MONITORING OF MOTOR GENERATOR AND INVERTER OPERATIONS USING OBD DIAGNOSTICS DEVICE IN HYBRID VEHICLE

NUR ANISSA NADIRA BINTI ZULKEFLI

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**A thesis submitted
in fulfilment of the requirements for the degree of
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Fakulti Teknologi dan Kejuruteraan Mekanikal
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DEDICATION

To honour my late grandfather, Hj Hamzah bin Abdul, this thesis is devoted. His constant support, wisdom and encouragement guided me throughout this life. Even though he is no longer with me in physically but forever rent free in my mind giving me motivation and support. This work is a tribute to his enduring support and invaluable lessons he imparted. I am forever grateful for his love and guidance, which have helped me shape the person I am today. Thank you for always believing in me. This accomplishment is for you.

ABSTRACT

Hybrid Electric Vehicle (HEV) are pivotal in addressing environmental challenges, emphasizing reduced emissions and fuel efficiency. Despite their advancements, optimizing HEV performance through real-time monitoring remains unexplored. This study investigates the operations of motor generator and inverters in Toyota Prius 3 using the Launch X431 Pro Scan Tool, focusing on key parameters such as RPM, torque, inverter temperature and engine coolant temperature across Eco and Sport modes. The research identifies critical gaps in understanding HEV dynamics and aims to enhance performance monitoring capabilities. The methodology includes real-time data collection during controlled test runs, analysing the variations in engine parameters under different speeds and driving modes. Results indicate that Eco mode prioritizes energy efficiency with smoother transitions, whereas Sport mode emphasizes performance with aggressive power delivery and higher thermal loads. These findings highlight the importance of advanced diagnostic tools improving HEV efficiency and sustainability. The study concludes that optimizing HEV operations through detailed parameter analysis can significantly contribute to environmentally friendly automotive advancements.

ABSTRAK

Kenderaan Elektrik Hibrid (HEV) adalah penting dalam menangani cabaran alam sekitar, menekankan pengurangan pelepasan dan kecekapan bahan api. Walaupun kemajuan mereka, prestasi HEV yang optimum melalui pemantauan masa nyata masih belum diterokai. Kajian ini menyiasat operasi penjana motor dan penyongsang dalam Toyota Prius 3 menggunakan Alat Imbas Pelancaran X431 Pro, memfokuskan pada parameter utama seperti RPM, tork, suhu penyongsang dan suhu penyejuk enjin dalam mod Eco dan Sport. Penyelidikan mengenal pasti jurang kritikal dalam memahami dinamik HEV dan bertujuan untuk meningkatkan keupayaan pemantauan prestasi. Metodologi termasuk pengumpulan data masa nyata semasa ujian terkawal, menganalisis variasi dalam parameter enjin di bawah kelajuan dan mod pemanduan yang berbeza. Keputusan menunjukkan bahawa mod Eco mengutamakan kecekapan tenaga dengan peralihan yang lebih lancar, manakala mod Sukan menekankan prestasi dengan penghantaran kuasa yang agresif dan beban terma yang lebih tinggi. Penemuan ini menyerlahkan kepentingan alat diagnostik lanjutan yang meningkatkan kecekapan dan kemampanan HEV. Kajian itu menyimpulkan bahawa mengoptimumkan operasi HEV melalui analisis parameter terperinci boleh menyumbang dengan ketara kepada kemajuan automotif yang mesra alam.

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My utmost appreciation goes to my very kind supervisor, Ts. Dr. Nur Rashid bin Mat Nuri @ Md Din for his invaluable guidance and continuous encouragement. His expertise and constant patience for guiding and providing priceless insights will forever be remembered. Special thanks to Mr. Muhammad Rabbani bin Abd Rasid for his assistance with the technical aspects and for facilitating access to the equipment needed for this project.

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LIST OF ABBREVIATIONS AND SYMBOLS

HEV	-	Hybrid Electric Vehicles
OBD-II	-	On Board Diagnostic II
ECU	-	Engine Control Unit
DTC	-	Diagnostic Trouble Codes
MIL	-	Malfunction Indicator Light
FCS	-	Fuel-Cell Systems
UC	-	Ultra-Capacitors
EMS	-	Energy Management Systems
FLC	-	Fuzzy Logic Control
GA	-	Genetic Algorithms
ECMS	-	Equivalent Consumption Minimization Strategy
CAV	-	Connected and Automated Vehicles
RDE	-	Real-World Driving Emissions
WLTC	-	Worldwide Harmonised Light Vehicles Test Cycle
SOC	-	State of Charge
BMS	-	Battery Management Systems
RPM	-	Revolution per Minute
ICE	-	Internal Combustion Engine
PSD	-	Power Split Device
MG1	-	Motor Generator 1
MG2	-	Motor Generator 2
PHEV	-	Plug-In Hybrid Vehicle
SHT	-	Series Hybrid Transmission
SPHT	-	Series-Parallel Hybrid Transmission
FCHEV	-	Fuel-Cell Hybrid Electric Vehicles
FTKM	-	Fakulti Teknologi & Kejuruteraan Mekanikal
SPM	-	Single Particle Model

SVM	-	Support Vector Machine
WOME	-	Waste Oil Methyl Ester
NEDC	-	New European Driving Cycle
ST	-	Spark Timing
MIT	-	Methanol Injection Timing
ETCS	-	Electronic Throttle Control System
RCP	-	Rapid-Control-Prototype
L/100km	-	Liters per 100 kilometers
Nm	-	Newton meter
km/h	-	Kilometers per hour
kW	-	Kilowatt
cc	-	Cubic centimeters
λ	-	Fuel Ratio
MSR	-	Methanol Energy Substitution Ratios
HC	-	Hydrocarbon
NOx	-	Nitrogen Oxide
CO	-	Carbon Monoxide
ηet	-	Brake Thermal Efficiency
IT	-	Inverter Temperature
ECT	-	Engine Coolant Temperature

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The automobile industry has undergone an evolution as a result of the search for sustainable transportation solutions, with hybrid vehicles emerging as a major focal point in the effort to cut emissions and increase fuel efficiency. Hybrid cars are a conventional gasoline-powered cars since they combine internal combustion engines with electric propulsion systems. Nonetheless, maximising the fuel efficiency of hybrid cars requires a sophisticated comprehension of their performance indicators and operational dynamics.

