature

A study investigates the ageing behaviours of cycled Lithium-ion batteries at temperatures from −20 °C up to 70 °C, to understand how temperature influences degradation mechanisms. Commercial 18650-type high-power cells with a LixNi1/3Mn1/3Co1/3O2/LiyMn2O4 blend cathode and graphite/carbon anode were used. The cells were cycled at 1 C until their discharge capacity went below 80%, with aging assessed through electrochemical methods and Post-Mortem analysis, including SEM, EDX, ICP, XRD, and electrode polarization studies in pouch cells with reference electrodes.(Waldmann et al., 2014).

The results revealed two different ageing mechanisms. Below 25 °C, ageing was dominated by Lithium plating, which increases with decreasing temperature. Above 25 °C, the ageing was driven by cathode degeneration and growth of SEI layers on anodes. An Arrhenius plot underlined these transitions and showed the chemical and structural changes that drive battery degradation at different temperatures (Waldmann et al., 2014).

2.11 High-Voltage Battery's State of Charge

Li-ion batteries have been preferred in most EVs owing to their high voltage, energy density, low self-discharge, and long lifecycles. Efficient performance of the EVs, however, relies on accurate SOC estimation within a BMS, which is crucial for long battery life and avoidance of potential failures. Estimation of SOC is a complex task since it depends on many factors such as battery age, ambient temperature, among others. These make the process require advanced methods that will help improve accuracy and robustness in SOC estimation for EV applications (How et al., 2019).

Some of the state-of-the-art SOC estimation methodologies, such as model-based and data-driven approaches, are highlighted in this review. The model-based methodologies are built upon complex mathematical equations fitted for battery behaviour under various conditions, whereas advanced algorithms learn battery behaviour from big datasets in data-driven techniques. The benefits- and limitations-based models, along with estimation errors, are presented in this review. It also talks about challenges in environmental and operational factors and gives recommendations for the development of SOC estimation techniques to improve lithium-ion battery performance in next-generation EVs (How et al., 2019).

2.12 High-Voltage Battery's Current Limits

Fast charging of lithium-ion batteries is believed to be one of the important preconditions for quickening the adoption rate of electric vehicles. However, it presents several serious challenges, such as capacity fade, lithium plating, and thermal runaway have compromised performance and safety. These problems can be tackled by optimized charging protocols should be developed which can ensure minimum degradation while keeping safety and efficiency intact (Xu et al., 2019).

A study has proposed an optimum multistage charging protocol that reduces capacity fade due to SEI growth, minimizes lithium plating, and prevents thermal runaway by controlling temperature rise. In this respect, suboptimal charging current profiles were determined by using the dynamic programming optimization algorithm coupled with the electrochemical-thermal-capacity fade model for monitoring internal battery states. The results showed that the optimized charging strategies reduced the capacity fade by 4.6%, increased the SEI potential by 57%, and decreased the temperature rise by 16.3%, compared with constant current charging within 3300 charge-discharge cycles, hence very effective for improving battery performance and prolonging its cycle life (Xu et al., 2019).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project is about the development of an integrated framework on high-voltage batteries' monitoring within HEVs by using OBD II devices. In this aspect, it means OBD II technologies utilization by gathering information, analysing life detection of failures, and recommending the practicality so that the batteries stay longer in a good state, overall improving the vehicles' performances.

The parameters of the high-voltage battery in a hybrid electric vehicle will be analysed, specifically for a Toyota Prius 3, using On-Board Diagnostics II devices. This analysis is very important in understanding performance, efficiency, and longevity, which are key features of the battery system in the vehicle hybrid technology. A few life monitoring sessions were performed to obtain the required data, and at the same time, several methods are employed to obtain the battery parameters correctly. In this regard, the high-voltage battery can be comprehensively studied for its behaviours under different conditions, which indeed provides significant information that may develop future improvements in hybrid vehicle technology.

3.1.1 Flowchart

Figure 3.1 below shows the systematic flow of project development. It starts with the project title and then goes through some critical steps involving objectives, research, methodology construction, and installation of the application. After installation, it undergoes testing, data collection, and analysis to ensure accurate results. When the results are verified, documentation and reporting conclude the process. This ensures that the project is efficiently completed in a very effective manner.

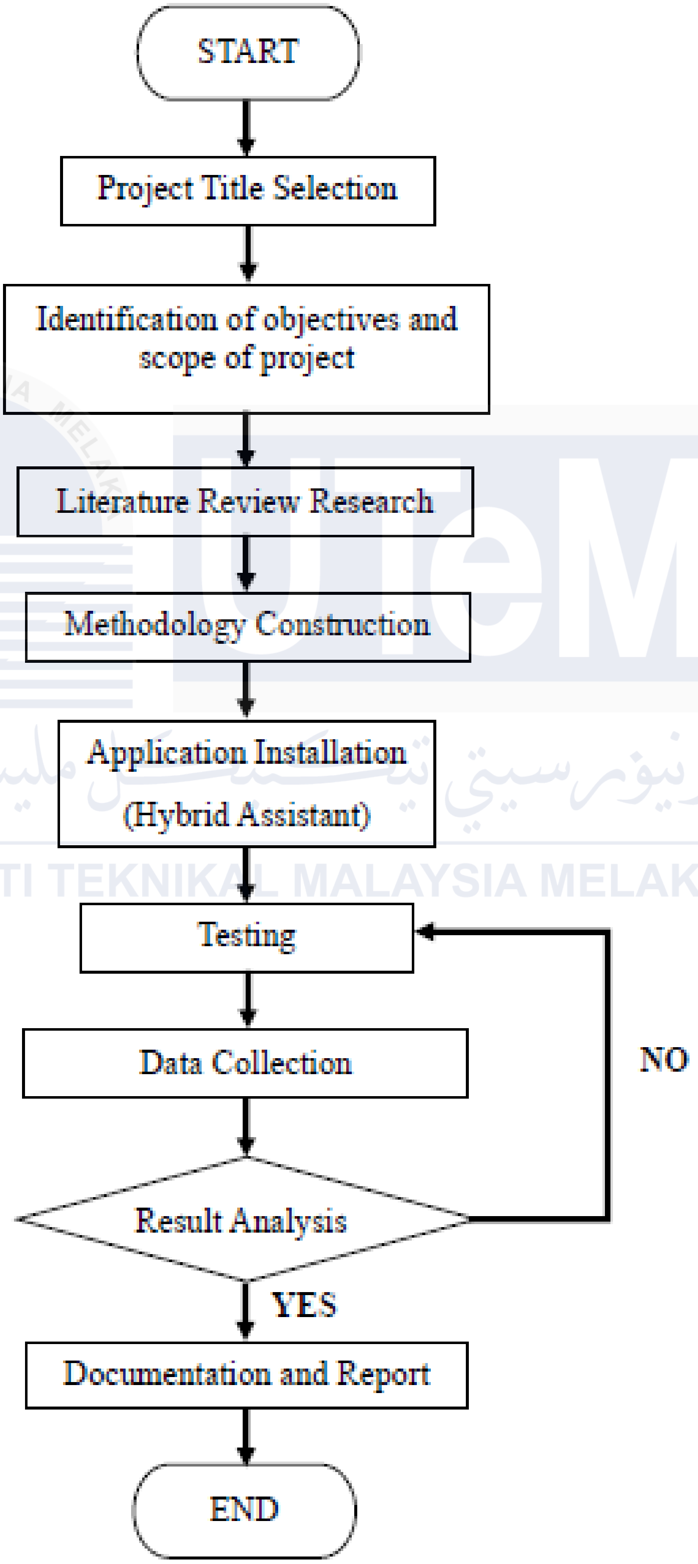

Figure 3.1 Flowchart

3.1.2 Selection of The Project Title

This segment highlights the project title selection method. The "Monitoring of High-Voltage Battery Operations Using OBD Diagnostics Device in Hybrid Vehicle" titled reveals that this project's core concern and work will target high voltage battery monitoring and its development in a hybrid electric vehicle or HEV. Its selection criteria involve identifying suitable methods for choosing a battery management and to identify what role would an OBD device plays in achieving those. The main goals of this research involve the improvement in battery health regarding electric vehicles, the advance in diagnostic technologies, and how it can hopefully affect vehicle efficiency and reliability.

3.1.3 Development of Project Outline

A project outline generally gives a full roadmap of the whole process of research and development. It initiates from the introduction and background, providing a sketch of hybrid vehicles and why there is a need for monitoring a high-voltage battery. A small background is given regarding OBD (On-Board Diagnostics) diagnostic devices and their history and evolution to set the context of relevance and application.

The project objectives are clearly stated that the OBD-II devices are to be used to conduct an online monitoring operation of Toyota Prius Hybrid vehicles, monitor the high-voltage battery in various driving modes, and to analyse parameters related to the high-voltage battery of the Toyota Prius C models. The stated objectives make room for a well-focused and structured investigation in the battery health and performance.

The literature review will be characterized by detailed study and analysis regarding the available technologies and methodologies for the monitoring of batteries and past research related to the degradation of batteries in hybrid vehicles. This background information will help to reveal the gaps in knowledge that currently exist and set the ground for the proposed research.

This section shall describe the development of the monitoring system, including the integration of OBD diagnostic devices into the battery management system of the vehicle. It will also outline data collection and analysis techniques to be used to ensure a structured approach to gathering and interpreting data for the successful realization of the objectives of the project.