In this regard, On-Board Diagnostics (OBD) diagnostic technology can be very helpful regarding observing and analysing fuel consumption patterns in hybrid cars. OBD systems operate with a considerable amount of real-time data that could be tapped into for evaluating and optimizing fuel economy in hybrid powertrains. Essentially, OBD systems installed in most modern cars are installed for emissions monitoring and engine diagnostics. With OBD, researchers can tap into its technology capabilities to gather the relevant information on elements affecting fuel consumption.

In this framework, considering the rise in fuel prices and the sensitivity regarding environmental issues, fuel consumption via OBD-diagnostic devices comes out as an important field of research and development, opening paths toward more ecological and energy-friendly transportation systems. The complexity of fuel consumption monitoring in hybrid vehicles has been explored here using the prism of OBD technology.

1.2 Problem Statement

Hybrid cars have become a signature feature of the modern automotive world, with an increasing emphasis on greener transportation and the need to reduce carbon emissions. However, despite the rise in their popularity and environmental benefits, fuel efficiency management and optimization in hybrid cars remain an intricate challenge. Hybrid cars have the combination of internal combustion and electric motor engines. Several parameters define various patterns of the operation of such engines; among them, one can distinguish driving mode, passenger loading, state of charge, fuel injection timing, throttle position, and efficiency of regenerative brake.

Currently, there is an insufficient number of extensive, real-time monitoring systems capable of properly tracking and analysing the operating of engine operation in hybrid vehicles. While On-Board Diagnostic (OBD) devices provide a common platform for vehicle diagnostics and their ability to monitor internal combustion engine operation has considerably investigated. This gap affects the dependability and efficiency of HEV by resulting in inadequate knowledge of engine performance and improper maintenance schedules.

Therefore, this project aims to create a real-time fuel consumption monitoring system using OBD diagnostic device for hybrid vehicles specifically on Toyota Prius. This system will provide accurate and detailed information of the fuel consumption which should assisting drivers where people tend to have an anxiety when it comes to HEV and utilize in increasing fuel efficiency, reduce costs and minimize environmental impact.

1.3 Objective

The objective of this project are :

a) To conduct and analyse online monitoring of motor generator and inverter real-time data using Launch X431 Pro Scan Tool diagnostic device on Toyota Prius 3.

b) To access motor generator and inverter parameter in several driving mode and vehicle speed.

1.4 Scope

Following below are the project's scope :

a) An OBD-II wireless adapter will be used.

b) Toyota Prius 3 will be used.

c) Launch X431 Pro Scan Tool will be used.

d) Monitoring the fuel consumption parameters through scan tool.

e) Live monitoring will be conduct using Toyota Prius 3.

1.5 Summary

For this research of monitoring of engine operation specific in fuel consumption using OBD-II diagnostic device report, there will consists of five chapter in total. The chapters are Introduction, Literature Review, Methodology, Result and Analysis and last, Discussion and Conclusion. The thesis outline for each chapter is summarised in detail below :

Chapter 1 : Introduction. In this section the report, the project categories will be briefly described. The objectives of the project will be outlined in this section. This chapter also will include the project scopes.

Chapter 2 : Literature Review. This chapter will explain the preparation of life monitoring of fuel consumption in detail. This section will provide a deeper description and understanding of the project title which will be supported by previous research. This section will help to build the conceptual ideas for this project that have been studied before.

Chapter 3 : Methodology. The methodology part of the project shows overall flow of this entire project. This section will discuss the development of a life monitoring of fuel consumption in hybrid vehicle.

Chapter 4 : Result and analysis. This section of the report will explain about the outcome obtained from the overall project process.

Chapter 5 : Discussion and conclusion. In this last chapter, it will present the conclusion for this project. Lastly, it will highlight the accomplishments, practicalities and future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Hybrid vehicles are becoming more and more popular due to their higher fuel efficiency and lower emissions as the automotive sector is shifting towards sustainable mobility. Real-time monitoring of fuel consumption is essential for maximizing performances in a hybrid vehicle. The aim of this literature study is to analyze how fuel use can be monitored, issues can be diagnosed, and overall performance can be improved by diagnostic devices. Diagnostics equipment can give valuable insight into how hybrid vehicles work that will enable them to help develop a greener transportation future.

This section will present an elaborative analysis of the theoretical and conceptual concepts associated with the title of the project. This will assess all the theoretical and conceptual ideas that are related to the title of the project. The theoretical and conceptual ideas explained in this chapter are supported by previous research in the form of journals, articles, and books.

2.2 Hybrid Electric Vehicle (HEV)

Hybrid electric vehicles (HEV) represent a significant innovation in the automotive industry, combining traditional internal combustion engines with electric propulsion systems to enhance fuel efficiency and reduce emissions. It is a complex system made of numerous hardware components and software algorithms interconnected through mechanical links and electrical communications network. This dual powertrain system allows HEVs to optimize energy usage by switching between or simultaneously using the gasoline engine and electric motor, depending on driving conditions (Husain, n.d.).

The popularity of hybrid electric cars, or HEVs, is rising because of environmental issues like fuel depletion and climate change. They provide a way to lower greenhouse gas emissions and energy usage in the transportation industry. The review discusses fuel efficiency advantages, HEVs layouts, system components, and prospects for energy reduction. In urban cycles, hybrid electric vehicles (HEVs) can increase fuel efficiency by around 24% when used in parallel, series, and series-parallel multi-mode combinations. Autonomous characteristics and system dependability present challenges. Future hybrid vehicles will confront the difficulties and variables listed below. Control techniques are essential for controlling energy flow, engine dynamics, battery state of charge, and HEVs performance (Reitz et al., 2020)

The importance of hybrid vehicles has increased because of environmental issues like oil scarcity and global warming. Hybrid Electric Vehicles (HEV) combine electric and internal combustion engines to provide advantages such as energy recovery through regenerative braking. Larger batteries are found in Plug-In Hybrid Electric Vehicles (PHEV), which are charged by both the engine and electrical outlets. The progression of hybrid technology is best shown by the Toyota Prius series, wherein economy and performance are increased with each new iteration. Although hybrid cars are more environmentally friendly, economical, and have lower emissions, they can be more difficult and costly to repair (Prajapati et al., 2014).

2.2.1 Series Hybrid

A series hybrid is a hybrid car that runs on a battery to power the motor that turns the wheels. It has a straightforward drivetrain setup. In this setup, the internal combustion engine (ICE) serves just as a generator to provide electricity for the battery, which powers the electric motor, rather than being directly attached to the wheels. When compared to conventional automobiles, this design improves total fuel efficiency and lowers emissions by enabling the ICE to function at its most efficient range (What Is A Series Hybrid Vehicle? | HEV Blogs, n.d.). Figure 2.1 shows a series hybrid system.

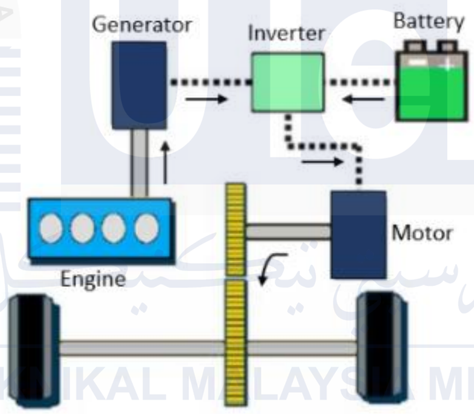

Figure 2.1 Series hybrid system.

2.2.2 Parallel Hybrid

In a parallel hybrid, the drivetrain is powered concurrently by the engine and motor, with efficiency being maximised via computer control. This direct connection to the transmission eliminates the need for converting mechanical energy to electrical and back, enhancing efficiency during highway driving but slightly reducing it in stop-and-go traffic. Compared to series hybrids, these hybrids usually have bigger engines and smaller battery packs. Regenerative braking is mostly used for battery recharging, with motor assistance occurring occasionally (*Series vs. Parallel Hybrid Cars: What's the Difference | Capital One Auto Navigator*, n.d.).

Several research have concentrated on the emissions and fuel economy of parallel hybrid powertrains. Compared to conventional cars, parallel hybrids yield reduced CO2 emissions and improved fuel usage, according to Taymaz and Benli (2014). To look into battery properties, Alegre et al. (2017) created sub-models for electric and parallel hybrids. A unique parallel hybrid known as "Through the Road" was examined for energy management by Pisanti et al. (2014). Research on fuel efficiency for plug-in and light commercial cars was conducted by Montazeri-Gh and Mahmoodi-K (2016) and Millo et al. (2017) (Karaoğlan et al., 2019). Figure 2.2 shows a parallel hybrid system.

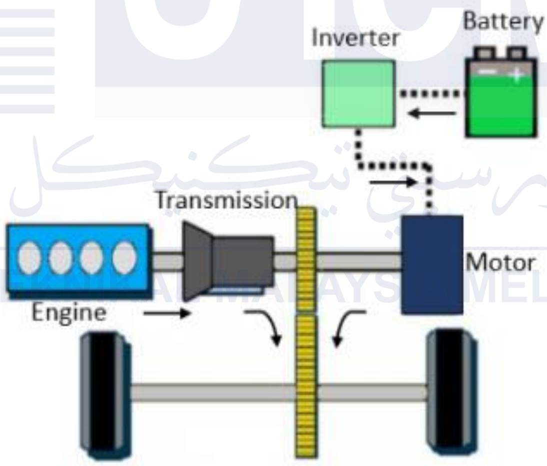

Figure 2.2 Parallel hybrid system.

2.2.3 Series – Parallel Hybrid

A series-parallel hybrid electric vehicle (SPHEV) combines elements of both series and parallel hybrid configurations, using an engine and two electric motors to optimize fuel efficiency. Based on the driving conditions, this adaptable configuration enables the vehicle to seamlessly transition between series and parallel modes. When operating in parallel mode, the engine and motors can move the wheels directly, while operating in series mode, the engine produces electricity to power the motors or recharge the battery. This adaptability maximises effectiveness in a variety of driving situations (Wang et al., 2018).

The fuel-saving potential of Series Hybrid Transmissions (SHT) and Series-Parallel Hybrid Transmissions (SPHT) for various vehicle types and driving cycles is compared in this study. SPHT exhibits significant fuel-saving benefits over SHT, particularly in high-speed driving cycles for Type C vehicles, where SPHT saves roughly 7.2% more fuel than SHT according to the Worldwide Harmonised Light Vehicles Test Cycle (WLTC). With a focus on the influence of driving cycles on fuel-saving potential and the necessity of taking cost and technology maturity into account throughout HEV design processes, the research offers insights into technical path selection for SHT and SPHT (Xu et al., 2022). Figure 2.3 below shows series-parallel hybrid system.

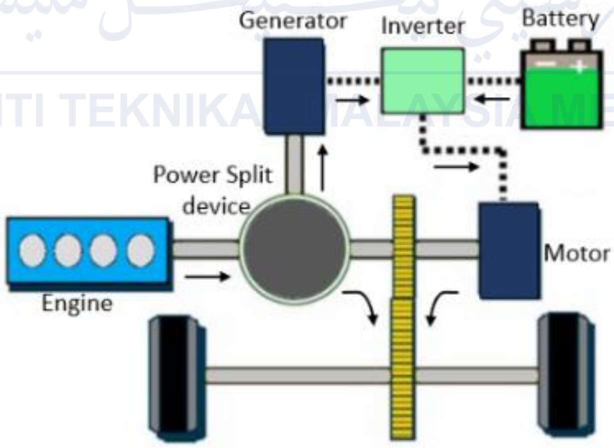

Figure 2.3 Series-parallel hybrid system (Jadhav, S. (2021, July 18).