3.1.4 Software Implementation

The next segment shall focus on the software implementation part of the project, comprised of quite a few important features such as the design of the software application, using the Hybrid Assistant and intended to be developed in such a way that it shall seamlessly interface with the OBD diagnostic tool. The application is to feature components such as real-time monitoring and data logging and alarm systems over abnormal battery conditions.

System integration is the next major process in which the software is applied to the existing battery management system of the vehicle. This enables compatibility with the various OBD protocols, allowing the applicability of the tool in numerous hybrid models for the integration of vehicles.

After this, a sequence of rigorous tests and debugging methodologies are conducted where the software functioning of the tool is tested, and any software bugs or problems are located and removed so that the application works efficiently and without any flaw.

Another important aspect is the usability of the interface. Interface usability will make the monitoring system a development which can easily be interacted with. The interface shall provide straightforward, easy and useful information to the user to make noticeable monitoring and management of the high voltage battery.

Lastly, step-by-step documentation of the software development process is prepared. It involves the end user's manual as well as technical documentation that helps the users to install and run the software easily and make sure that the user has all the means to use the system.

3.2 Toyota Prius

The main subject in this project is the Toyota Prius, a beginning model in the world of hybrid electric vehicles. Renowned for its innovative technology and environmental benefits, the Prius serves as an ideal subject for analysing high-voltage battery parameters. This project aims to delve into the specifics of the Prius's battery system to better understand its performance, efficiency, and overall functionality.

Table 3.1 Specification of the Toyota Prius's battery.

Battery Type	Nickel-Metal Hydride (NiMH)	Lithium-Ion (Li-ion)
Battery Voltage	201.6 volts	207.2 volts
Battery Capacity	6.5 Ah	4.4 Ah
Number of Cells	28 modules with 6 cells each (total 168 cells)	56 cells (individual cells)
Battery Energy	1.3 kWh	0.75 kWh

The cooling system of the Toyota Prius's battery is an air-cooled system equipped with a fan, designed to support best operating temperatures. The battery pack is strategically found under the rear seats, perfecting space and weight distribution within the vehicle. Typically, Toyota offers an 8-year or 100,000-mile warranty for the hybrid battery, though this can be changed depending on the region and specific model year.

3.2.1 Prius 3

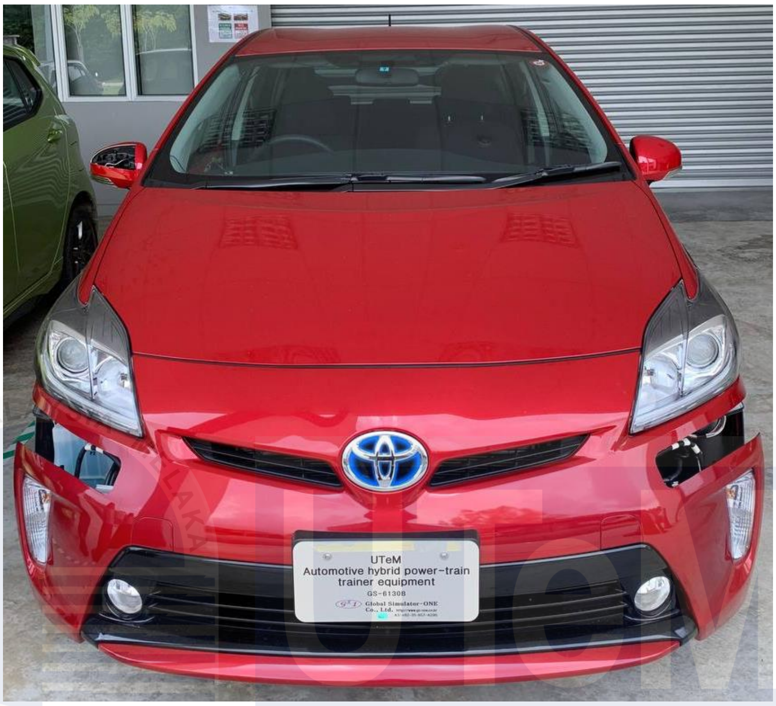

Figure 3.2 Toyota Prius 3

The Toyota Prius 3 as shown in Figure 3.2, known as the third-generation Prius, is a popular hybrid vehicle that was introduced in 2009. New releases of the car model came loaded with a great new look and state-of-the-art technologies that promoted new consumption levels. Toyota's Hybrid Synergy Drive engine coupled an electrical motor to the 1.8-litres, four-cylinders petrol. Together, they ensured an excellent horsepower at 134 for the Prius3.

This setup returns acceptable performance for city and highway driving. The car has been fitted with a CVT that optimizes power delivery and fuel economy. The key benefits that come with the Prius 3: The fuel economy was great. For instance, the EPA estimated 51 mpg in city traffic and 48 mpg on the highway; hence, it was among the best fuel-efficient vehicles upon introduction to the market.

Table 3.2 Toyota Prius Battery’s Specifications.

Battery Type	Nickel-Metal Hydride (NiMH)
Battery Voltage	± 201.6 Volts
Number of Cells	28 modules, each contains 6 cells
Battery Capacity	6.5 Ah (ampere-hours)
Battery Weight	± 53 kg
Energy Storage	±1.31 kWh (kilowatt-hours)
Battery Power Output	27 kW

3.3 OBD-II

OBD-II is a standard connection in modern vehicles from which real-time data and diagnosis information is available on the onboard computer of the vehicle. This research is completed using an OBD-II device with a compatible software application that will accomplish the objective mentioned in Chapter 1. The hybrid vehicle communicates with the OBD-II device and the onboard computer of the vehicle for retrieval of crucial data about different parameters of a battery, including battery’s temperature, battery state of charge, and battery charge and discharge current limit. This real-time information becomes quite important in conducting life monitoring sessions and performance evaluation of a high-voltage battery with perfect accuracy under varied operational conditions like acceleration, deceleration, and other driving modes.

3.3.1 Adapter

The OBD-II wireless adapter is a small piece of hardware that plugs into the OBD-II port in the vehicle, as shown in the Figure below, usually under the dash on the driver's side of the car. Fundamentally, it is an interface between the onboard computer of the vehicle and some external device, like a smartphone, tablet, or laptop. This adapter makes it easy to access real-time diagnostic information via wireless transmission with either Bluetooth or Wi-Fi. The adapter will be very instrumental in this project for data collection regarding the batteries and ensures smooth communication with the software application used for analysis.

Figure 3.3 An OBD-II Wireless Adapter

3.3.2 Hybrid Assistant

Hybrid Assistant is a specialized software application designed to process and analyse the data retrieved from the OBD-II system. It explains raw diagnostic information in a way that is very useful to understand the health, efficiency, and operational dynamics of the battery. The manipulation of the Hybrid Assistant software will enable the project to point out possible areas of improvement in the performance of the battery and monitor the parameters of the battery over time. In the context of this study, Hybrid Assistant is used specifically to go in-depth with the Toyota Prius high-voltage battery behaviour with the aim of optimizing performance and efficiency under different driving conditions.

Figure 3.4 Hybrid Assistant App Logo

3.4 Monitoring Parameters

During understanding and optimizing the performance of the high-voltage battery in a Toyota Prius, several critical parameters directly impacting its condition, effectiveness, and general performance should be considered. These parameters give insight into the state of the battery and, thus, could reflect its possible capability to satisfy demands during varied driving conditions. This consists in explaining on the test run with the device using an OBD-II device and application Hybrid Assistant with data gathering processing: the High-voltage battery temperature in the SOC of Current limit. These can give complete information into how the behaviour of the batteries runs under different situations, hence help further in finding their patterns or even defects possibly inside that may have to be tested on.

3.4.1 High-Voltage Battery's Temperature

Among the most significant parameters influencing performances, safety, and life of a high-voltage battery is its temperature. In general, batteries operate best within a narrow range of temperature, between approximately 20°C to 40°C for nickel-metal hydride battery, and between -10°C to 50°C as for maximum allowable range. If too hot due to overcharge, over-discharge, or environmental factors, thermal runaway may occur; efficiency could be lost, and even permanent damage to the cells may result. On the other hand, low temperatures reduce the reaction rate in the chemicals of the batteries, thus automatically cutting down both the capacity and power output. Temperature observation will enable effective thermal control to keep performances at their best and help prevent overheating or under-performance during extreme conditions.

3.4.2 High-Voltage Battery's State of Charge

The battery's state of charge represents the unconsumed amount of energy in the battery as a percentage of the total capacity. It is commonly expressed as a percentage, with 100% SOC indicating that the battery has been completely charged and 0% SOC indicating that it is totally drained. The optimal operating range for SOC is between 20% to 80%. While the maximum allowable range is between 10% to 90%. SOC plays a very important role in planning energy consumption, managing regenerative braking, and maintaining the efficiency of the vehicle. Good SOC monitoring helps prevent overcharging since it leads to degradation of the cells in a battery, as well as deep discharging, which can reduce the lifetime of a battery. Hence, the knowledge of SOC dynamics under different driving conditions-such as during acceleration or deceleration-presents the opportunity for enhancing energy management with optimization in terms of range and performance for the vehicle.