2.3 Internal Combustion Engine

The internal combustion engine (ICE) highlights the necessity of improving ICE to lessen the transportation sector's environmental effect. The prevailing infrastructure and obstacles confronting alternative energy sources are expected to keep ICE dominant in the transportation energy sector until 2040, even with the rise of battery electric vehicles and other alternatives. The document highlights the potential for major fuel consumption reductions through technologies including lightweighting, hybridization, and lean-burn engines, which can significantly increase ICE efficiency and exhaust pollutant control (Leach et al., 2020).

Understanding the role of internal combustion engines in global power and efforts to reduce emissions and fuel use. Internal combustion engines (ICE) are vital despite the shift to electric vehicles due to their well-established infrastructure and continued technological advancement. It also discusses the debate over whether internal combustion engines need big improvements to reduce greenhouse gas emissions and how engine combustion research will help the world shift away from CO2 emissions. The evaluation concludes by highlighting engine technological advances, the importance of balancing energy and environmental issues, and the future role of internal combustion engines. (Reitz et al., 2020). Figure 2.4 below shows a common type of internal combustion engine.

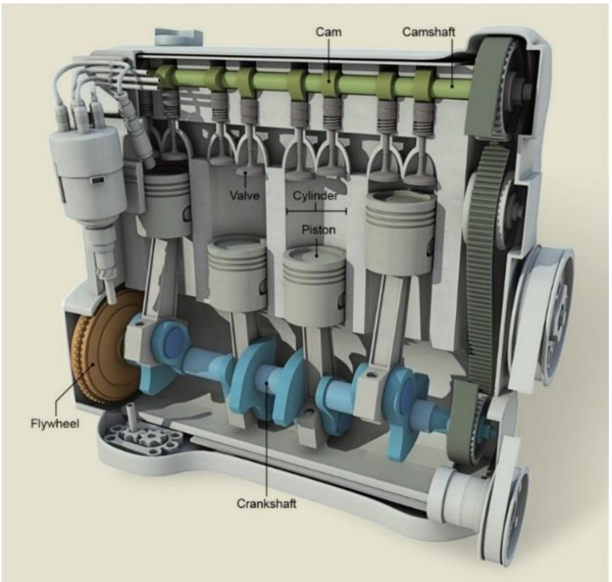

Figure 2.4 General type of internal combustion engine (Dartnell, L., Mayo, J. M., & Twombly, M. (2024, February 20).

2.4 High Voltage Battery

This paper explores the critical role of Battery Management Systems (BMS) in ensuring the safe and efficient operation of batteries in electric and hybrid vehicles (EVs/HEVs). The BMS oversees key functions, including state evaluation (State of Charge - SOC, State of Health - SOH, and State of Life - SOL), charge control, cell balancing, and thermal management. These systems address challenges posed by the variability of battery performance under different operating and environmental conditions. The journal highlights the evolution of BMS from portable electronics to EVs/HEVs, emphasizing the complexities of managing larger battery packs with high voltage and current requirements. It categorizes current BMS topologies into centralized, distributed, and modular systems, each with distinct advantages. The study also identifies limitations in existing BMS, such as inadequate data logging, lack of interoperability, and challenges with SOC/SOH/SOL estimation. (Xing et al., 2011)

Hybrid vehicles, while conceptually explored since the 1960s, have seen advancements in battery technologies like bipolar lead/acid and lithium-ion batteries. These vehicles offer the potential to double fuel efficiency compared to conventional cars by utilizing a primary engine for constant power and a surge unit for peak demands and regenerative braking. This study integrates a simplified lithium-ion battery model with a vehicle simulation to optimize battery power requirements for various driving cycles. It concludes that hybrid vehicles can achieve high mileage with a limited electric range but highlights discrepancies between the goals of the Partnership for a New Generation of Vehicles (PNGV) and actual requirements. PNGV overestimates power and energy demands, imposing unnecessary technological challenges. Driving cycle characteristics, particularly discharge time and maximum power level, are critical but only moderately influence battery design. The research underscores the need for integrated vehicle and battery models to understand the interaction between hybrid vehicle weight and battery power. (Fellner & Newman, 2000) . Figure 2.5 below shows a hybrid vehicle battery pack.

Figure 2.5 Hybrid Vehicle Battery

2.5 State-Of-Charge (SOC)

The hybrid vehicle state-of-charge (SOC) estimate shows that correct SOC assessment optimises battery performance and durability. Traditional SOC estimate methods are useful but often fail under operating settings. Hybrid methods that use various techniques to improve estimation accuracy are emerging. Modern stand-alone techniques are combined with hybrid methods to better estimate SOC by adjusting to Li-ion battery dynamics. Experimental validations reveal that hybrid SOC estimate outperforms conventional techniques, improving battery energy storage system management in hybrid automobiles. This shows the importance of advanced SOC modelling for hybrid car battery utilisation and lifespan (Misyris et al., 2019).

Battery Management Systems (BMS) in electric vehicles need precise lithium-ion battery state of charge (SOC) calculation. Battery models provide accurate SOC estimation. Empirical, ECM, electrochemical, and data-driven battery models exist. Each method has merits and cons, but ECMs and empirical models are simpler and faster. The review compares four typical battery models, a combined model, two RC ECMs, a Single Particle Model (SPM) and an SVM model, in accuracy and computational effort and recommends the combined model and ECM for LiFePO4 batteries based on application requirements (Meng et al., 2018).

2.6 Inverter

Electric vehicles (EVs) have been widely promoted for their ability to reduce energy consumption and emissions, addressing energy crises and environmental pollution. Ensuring the reliability of EV drive systems, particularly the insulated gate bipolar transistor (IGBT) module in inverters, is critical. This study introduces a swift calculation method for determining the power loss and junction temperature curves of an IGBT module. The method maps the relationship between EV operating states and the IGBT's on-state current and duty ratio and incorporates power loss and thermal network models to generate accurate junction temperature curves. Validation against Infineon's online simulation tool shows minimal differences in average power loss (3.23 W) and junction temperature (7.65 °C), demonstrating the method's reliability. The extracted junction temperature periodic mean and amplitude can aid in cumulative damage analysis and IGBT lifetime prediction. Additionally, the method provides insights into the effects of other factors on power loss and temperature during EV operation, making it a valuable tool for reliability and efficiency studies in EV drive systems. (Li et al., 2019).