3.4.3 High-Voltage Battery's Charge/Discharge Current Limit

The maximum discharge and charge current limits are defined by the charge and discharge currents the battery can bear under its design-based operation conditions. The range for charge current limit of NiMH is between 5kW to 20kW and between 10kW to 50kW for discharge current limit. If it exceeds these limits of discharging and charging, it may cause overheating, which hastens degradation and even safety risks of the battery. Primarily, such monitoring of these limits ensures that drawing power from or supplying power to the battery maintains levels where the battery health will ensure long-term use. Knowledge of these limits is important in the management of power delivery for vehicle performance during acceleration-high discharge current-and regenerative braking-high charge current. Maintaining the balance between current limits and operational demands optimizes performance while protecting the battery from undue stress.

3.5 Test Run

The test run has been designed to describe the experimental setup and methodologies adopted for collecting key data with respect to the performance of a high-voltage battery. Key parameters include battery temperature measurements, which shall be useful in evaluating how the temperature varies under different driving scenarios, and battery state of charge (SOC), monitoring changes within charge levels throughout the test. Apart from this, the observation of maximum current limits for the battery charging and discharging was made to understand the behaviour of an accumulator in acceleration and deceleration conditions. The test had been done in Sport and Eco mode position to study the performance of a traction battery in different driving styles with variant energy requirements. The measurements had been done in controlled conditions to maintain the consistency and correctness of the data.

3.5.1 Road Specifications

The test is done on a straight, flat road with no inclines to make sure that the road surface is even. The testing is done along a dry road during the test run, and testing should be performed only during a clear-weather day. This will ensure minimal outside causes that can affect the performance of the vehicle and findings data.

3.5.2 Driving Speed

This section explores the vehicle's driving speed performance, focusing on two primary aspects: acceleration and deceleration. The acceleration tests involve increasing the vehicle's speed from a static position to specific set speeds, analysing the time taken and its effects on parameters like the battery's state of charge (SOC) and current limits. While deceleration tests involve slowing the vehicle from the set speeds to a stop, assessing regenerative braking capabilities and its influence on battery performance.

3.5.2.1 Accelerating

The vehicle accelerates from initial zero speed to target speeds of 30 km/h, 40 km/h, 50 km/h, and 60 km/h. The pedal is completely pressed during acceleration until the required speed is reached. After reaching the speed, the pedal is released, and the vehicle is allowed to slow down without applying the brakes. The time it takes to reach each speed is recorded for analysing the pattern of acceleration and its influence on battery parameters like state of charge (SOC) and current limits.

3.5.2.2 Decelerating

The vehicle is first accelerated to following speeds of 30 km/h, 40 km/h, 50 km/h, and 60 km/h. Once those speed is attained, the pedal is pressed to 50% of its capacity to decelerate the vehicle. Each target speed required time to decelerate to a full stop was recorded. The process described helps test the braking aspect-regenerative if possible, which gives a general effect on battery performance regarding the change of battery's SOC.

3.5.3 Driving Mode

This section describes driving modes of the vehicle, including ECO Mode and Sport Mode, targeted at different driver preferences and purposes. ECO Mode is about energy efficiency, giving smooth acceleration without a high-power requirement to save the state of charge of the battery. While Sport Mode is directed at high performance and allows faster acceleration and sporty drives but with higher energy consumption.

3.5.3.1 ECO Mode

ECO Mode prioritizes energy efficiency, aiming to conserve the state of charge of the battery. In this mode, acceleration is smoother, and the system may limit high power output to reduce strain on the battery. In the test, ECO mode is integrated with predefined speed scenarios to study its influence on the time required to reach target speeds and overall energy consumption.

3.5.3.1 Sport Mode

Sport Mode prioritizes performance, enabling faster acceleration and potentially drawing higher current from the battery. The system is optimized for maximum power output, delivering a more dynamic driving experience. As with ECO mode, the predefined speed scenarios are tested to analyse the trade-offs between enhanced performance and battery efficiency.

3.6 Summary

This project, therefore, develops a framework comprehensive in nature to monitor the life of a high-voltage battery fitted in a hybrid electric vehicle through the derivation of OBD II devices. The system seeks to collect real-time data on the state of the battery, identification of failure modes, and advice on how to improve battery life and, consequently, vehicle performance and, more specifically, the line of cars the Toyota Prius 3 is. In view of the integration of OBD-II technology, the project will analyse battery parameters under various conditions to offer a window into battery behaviours and efficiency.

The innovation in the outlined project takes the form of selecting the project name that indicates the purpose of the research, developing a well-structured project outline, and developing software to interface with the OBD tools for real-time hardware monitoring and comprehensive data-logging. It is also highly user-friendly due to rigorous testing and debugging to make it OBD protocol centric. A great interface designed for easy installation and use, along with full documentation, will make the proposed software easily acceptable in OS platforms.

In the process, the project showcases the innovative technology and efficiency of the battery system used in the Toyota Prius. Preliminary testing will review and collect real-time data on the battery's parameters under various conditions, then project insight into the health and characteristics of battery operation. This will help with the formulation of optimized management of the battery, use of energy, and planning of routes supported by the knowledge garnered; thus, an increase in the performance and efficiency of hybrid vehicles.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents a detailed analysis of the data gathered from the Hybrid Assistant application on high-voltage battery parameters. The focus of this work is to show how these parameters change under various conditions evaluated throughout this project. These results will be represented in various forms, such as texts, tables, and graphical figures, for clear explanations of the changes of parameters in different modes of operation. This analysis will cover an overview of the battery characteristics, performance, efficiency, and reliability.

4.2 Data Collection

The performance and efficiency of HEVs completely depend on the proper management and understanding of various high-voltage battery parameters. This section presents data collection and comparative analysis of High-Voltage Battery critical parameters, including High-Voltage Battery's Temperature, State of Charge (SOC), and the Charge and Discharge Current Level of the High-Voltage Battery. Based on these parameters, the operational dynamics and driving performance of the HEVs can be analysed in different driving modes.

4.2.1 High-Voltage Battery's Temperature

4.2.1.1 Accelerating: ECO Mode

During acceleration in ECO mode, the temperature does not vary much since it lies within a range of 32°C to 34°C at different speeds can be seen in the Figure 4.1 below. With increased speed, such as at 60 km/h, this increases to as high as 34°C. This variation of temperature is very important to battery life and performance.

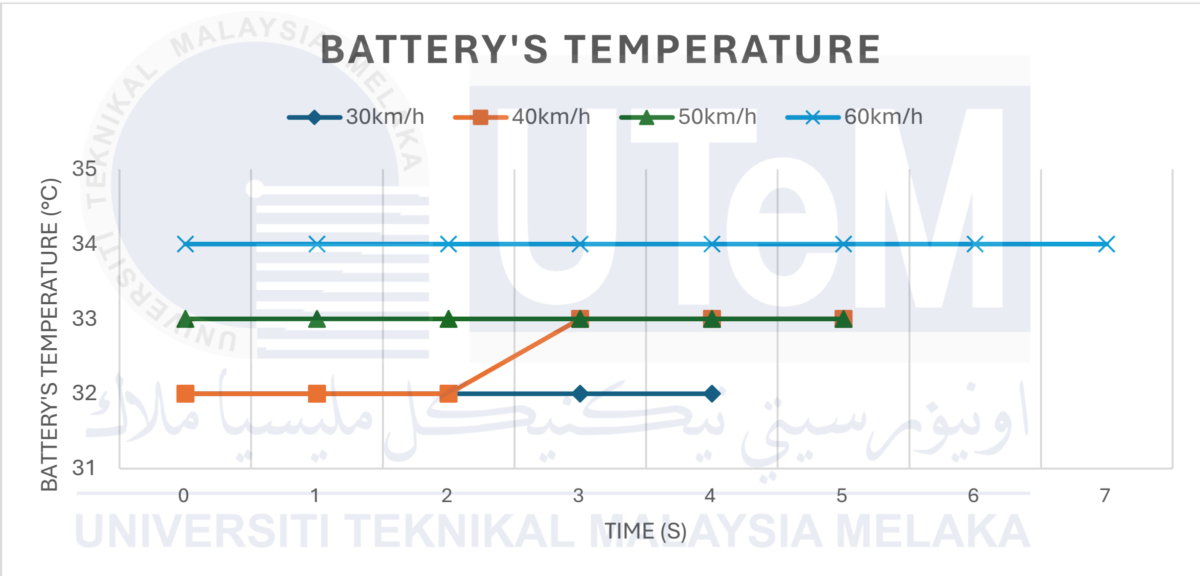

Figure 4.1 Battery's Temperature (°C) vs time (s) during accelerating in ECO Mode.

These operational temperatures are relatively moderate for a nickel-metal hydride battery, where the degradation is very slow at this temperature range. Maintaining this range reduces thermal stress in these cells continuously, which ultimately prolongs its life. It also shows very stable temperatures for the acceleration events in ECO mode. This means good energy usage without considerable heat generation or proper heat management inside the battery pack, which is indicative of the core feature-optimization for high fuel efficiency with less waste of energy.

4.2.1.2 Accelerating: SPORT Mode

The acceleration in SPORT mode shows in Figure 4.2, within the temperature range of 30 to 31°C, the battery behaves much more constantly across a wide range of speeds. Hence, from this, one could conclude that in SPORT mode, cooling and thermal control is prioritized-even when energy demand must be increased by sportive driving.