Multisource inverters (MSIs) have emerged as an innovative solution for integrating energy and power sources in electric vehicles (EVs). By eliminating the need for dc/dc converters and magnetic components, MSIs reduce the weight and volume of power electronics interfaces while enhancing power density and efficiency. This study introduces a novel three-phase MSI designed to integrate and actively control high-voltage and low-voltage dc sources. The proposed MSI minimizes the number of semiconductor devices in the current path across various operating modes, further improving efficiency. Its performance is validated through simulations and experiments on a laboratory prototype using a modified space vector modulation technique, demonstrating its effectiveness in EV applications. (Ebrahimi et al., 2022). Figure 2.6 below shows a inverter used in hybrid vehicle.

Figure 2.6 Inverter in hybrid vehicle.

2.7 Motor Generator (MG)

This study explores the design and evaluation of various electrical machine topologies for hybrid electric vehicle (HEV) applications, focusing on electromagnetic, thermal, and control considerations. The analysis considers permanent magnet synchronous machines (radial and axial flux types) and induction machines. The Embedded Permanent Magnet (EPM) machine demonstrated superior efficiency (up to 94.8%) and compactness, making it the most competitive option, while the Axial Flux Machine (AFM) offered benefits in integration due to its shorter axial length but faced challenges with high inertia. Thermal and electromagnetic design constraints, such as heat dissipation and field-weakening capability, were critical to ensuring reliable operation under fluctuating DC bus voltages and varying load conditions. Efficiency maps provided insights into the optimal operating zones for torque-speed characteristics. The findings underscore the importance of machine topology selection in enhancing the performance and sustainability of HEV powertrains. (Odvářka et al., 2009)

2.8 On-Board-Diagnostics (OBD)

This study investigates the effectiveness of an automotive scan tools training material package on enhancing problem-solving skills among undergraduate students. Through a structured experiment involving pre-tests and post-tests, the research found significant improvements in students' abilities after using the training package. The package not only surpassed the set efficiency criteria but also received favorable responses from students in terms of satisfaction levels. The authors suggest that this innovative approach can reduce cost and time while allowing students to solve problems with self-efficacy, and they recommend extending such research to other educational institutions and exploring new teaching methodologies in automotive technology. (Sudsomboon, n.d.)

On-Board Diagnostics II (OBD-II), serves as a crucial system for reducing vehicle emissions. It continuously monitors sensors, actuators, and subsystems within the powertrain, identifying potential malfunctions that could lead to increased emissions. By granting access to engine diagnostics from the Engine Control Unit (ECU), OBD-II provides valuable information, including Diagnostic Trouble Codes (DTC), applicable to cars, medium-duty, and heavy-duty vehicles. Mechanics and vehicle owners utilize OBD-II scanners to interpret this internal data, diagnosing issues indicated by the malfunction indicator light (MIL). Ultimately, OBD-II ensures compliance with emissions standards, contributing to environmental regulations and maintaining optimal vehicle performance (Singh & Singh, n.d.)

The focuses on using electronic sensors and the OBD-II diagnostics protocol to monitor vehicle operations and usage. Using the OBD-II protocol, researchers may retrieve data in real-time and estimate fuel use as well as examine how different driving styles affect consumption. OBD-II monitors various parameters, including engine coolant temperature, short-term fuel trim, engine RPM, vehicle speed, air flow rate, and O2 lambda equivalent. To comprehend their influence on vehicle performance and fuel consumption, the study highlights the significance of choosing important parameters for monitoring. Experiments are also used in the research to validate data, compute fuel consumption, and examine how driving style affects fuel usage (Rimpas et al., 2020). Figure 2.7 shows a scan tool that used in automotive industry.

Figure 2.7 Scan Tool used in automotive industry

The paper proposes two intelligent torque distribution strategies based on particle swarm optimization (PSO) and fuzzy logic control (FLC) to maximize hybrid electric vehicle (HEV) propulsion power. PSO uses torque transfer ratio (TTR) as a fitness function to select optimal torque candidates and differential arrangements, while FLC employs designed membership functions and rules for convenient torque vectoring. The paper also introduces a coordinated switching strategy to address transient ripples during drivetrain commutations and power source switchings by controlling switching period duration through transition functions. Simulations show the intelligent strategies converted 84-86% of generated torque into propulsion on non-uniform surfaces, while equal distribution yielded only 50% TTR. The coordinated switching reduced DC bus voltage ripples to ±5V, limited power ripples to 600W, and almost eliminated torque jerks. Real-time tests confirm it reduced transient torque overshoot from 69% to nearly zero, enhancing HEV driving comfort. (Oubelaid et al., 2022).

2.9 Previous Research Paper

The study represents a real-time predictive energy management strategy for plug-in hybrid electric vehicles aimed at optimizing fuel economy while minimizing battery degradation. It incorporates a velocity predictor, SOC reference generator, and online optimization using the continuation/generalized minimal residual algorithm. This strategy applies model predictive control techniques and advanced neural networks for the prediction of vehicle velocity and efficient energy flow management. This solution gives desirable performance, considering all three constraints: fuel consumption, electricity costs, and battery aging. Numerical simulations are carried out to verify this. The obtained results prove it to be effective in cost reduction and prolongation of battery life by satisfying real-time operation demands. Among them is the fuel efficiency versus battery preservation trade-offs, whereby the proposed algorithm outperforms the conventional approaches in attaining an optimal compromise between the twin objectives. Other findings of this study are the computational efficiency of the continuation/generalized minimal residual (C/GMRES) algorithm against other optimization techniques like a sequential quadratic programming and genetic algorithms, thereby establishing its practicality for real applications. (Guo et al., 2021).