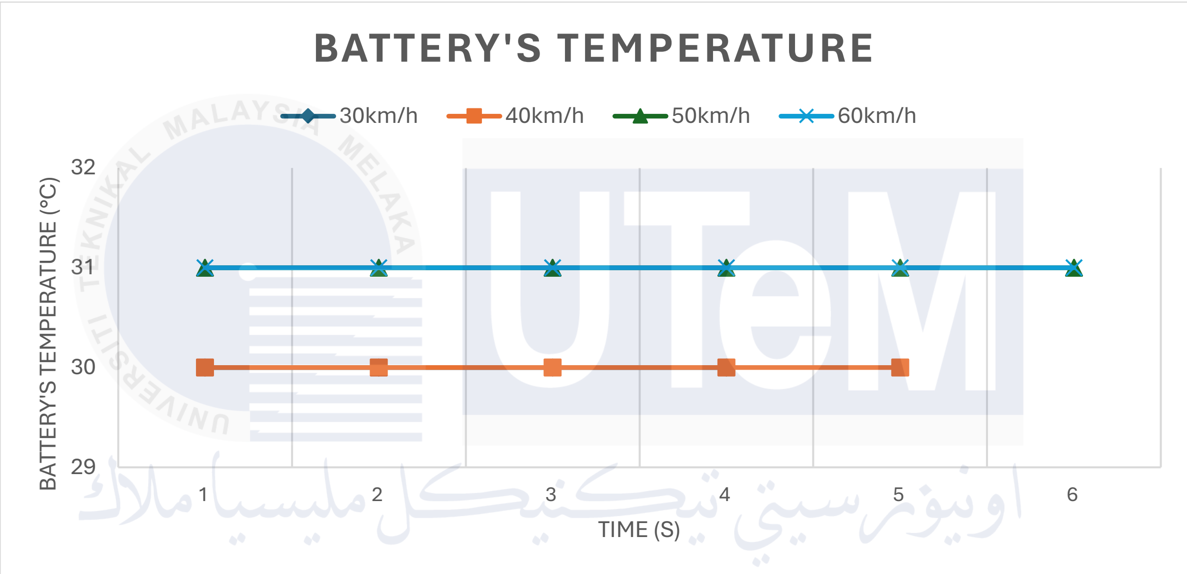

Figure 4.2 Battery’s Temperature (°C) vs time (s) during accelerating in SPORT Mode.

Lower and stable temperatures contribute to minimizing degradation, as chemical reactions responsible for battery wear are slowed down, probably reducing long-term degradation in batteries. Besides, the effective cooling system ensures that the battery is always able to provide high power output during aggressive driving without efficiency loss or risk of overheating.

4.2.1.3 Decelerating: ECO Mode

During deceleration, in ECO Mode, temperatures increase to 40-41°C for the batteries as shown in Figure 4.3. It is explained by the intensive work of regenerative braking that generated much heat in its process of energy recuperation. Within these limits, temperatures are not at a critical level; however, constant staying within the upper limit of 40-41°C may slightly increase the aging velocity.

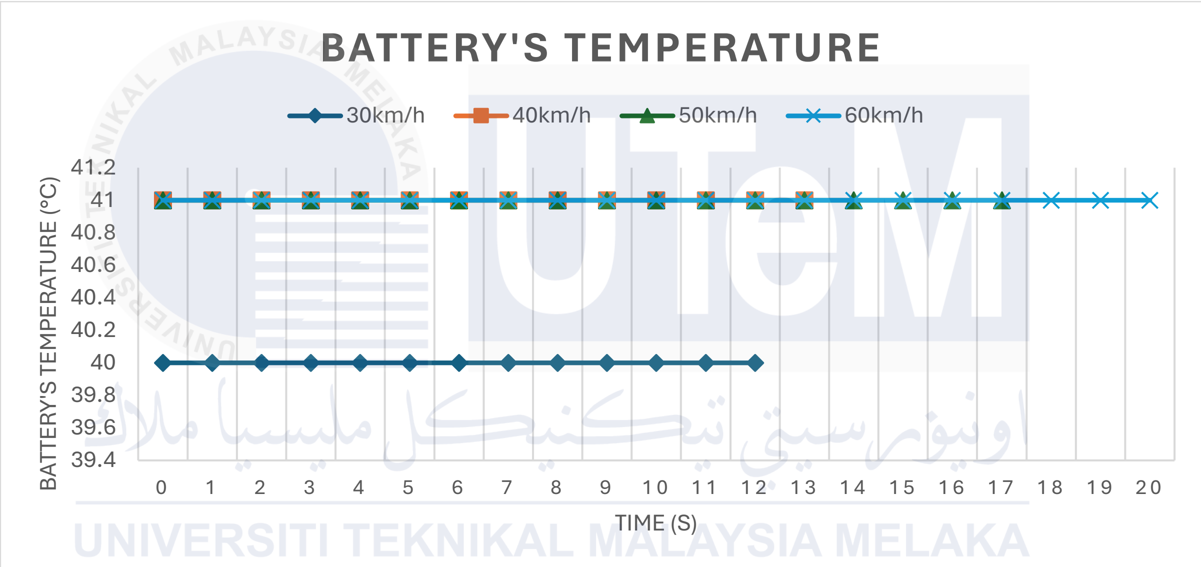

Figure 4.3 Battery's Temperature (°C) vs time (s) during decelerating in ECO Mode.

Higher temperatures could cause the degradation of the electrolyte and electrode wear over time, which might slightly reduce the overall capacity of the battery, affecting energy storage and delivery efficiency in the long run.

4.2.1.4 Decelerating: SPORT Mode

During deceleration with SPORT Mode engaged, the battery temperatures rose more moderately at 34-38°C but were lower compared to the rises observed in ECO Mode.

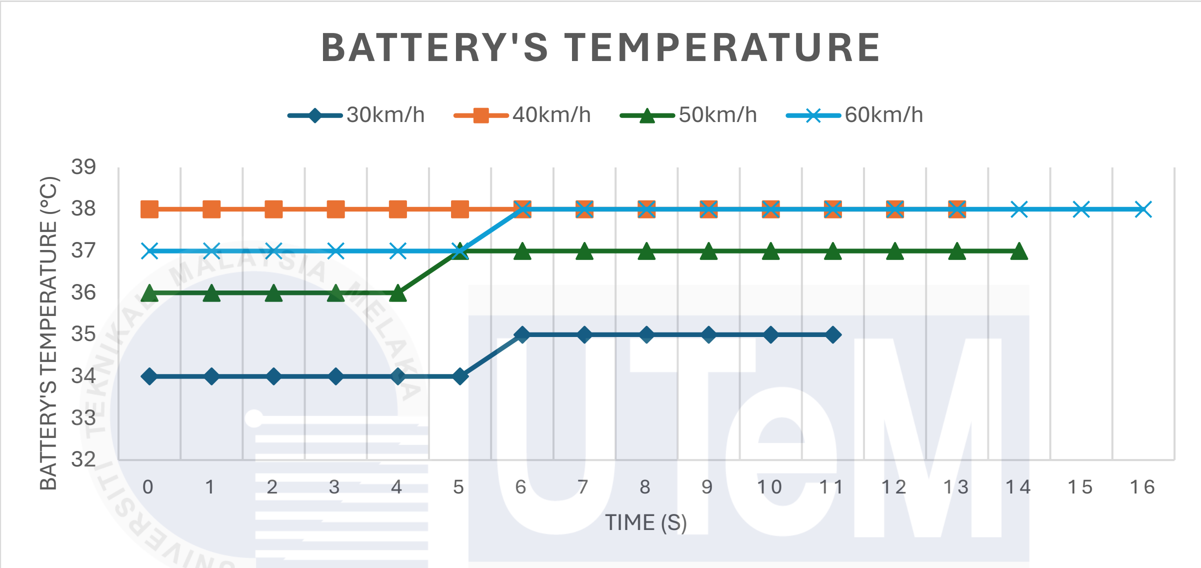

Figure 4.4 Battery's Temperature (°C) vs time (s) during decelerating in SPORT Mode.

This would mean regenerative braking is less intensive in SPORT Mode, or the heat dissipation is more efficient. Lower temperatures in the case of SPORT Mode contribute positively to the lifetime of the battery because such temperatures lower the risk of thermal degradation, even for very demanding driving conditions and sportier.

4.2.2 High-Voltage Battery’s State-of-Charge

4.2.2.1 Accelerating: ECO Mode

In ECO Mode, during acceleration, Figure 4.5 shows SOC decreases gradually at a rate of 0.04-0.05% per second, while the range remains between 41 and 46%. The gradual decline in SOC during acceleration proves that the energy is drawn from the battery in such a way that it does not burden its cells too much.

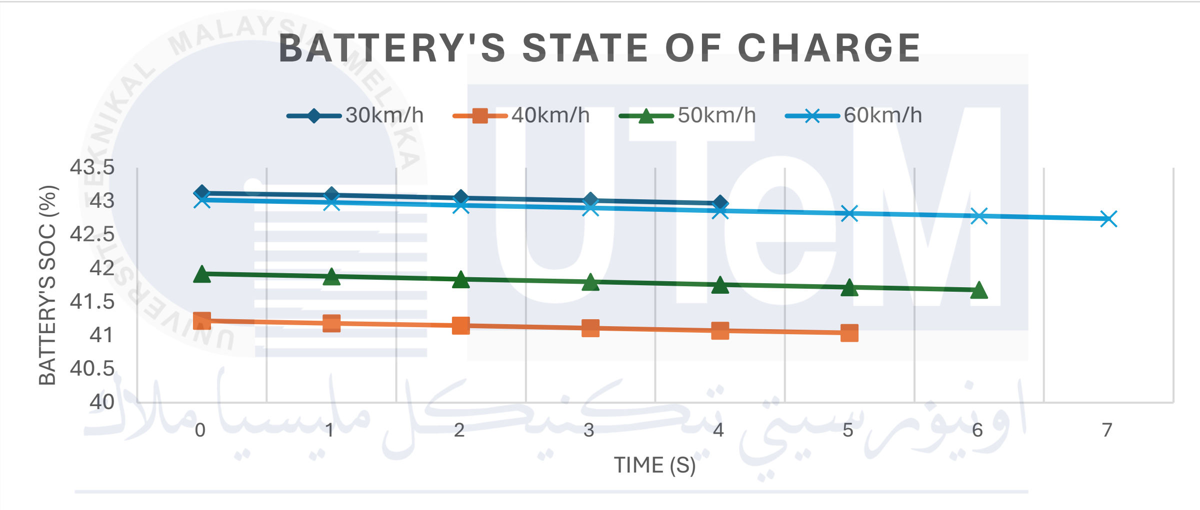

Figure 4.5 Battery’s SOC (%) vs time (s) during accelerating in ECO Mode.

This type of smooth discharge is beneficial for the life cycle of nickel-metal hydride batteries, since rapid changes in SOC introduce stress and accelerate degradation. Besides, the controlled discharge ensures consistent power delivery during acceleration, aligning with ECO Mode's focus on energy efficiency and smoother operation.

4.2.2.2 Accelerating: SPORT Mode

As illustrated in Figure 4.6, during the SPORT Mode, SOC declines much more steeply from 46% to 41%, notably for higher speed ranges. Such steepness could thus suggest a larger requirement for power due to the thermal and electrochemical solicitations the battery goes through.

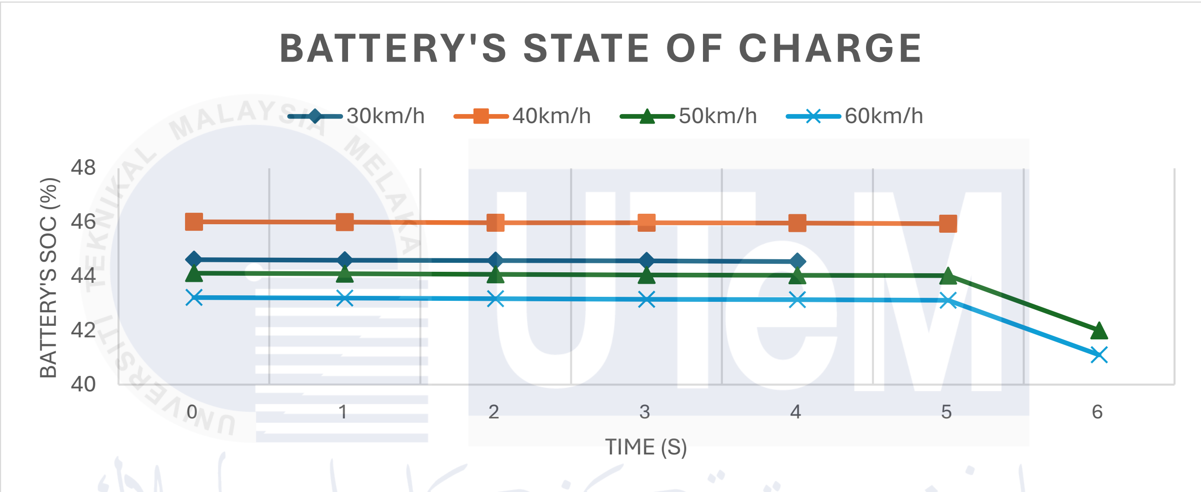

Figure 4.6 Battery's SOC (%) vs time (s) during accelerating in SPORT Mode.

With time, high-current discharges more frequently might accelerate degradation and reduce the usable capacity of the battery. While SPORT Mode is all about power and responsiveness, such aggressive SOC changes may affect the long-term health of the battery. However, the hybrid system is likely designed to tolerate these short bursts without significant immediate effects on the battery.

4.2.2.3 Decelerating: ECO Mode

In Figure 4.7, the SOC increases from 44% to 49.5% at 60 km/h during deceleration in ECO Mode, showing a good and efficient regeneration of energy. This consistent increase in SOC signifies that this kind of regenerative braking effectively recovers the maximum amount of energy.

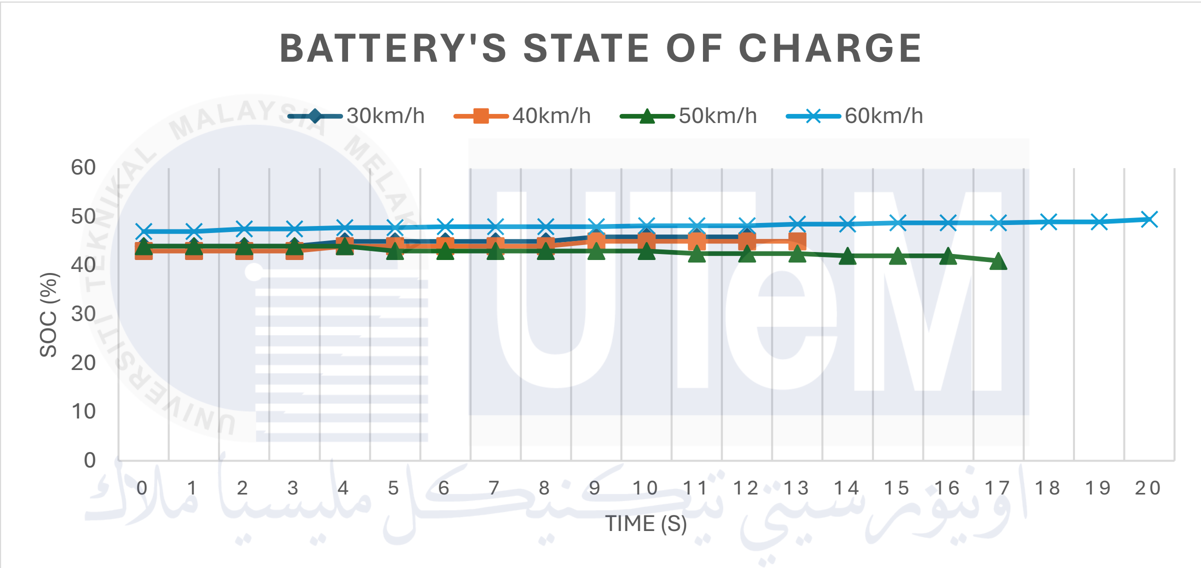

Figure 4.7 Battery's SOC (%) vs time (s) during decelerating in ECO Mode.

ECO Mode assists the sustaining of electric operation of the vehicle by recovering energy during deceleration and reduces the frequency of use of the internal combustion engine, thus giving better fuel economy. Besides, the moderate regeneration rate is good for the battery health since extreme charge currents could lead to capacity fade over time due to accumulated internal resistance build-up.

4.2.2.4 Decelerating: SPORT Mode

Figure 4.8 shows that, in SPORT Mode, the graph of battery SOC exhibits different trends at various speeds during deceleration. While at 30km/h, the SOC gradually increases from 44% to 46%, at 40km/h, it decreases slightly from 48% to 47%. Within the 50km/h speed condition, SOC decreases gradually from 49% to 47%, while at 60km/h, SOC only shows minor fluctuations between 49% and 48%. Aggressive initial regeneration may introduce higher charge currents that could increase internal heat and contribute to faster degradation if this pattern is repeated.

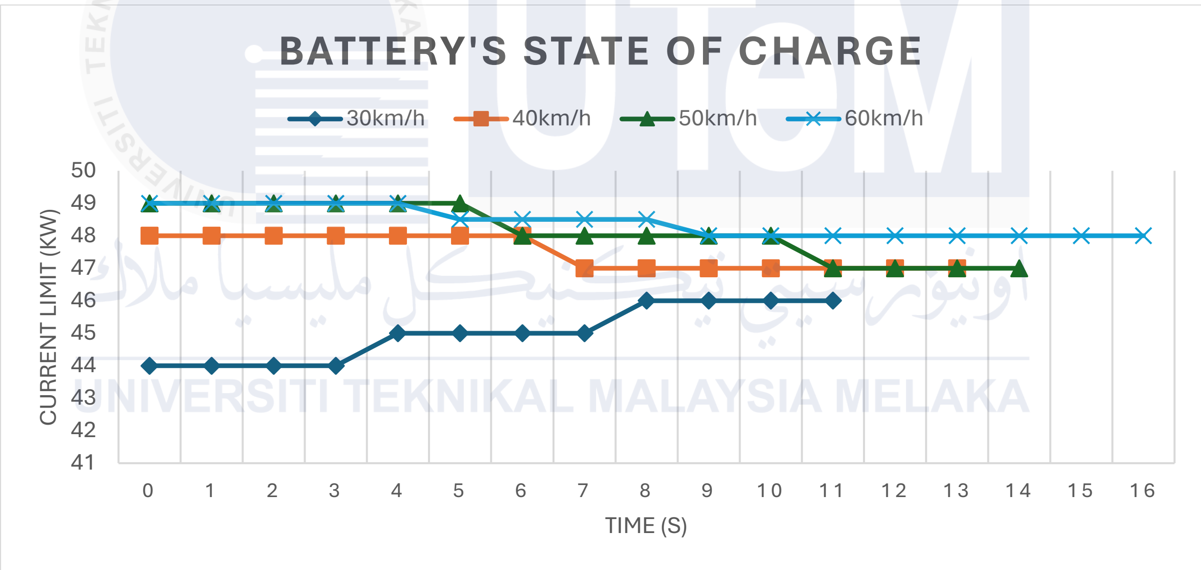

Figure 4.8 Battery's SOC (%) vs time (s) during decelerating in SPORT Mode.