The configuration of fuel cell plug-in hybrid electric vehicles with the employment of some fuel cell stacks operated at fixed output power and a method of on-off switching control significantly improves the durability of fuel cells. In this paper, three fuel cell stacks are employed, and a hysteresis-based power management strategy is developed for even active time distribution among stacks with minimized switching frequency. It follows that the durability of the fuel cell increases by 11.8, 4.8, and 6.9 times for urban, highway, and combined urban highway driving cycles, respectively. This is due to the fact that the average power demand in the real-world driving cycles is lower than the maximum power capacity of the vehicle. This approach, therefore, minimizes over-design needs and reduces fuel cell costs while allowing for extended driving range.(Zhang et al., 2019).

Fuel cell electric vehicles (FCEVs) are a promising solution for sustainable transportation, but high ownership costs limit their market competitiveness. This study introduces a real-time cost-minimization energy management strategy for fuel cell/battery hybrid electric vehicles to reduce operating costs. The strategy uses model predictive control, incorporating hydrogen consumption and energy source degradation in a multi-objective cost function. Dynamic programming, supported by forecasted speed data, optimizes power-splitting decisions over each receding horizon. The study examines the impact of factors such as battery state-of-charge regulation, optimization resolution, speed prediction methods, and prediction horizon length on performance. Comparative analysis shows that the proposed strategy reduces operating costs by 14.17% and extends fuel cell lifespan by 8.48% compared to a rule-based benchmark. With an average computation time of 266.26 ms per step, the strategy demonstrates real-time feasibility.(Zhou et al., 2021).

2.10 Summary

This chapter focuses on hybrid electric vehicles, their components, and the use of diagnostic devices such as scan tools to monitor performance and optimize efficiency. It highlights the environmental benefits of HEV, combining internal combustion engine with electric motors for reduced emissions and improved fuel economy. This chapter addresses some of the hybrid configurations like series, parallel, and series-parallel hybrid, focusing on respective operational advantages of each type and the way energy is managed in them.

The review discusses the role of critical components like batteries, with a focus on how the BMS should implemented to ensure safety, performance, and life span. It also contributes by highlighting the potential contribution of technology advancement in batteries for further improvement of HEVs' energy utilization. It further elaborates on the sustained role of the ICE in this transition toward electric vehicles, citing recent innovations in reducing its emissions and increasing efficiency. It throws light on the use of OBD technology in real-time HEV monitoring and its ensuing capability for tracking vital operating parameters like fuel consumption, engine speed, and torque. The system helps in the identification of driving patterns, achieving optimisation in performance, and ensuring full compliance with regulations. The chapter also goes on to discuss the important performance parameters related to state of charge, motor generator operation, torque, and inverter functionality. These elements enable knowledge of thermal and power management for hybrid systems.

It concludes with the summation of all available knowledge on HEV, encompassing their environmentally friendly and economic efficiency. In developing hybrid technologies, the implementation of diagnostic equipment for performance and optimally updated capabilities is important in establishing a successful record.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology of the research on life monitoring of motor generator and inverter by using Scan Tool diagnostics devices in hybrid vehicles focuses on a systematic approach in terms of data collection, analysis, and interpretation. In this study, real-time data on MG1 and MG2 torque, inverter temperature of MG1 and MG2, MG1 and MG2 RPM, and engine coolant temperature are collected with the use of Launch X431 Pro Scan Tool devices. Our aim is to implant these devices in a fleet of hybrid cars so that we can track and log their operational data over time under various driving circumstances. Additionally, the data collected shall be analysed for patterns, anomalies, and correlations between driving behaviour and engine behaviour. The outcome of this comprehensive study will provide recommendations on how hybrid vehicle development with high performance, low emission, and improved fuel economy contributes to an environmentally friendly and sustainable transport system.

3.2 Project Workflow

The project workflow encompasses a series of systematic steps to ensure that the data collection and analysis are both accurate and complete. The research title is searched for, followed by explaining each flow in detail. This is followed by the implementation and testing of the scan tool. Then, data collection and result analysis are performed. Finally, the report is submitted, and the research is documented. This structured workflow ensures a through approach to understanding more about this research. Figure 3.1 shows the flowchart for the workflow of the project.