These patterns are indicative that the SOC of the battery during deceleration phases keeps on being relatively stable, although most of the time with higher speeds maintaining higher SOC. These smooth and gradual changes in SOC are indicative of an effective energy management during deceleration; the data more particularly underlines the fact that the regenerative braking system seems most effective at keeping charge when the vehicle is running at higher speeds. Besides, the lower energy recovery during SPORT Mode reduces system efficiency, which directly reflects in increased fuel consumption because the internal combustion engine needs to compensate for the reduced electric contribution.

4.2.3 High-Voltage Battery Current Limit

4.2.3.1 ECO Mode

As shown in Figure 4.9, during ECO Mode, CCL maintains approximately -25.2kW in standard operation, with somewhat reduced values between -21.6kW and -24kW when decelerating as shown in Figure 4.10. The current limit of the discharging power source (DCL) is always limited to 20.44Kw for both accelerating and decelerating.

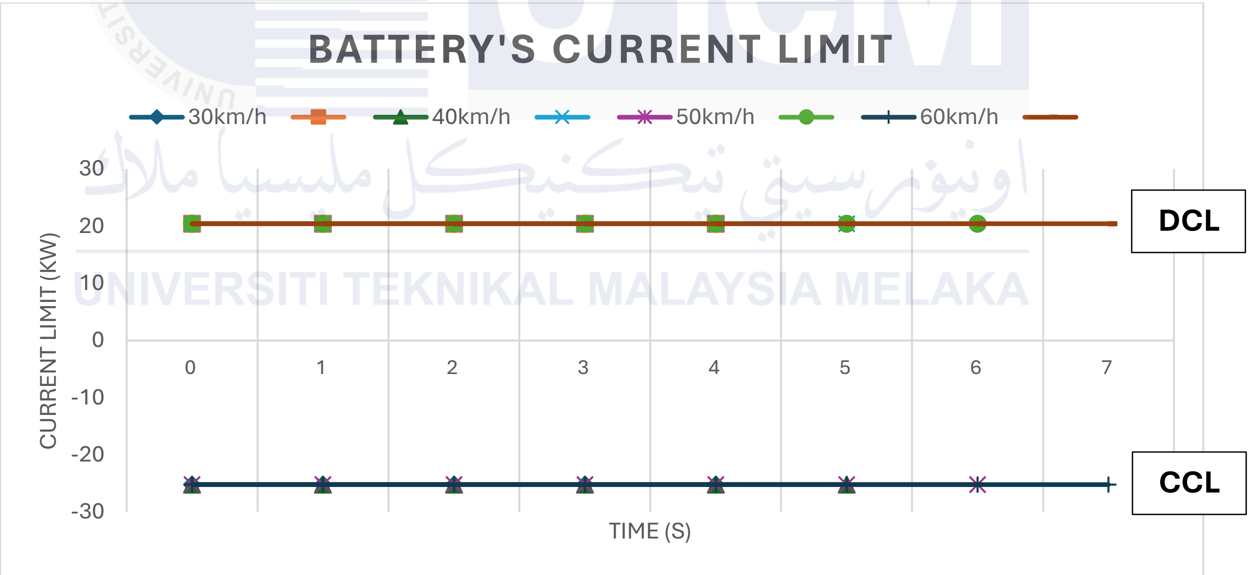

Figure 4.9 Battery's Current Limit (kW) vs time (s) during accelerating in ECO Mode.

These moderate and steady current limits mark effective protection of the battery against unnecessary stress factors that may influence cell overloads. This protects cell integrity, ensuring a high cycle lifetime, and can avoid rapid wear from high-current peaks. Lower charging currents when decelerating indicate a much more delicate regenerative braking approach, lowering thermal stress by avoiding excessive currents when charging the batteries-which are two main aspects of preserving the battery health. Moreover, the limit on steady-state discharge current guarantees predictable power output during acceleration, thus ensuring smooth and fuel-efficient operation.

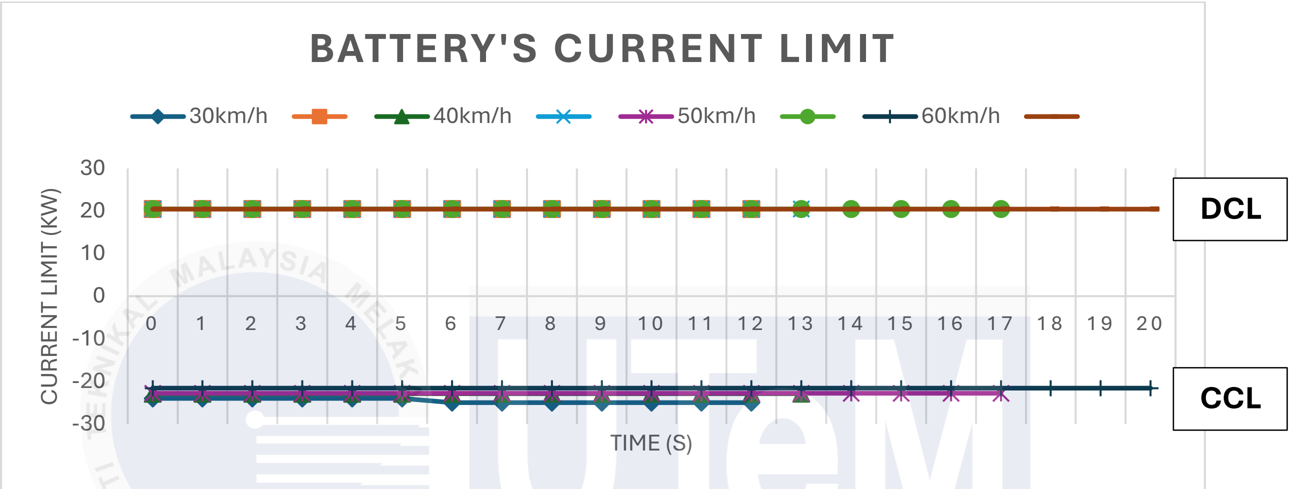

Figure 4.10 Battery’s Current Limit (kW) vs time (s) during decelerating in ECO mode.

4.2.3.2 SPORT Mode

In SPORT Mode, both the CCL and DCL are likely in ECO Mode but show more variation, especially during deceleration as can be seen in Figure 4.12. The higher variability in current limits is indicative of the emphasis on immediate performance in SPORT Mode, quick energy transfer for aggressive driving, and responsive acceleration.

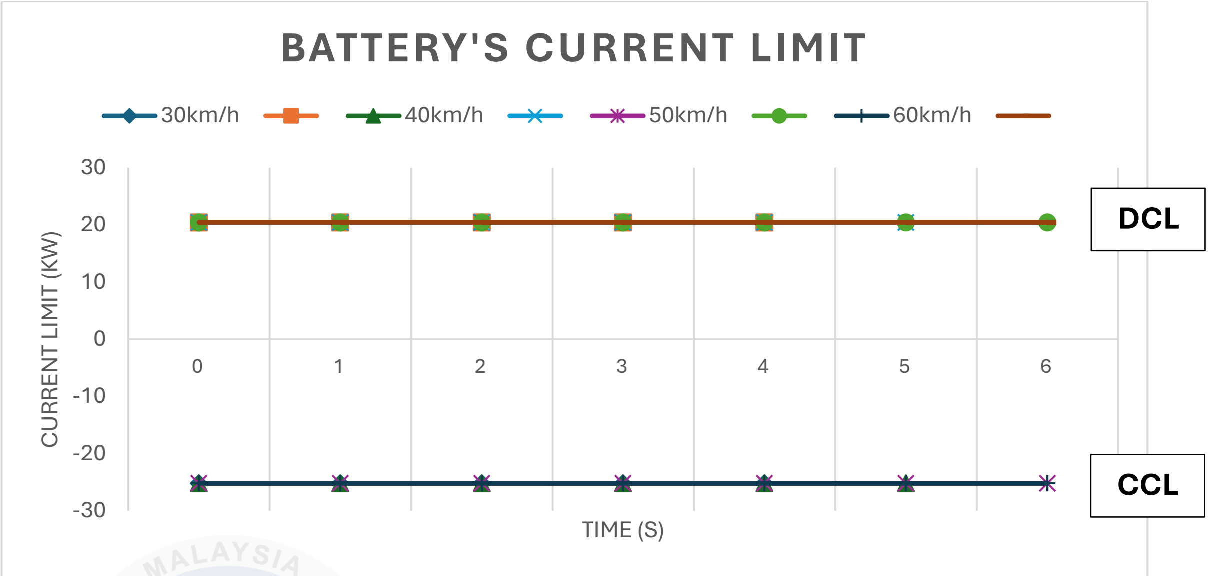

Figure 4.11 Battery's Current Limit (kW) vs time (s) during accelerating in SPORT mode.

However, frequent fluctuations in current limits introduce thermal and mechanical stresses within the battery cells, which, with time, can result in localized wear that could reduce the overall capacity and efficiency of the battery.

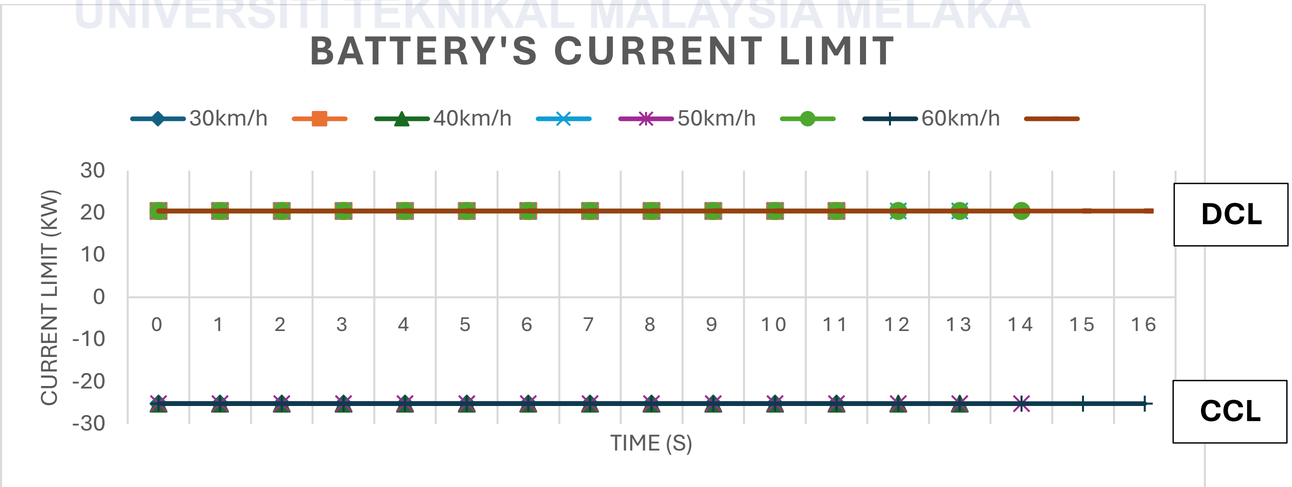

Figure 4.12 Battery's Current Limit (kW) vs time (s) during decelerating in SPORT mode

4.3 Observations

Table 4.1 Evaluation of Prius 3's High-Voltage Battery

Driving Mode and Speed		Temperature (°C)		State-of-Charge (%)		Current Limit (kW)	
			Exp		Exp		Exp
ECO	Accelerating	Operating range: 20 – 40 Allowable range: -10 – 50	32 – 34	Operating range: 20 – 80 Allowable range: 10 – 90	41 – 46	CCL: 5 – 20 DCL: 10 – 50	CCL: -25.2 DCL: 20.44
	Decelerating		40 – 41		39 – 49		CCL: -21.6 DCL: 20.44
SPORT	Accelerating		30 – 31		41 – 46		CCL: -25 DCL: 20
	Decelerating		34 – 38		44 – 49		CCL: -26 DCL: 20

4.3.1 High-Voltage Battery's Temperature

Based on Table 4.1 the operational temperatures experienced in both ECO and SPORT modes were from 30-41°C and were generally within the safe range of nickel-metal hydride batteries. However, some minor acceleration in aging over the life span may result from repeated peak exposures during ECO Mode deceleration at the top of that range (40-41°C). Operating at higher or lower temperature than the allowable rang which is between -10°C to 50°C, may increase thermal stress and wear on the battery components. If such patterns continue, they could shorten the total years of serviceability of the battery by a few years.

With increasing temperature, chemical reactions within the battery become more vigorous and the capacity fade likelihood also starts to increase. It could mean a gradual decrease in the capability of the battery to hold a charge and therefore an overall reduction in the electric-only range and overall efficiency.

Regarding performance, stable acceleration temperatures in both modes reflect robust thermal management that supports consistent power delivery with no instance of thermal throttling. However, higher deceleration temperatures in ECO Mode can ultimately affect short-term performance whenever the battery starts to approach its thermal threshold. Again, this reduces efficiency in regenerative braking, further weakening the overall systems' performance in the process.

4.3.2 High-Voltage Battery's State-of-Charge

In ECO Mode, the gradual SOC changes and optimal SOC range are indicative of better battery preservation over time. Consistently operating the battery near the allowable range may lead to faster capacity loss over time. The controlled fluctuations also tend to minimize the stress on the battery, therefore longevity. Such aggressive SOC fluctuations in SPORT Mode may quicken the wear on battery cells and potentially result in a slight reduction of battery lifespan if used more frequently.

Rapid cycling of SOC may result in more mechanical stress in the electrode materials and a faster degradation rate in the case of electrolyte components. Changes in SOC are steeper in SPORT Mode, which may lead to localized degradation of some cells. This decreases both the overall capacity of the battery pack and its effective energy efficiency.

ECO Mode makes the system more efficient, which it allows for better energy recovery and maintains SOC changes in balance, reaching smoothness and economy. On the other side, SPORT Mode will privilege immediate delivery and performance but will have to pay with reduced energy recovery and higher consumption because the internal combustion engine will balance the diminished electric contribution.

4.3.3 High-Voltage Battery's Charge/Discharge Current Limit

From a performance perspective, ECO Mode benefits from consistent current limits that provide stable energy delivery. This stability optimizes efficiency and ensures smooth transitions between charging and discharging that are in line with ECO Mode's goals of maximizing fuel economy and maintaining predictable vehicle behaviours. In contrast, SPORT Mode features higher and more variable current limits, allowing for more aggressive energy usage. This improves responsiveness and power delivery but at the cost of somewhat reduced efficiency and possibly higher thermal loads on the battery.

This further enhances the battery life in ECO Mode, which causes slower degradation from more consistent current limits, and lower charging currents upon deceleration minimizes stress on the battery cells and reduces further accelerated degradation. That would, of course, offer an increased usable life after some time since the cells aren't that worn out. Furthermore, the battery temperatures remain optimum because of reduced charging current while decelerating, which avoids heat-related degrading too. On the contrary, SPORT Mode involves higher chances of deterioration. Variation of current limits, along with the high energy request, can generate greater thermal and mechanical stress. If all conditions are repeated several times they will accelerate the capacity fade, consequently reducing the real life of the battery.

The moderate and consistent current limits of ECO Mode contribute to reducing the rate of internal resistance build-up and electrolyte degradation, enabling the battery to store and deliver energy efficiently over time. In contrast, SPORT Mode, with its more aggressive current fluctuations, may cause microstructural damage to the electrode materials, increasing the rate of degradation. This will result in reduced capacity, higher internal resistance, and diminished efficiency of regenerative braking in the long run.

4.4 Summary

The analysis of high-voltage battery parameters in HEVs gives evidence of big influences of operating modes on battery performance, lifetime, and efficiency. In the ECO Mode, the battery exhibits a stable temperature profile, gradual State-of-Charge variations, and consistent charge/discharge current limits, which all enhance longevity by minimizing thermal and mechanical stresses, preserving cell integrity, and reducing the rate of capacity fade.

Besides, the energy recovery during deceleration is well-balanced in ECO Mode, enhancing fuel economy and maintaining optimum efficiency of the system.

At the same time, SPORT Mode is more concerned with immediate performance and responsiveness, where lower stable temperatures at acceleration, steeper SOC changes, and variable current limits are observed. While these characteristics serve the purposes of dynamic driving and rapid energy delivery, they introduce additional thermal and mechanical stress onto the battery. This can accelerate capacity fade and electrolyte degradation over time, which would slightly shorten the lifespan and efficiency of the battery. However, with SPORT Mode, the robust thermal management prevents the battery from going out of a safe operating range and thus reduces the chance of severe degradation.

To conclude, both modes keep the parameters of the battery within safety thresholds, while their long-term effects are different. ECO Mode supports better preservation and efficiency of the battery, which is ideal for everyday use, while SPORT Mode trades some longevity for increased performance. In both modes, effective thermal and energy management systems ensure consistent power delivery and regenerative braking efficiency, underlining the importance of tailored operating strategies for hybrid vehicles to optimize their battery performance and reliability.

CHAPTER 5

CONCLUSION

This proposal for the research project was done based on how to use OBD-II with Toyota Prius Hybrid to operate runtime, high voltage, and battery monitoring with load testing. From the general conclusion, it emanates that if the trend of maintenance of high accuracy is maintained during continuous monitoring of health and performance of a battery, it will be important to operate the HEVs at their optimum features. With the adoption of OBD-II, the critical information for a state of charge, state of health, temperature, cell voltages of high voltage batteries, and cumulative consumption of energy would be able to be compiled.

This allowed close monitoring of the battery behaviours under diverse driving conditions so that efficiency performance and possible degradation mechanisms could be understood. The results show that the adoption of periodic monitoring techniques drastically minimizes chances of unexpected battery failures, thus enhancing the extendibility, reliability, and durability of HEVs; it demonstrated that OBD-II devices do work as an effective tool against battery life monitoring for a cost-effective and viable strategy implemented both by vehicle owners and fleet managers.