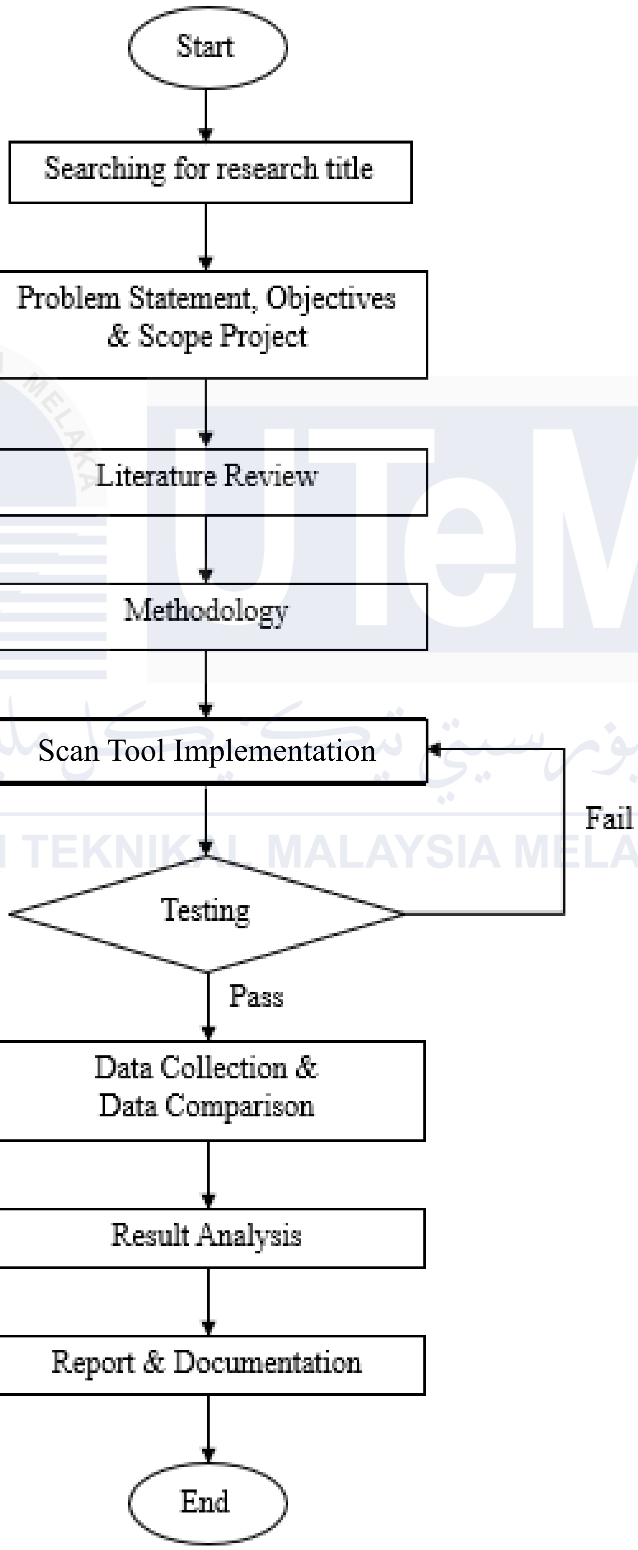

Figure 3.1 Flowchart

3.3 Toyota Prius 3

The Toyota Prius 3 was chosen for this research project due to its prominence as a leading hybrid vehicle with advanced hybrid technology and excellent fuel economy. The Toyota Prius 3 is the third generation of the standard Prius model, which is a mid-size hatchback. Toyota Prius 3 comes fitted with a 1.8-liter four-cylinder coupled with an electric motor, with the same net result of approximately 134 horsepower or 100kW. The Prius 3 is fitted with more features and technology, including a larger infotainment system, more comprehensive driver assistance features, and higher-end interior materials. Being a larger and more feature vehicle, the Prius gives more space and luxury feelings to the driver.

The Prius provides a solid platform for researching motor generator, inverter temperature, and engine coolant temperature patterns since it combines an electric motor with a conventional internal combustion engine. With an installed X-431 diagnostics system, the Prius is an excellent choice for fuel consumption monitoring as it offers a wide range of real-time data on various parameters of the engine and vehicle. The insights gathered from the study will lead to a better understanding of the performance of a hybrid vehicle so that fuel efficiency may be improved and emissions decreased. Figure 3.2 below shows a Toyota Prius 3 used in this project.

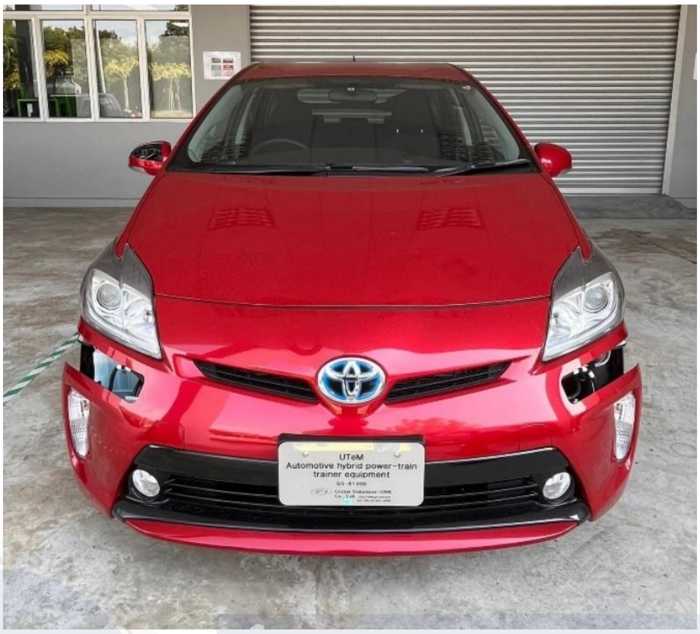

Figure 3.2 Toyota Prius 3

Table 3-1 Toyota Prius 3 engine's specifications

Engine Type	1.8L 4-cylinder Atkinson cycle
Engine Code	2ZR-FXE
Displacement	1798 cc
Bore x Stroke	80.5 mm x 88.3 mm
Compression Ration	13.0 : 1
Max Power Output	90 hp (73 kW) at 5200 rpm
Max Torque	142 Nm at 4000 rpm
Fuel System	Electronic Fuel Injection (EFI)
Total System Power	134 hp (100 kW)

3.4 Scan Tool

This work implementation utilizes a special tool for the scan called Launch X431 Pro Scan Tool, which was designed for diagnose and monitor vehicle behaviour and characteristics. Launch X-431 Pro provides real time monitoring and enables detailed analysis of the vehicle's engine operation and general performance. By interfacing with the vehicle's system, the Launch X431 Pro Scan Tool collects and processes data on several engine parameters and provides information related to coolant temperature of engine, MG1 and MG2 inverter temperature, torque of MG1 and MG2, and MG1 and MG2 RPM for hybrid vehicles. With this easy-to-use software along with advanced features in diagnostics, users can enhance operational efficiency and reliability by a better monitoring and management of hybrid cars.

The Launch X431 Pro Scan Tool technology is a professional diagnostic tool that is widely used for vehicle diagnosis and troubleshooting in the automotive industry. These complex features and broad functionalities make it suitable for modern vehicle analysis, such as hybrid systems like that of Toyota Prius 3. The study on life monitoring of motor generator and inverter in the Toyota Prius 3 requires a scan tool. Compatible with GUI (Graphical User Interface); a standard interface for access to the car’s Engine Control Unit (ECU), designed for intuitive, touchscreen-based experience, enabling a seamless interaction with the tools’ features and function. From what I read, it is capable enough to log all the data required for this research like engine coolant temperature, MG1 and MG2 of torque, inverter temperature and RPM.