This also filled the gap that the current monitoring systems have today, thus proving that the technology of OBD-II is possible to be implemented along with a friendly user software application to allow live data viewing and diagnostics in making intelligent decisions in vehicle maintenance and operation for the end user.

RECOMMENDATION

This is to conclude that future projects have highly advanced diagnostic tools and algorithms for more precise data analysis. By integrating machine learning with predictive analysis, this could make possible the anticipation of battery issues before they become critical, hence improving on maintenance schedules with less unexpected down time. This will also be possible in increasing the scope of diagnostic tools to include thermal management and battery aging indicators in gaining comprehensive understanding of battery health and performance. These will not only upgrade the accuracy of the monitoring system but also provide the way for much more proactive and effective management of batteries.

Development should be done and implemented in this research is, the testing process should begin systematically with testing in ECO mode during acceleration. After completing this phase, the engine should be allowed to rest and return to its initial state to stabilize any potential thermal or performance fluctuations before proceeding further. Next, the focus shifts to testing the battery in ECO mode during deceleration, followed by another break for the system to return to its initial state. This sequential testing in ECO mode is important to understand how the battery responds to different driving conditions while prioritizing fuel efficiency and low power demand. Following the completion of the ECO mode tests, the procedure moves to testing the battery under SPORT mode during acceleration and deceleration. By following this structured and progressive sequence, the research ensures that each test is conducted under optimal and controlled conditions, providing accurate findings into the battery's performance, lifespan, and degradation characteristics across various driving modes and speed.

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APPENDIX

APPENDIX 1 PSM 1 Gantt Chart

Week / Task		W1	W2	W3	W4	W5	W6	W7	W8 (Mid Term Break)	W9	W10	W11	W12	W13	W14
PSM 1 Briefing	P														
	A														
Meeting with Supervisor	P														
	A														
Log Book	P														
	A														
Chapter 1 : Introduction	P														
	A														
Chapter 2 : Literature Review	P														
	A														
Chapter 3 : Methodology	P														
	A														
Chapter 4 : Preliminary Result	P														
	A														
Software Implementation & Test Run	P														
	A														
Preliminary Result	P														
	A														
Report Composing	P														
	A														
Slide Presentation Preparation	P														
	A														
Presentation	P														
	A														

Plan	
Actual	

APPENDIX 2 **PSM 2 Gantt Chart**

Week / Task		W1	W2	W3	W4	W5	W6	W7	W8 (Mid Term Break)	W9	W10	W11	W12	W13	W14	W15
PSM 2 Briefing	P															
	A															
Meeting with Supervisor	P															
	A															
LogBook	P															
	A															
Scan Tool Implementation	P															
	A															
Test Run	P															
	A															
Chapter 3: Methodology	P															
	A															
Chapter 4 : Result and discussion	P															
	A															
Report Composing	P															
	A															
Report Submission	P															
	A															
Technical report writing	P															
	A															
Poster Presentation Preparation	P															
	A															
Presentation	P															
	A															

Plan	
Actual	

APPENDIX 3 Tables of Data

3.1 High-Voltage Battery's Temperature

3.1.1 Accelerating

TIME (S)	ECO MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
0	32	32	33	34
1	32	32	33	34
2	32	32	33	34
3	32	33	33	34
4	32	33	33	34
5	-	33	33	34
6	-	-	-	34
7	-	-	-	34

TIME (S)	SPORT MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
1	30	30	31	31
2	30	30	31	31
3	30	30	31	31
4	30	30	31	31
5	-	30	31	31
6	-	-	31	31

3.2.2 Decelerating

TIME (S)	ECO MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
0	40	41	41	41
1	40	41	41	41
2	40	41	41	41
3	40	41	41	41
4	40	41	41	41
5	40	41	41	41
6	40	41	41	41
7	40	41	41	41
8	40	41	41	41
9	40	41	41	41
10	40	41	41	41
11	40	41	41	41

12	40	41	41	41
13	-	41	41	41
14	-	-	41	41
15	-	-	41	41
16	-	-	41	41
17	-	-	41	41
18	-	-	-	41
19	-	-	-	41
20	-	-	-	41

TIME (S)	SPORT MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
0	34	38	36	37
1	34	38	36	37
2	34	38	36	37
3	34	38	36	37
4	34	38	36	37
5	34	38	37	37
6	35	38	37	38
7	35	38	37	38
8	35	38	37	38
9	35	38	37	38
10	35	38	37	38
11	35	38	37	38
12	-	38	37	38
13	-	38	37	38
14	-	-	37	38
15	-	-	-	38
16	-	-	-	38

3.2 High-Voltage Battery's State-of-Charge

3.2.1 Accelerating

TIME (S)	ECO MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
0	43.12	41.22	41.92	43.02
1	43.09	41.18	41.88	42.98
2	43.05	41.15	41.84	42.94
3	43.01	41.11	41.8	42.9
4	42.97	41.07	41.76	42.86
5		41.04	41.72	42.82

6			41.68	42.78
7				42.74

TIME (S)	**SPORT MODE**			
	SPEED (KM/H)			
	30KM/H	**40KM/H**	**50KM/H**	**60KM/H**
0	44.62	46.02	44.12	43.22
1	44.6	46.01	44.1	43.2
2	44.59	45.99	44.08	43.18
3	44.57	45.98	44.06	43.16
4	44.55	45.97	44.04	43.14
5	-	45.95	44.03	43.12
6	-	-	42.01	41.1

3.2.2 Decelerating

TIME (S)	**ECO MODE**			
	SPEED (KM/H)			
	30KM/H	**40KM/H**	**50KM/H**	**60KM/H**
0	44	43	44	47
1	44	43	44	47
2	44	43	44	47.5
3	44	43	44	47.5
4	45	44	44	47.8
5	45	44	43	47.8
6	45	44	43	48
7	45	44	43	48
8	45	44	43	48
9	45.9	45	43	48
10	45.9	45	43	48.2
11	45.9	45	42.5	48.2
12	45.9	45	42.5	48.2
13	-	45	42.5	48.5
14	-	-	42	48.5
15	-	-	42	48.8
16	-	-	42	48.8
17	-	-	41	48.8
18	-	-	-	49
19	-	-	-	49
20	-	-	-	49.5

TIME (S)	SPORT MODE			
	SPEED (KM/H)			
	30KM/H	40KM/H	50KM/H	60KM/H
0	44	48	49	49
1	44	48	49	49
2	44	48	49	49
3	44	48	49	49
4	45	48	49	49
5	45	48	49	48.5
6	45	48	48	48.5
7	45	47	48	48.5
8	46	47	48	48.5
9	46	47	48	48
10	46	47	48	48
11	46	47	47	48
12	-	47	47	48
13	-	47	47	48
14	-	-	47	48
15	-	-	-	48
16	-	-	-	48

3.3 High-Voltage Battery’s Current Limit

3.3.1 Accelerating

TIME (S)	ECO MODE							
	30KM/H		40KM/H		50KM/H		60KM/H	
	CCL	DCL	CCL	DCL	CCL	DCL	CCL	DCL
0	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
1	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
2	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
3	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
4	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
5	-	-	-25.2	20.44	-25.2	20.44	-25.2	20.44
6		-	-	-	-25.2	20.44	-25.2	20.44
7	-	-	-	-	-	-	-25.2	20.44

TIME (S)	SPORT							
	30KM/H		40KM/H		50KM/H		60KM/H	
	CCL	DCL	CCL	DCL	CCL	DCL	CCL	DCL
0	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
1	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
2	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
3	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
4	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
5	-	-	-25.2	20.44	-25.2	20.44	-25.2	20.44
6	-	-	-	-	-25.2	20.44	-25.2	20.44

3.3.2 Decelerating

TIME (S)	ECO MODE							
	30KM/H		40KM/H		50KM/H		60KM/H	
	CCL	DCL	CCL	DCL	CCL	DCL	CCL	DCL
0	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
1	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
2	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
3	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
4	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
5	-24	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
6	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
7	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
8	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
9	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
10	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
11	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
12	-25	20.44	-22.9	20.44	-22.8	20.44	-21.6	20.44
13	-	-	-22.9	20.44	-22.8	20.44	-21.6	20.44
14	-	-	-	-	-22.8	20.44	-21.6	20.44
15	-	-	-	-	-22.8	20.44	-21.6	20.44
16	-	-	-	-	-22.8	20.44	-21.6	20.44
17	-	-	-	-	-22.8	20.44	-21.6	20.44
18	-	-	-	-	-	-	-21.6	20.44
19	-	-	-	-	-	-	-21.6	20.44
20	-	-	-	-	-	-	-21.6	20.44

TIME (S)	SPORT MODE							
	30KM/H		40KM/H		50KM/H		60KM/H	
	CCL	DCL	CCL	DCL	CCL	DCL	CCL	DCL
0	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
1	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
2	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
3	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
4	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
5	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
6	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
7	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
8	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
9	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
10	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
11	-25.2	20.44	-25.2	20.44	-25.2	20.44	-25.2	20.44
12	-	-	-25.2	20.44	-25.2	20.44	-25.2	20.44
13	-	-	-25.2	20.44	-25.2	20.44	-25.2	20.44
14	-	-	-	-	-25.2	20.44	-25.2	20.44
15	-	-	-	-	-	-	-25.2	20.44
16	-	-	-	-	-	-	-25.2	20.44