These parameters are continuously monitored in the study with the use of a Launch X431 Pro Scan Tool, which enables accurate and precise data of motor generator and inverter to be obtained under different driving situations. The diagnostic tool does not only facilitate easier troubleshooting and performance optimization but also makes it possible to go deeper into the efficiency of the hybrid system, hence contributing to the development of automotive technologies that will be more fuel-efficient and sustainable. Figure 3.3 below shows a Launch X431 Pro Scan Tool that been used for to complete this study.

Figure 3.3 Launch X431 Pro Scan Tool

3.5 Parameter Study

In this study, several parameters have been selected to present the performance and efficiency of the Toyota Prius 3 in various driving conditions and modes. The chosen parameters are central for understanding the functionality of the hybrid system, especially its power distribution, thermal management, and overall efficiency. The parameters include torque, rotational speed (RPM), and inverter temperature of motor generator 1 (MG1) and motor generator 2 (MG2), and the engine coolant temperature.

3.5.1 MG1 and MG2 Torque

Torque output from MG1 and MG2 is another important aspect in power distribution and efficiency. MG1 can act mainly as a generator and starting motor. Its torque becomes negative when it charges the hybrid battery and positive at the time of starting up the engine. Variation in its torque thus reflects the balance between regeneration and support of the engine.

MG2 provides the principal drive motor with positive torque for the propulsion of the vehicle and negative torque for regenerative braking when battery recharge is required. Its operation relates to the factors of acceleration, energy efficiency, and effective braking.

3.5.2 MG1 and MG2 RPM

The rotational speed of MG1 and MG2 is one of the most important parameters that give insight into the dynamic performance and efficiency of hybrid vehicles. MG1 mostly works as a generator, converting the mechanical energy from the internal combustion engine into electrical energy for recharging the hybrid battery or supplying power to other systems. On the other hand, MG2 operates as a motor and a generator, respectively, driving wheels in electric-only or hybrid operation, while during braking, capturing energy to improve efficiency. The information on RPM allows monitoring and analyses related to power distribution, energy recovery rates, and the overall behaviour of the system in different driving conditions.

3.5.3 MG1 and MG2 Inverter Temperature

MG1 and MG2 cooperate with the inverters in order to manage electrical energy flow efficiently. Inverters transform DC coming from the battery into AC for the motor generators. The temperature of the inverters has a direct influence on efficiency and life expectancy regarding the power electronics. Excessive heat degrades components, reduces efficiency, and therefore invites potential failure; temperature management is one of the main areas under the study. Here, the temperatures of inverter associated with MG1 and MG2 will be applied as a critical role to appraise thermal performance and hence the general hybrid vehicle power-train health in this work. The findings from this work serve not only to further enhance hybrid reliability and efficiency, but they may also help extend the useful lifetime of vital critical components.

3.5.4 Engine Coolant Temperature

The most critical operating and performance parameter of hybrid vehicles is the temperature of the engine coolant, which directly influences internal combustion engine efficiency, durability, and emissions. For this purpose, the coolant can be employed as a heat transfer medium, ensuring that the engine temperature is maintained in an optimal range to avoid overheating or overcooling conditions that may cause poor combustion or increased wear. For that, the current paper discusses in detail engine coolant temperature as influential in affecting hybrid vehicle thermal management and energy efficiency. In addition to its supporting role for advanced thermal management systems development, the present study aims at enabling reductions of fuel consumption and emissions.

3.6 Driving Mode

In hybrid vehicles, the driving mode is sport mode and eco mode, which plays a vital role in performance and efficiency optimization regarding driver preference and road conditions. In this test run, two modes are considered to provide insight into how the vehicle balances performance and efficiency, showing its adaptability to diverse requirements. Figure 3.4 below shows the mode for Sport Mode and Eco Mode in Toyota Prius 3 that used for the test run.

Figure 3.4 Type of hybrid modes

3.6.1 Eco Mode

Eco Mode is designed to maximize fuel efficiency by optimizing the vehicle's powertrain and reducing energy consumption. When it is activated, eco mode makes the throttle response less aggressive for smoother acceleration, minimizing unnecessary fuel usage. It also modifies operation of the climate control system to conserve energy by reducing the load on the hybrid system. It also amplifies the regenerative braking mode to capture the most energy possible during deceleration for recharging the battery. Giving priority to efficiency over performance, eco mode helps to achieve lower fuel consumption and reduced emissions.

3.6.2 Sport Mode

Sport mode on the hybrid system is more responsive and engaging, amplifying performance attributes. In this mode, the parameters of the hybrid system are changed to provide quicker acceleration and a more dynamic feel. The internal combustion engine and electric motor work together more aggressively, putting performance over efficiency. This will increase fuel consumption compared to eco-mode, but sport mode is ideal for situations where performance is desired.

3.7 Driving Speed

In this work, both accelerations and decelerations are considered in trying to understand the dynamic performance and efficiency of a hybrid vehicle. The basis of this parameter is to capture the real-world data as to how the hybrid system responds to any variation in speed.

Besides, it also set the speed intervals at 30 km/h, 40 km/h, 50 km/h, and 60 km/h, respectively. The intention is to collect diverse data in order to analyze the performance and efficiency of hybrid vehicles. These set speeds enable a systematic assessment of the behavior of the hybrid system in cases of acceleration and deceleration along different ranges of speeds.

3.8 Testing Route

The road chosen for this project is just beside the Faculty of Mechanical Engineering Technology (FTKM), Universiti Teknikal Malaysia Melaka UTeM), serving as an ideal testing ground for this research into hybrid vehicle performance. It is a straight, well-paved road with no inclines to make sure that the road surface is even, which means a controlled environment in conducting the test run of speeds at various velocities, ensuring that any data collected is both consistent and reliable. The testing is done along a dry road during the test run and the testing should be performed only during a clear-weather day. This road will be suitable for the achievement of stable acceleration and deceleration, hence a strategic choice for evaluating hybrid vehicle dynamics under real-time conditions. Figure 3.5 below shows the route used for the study.

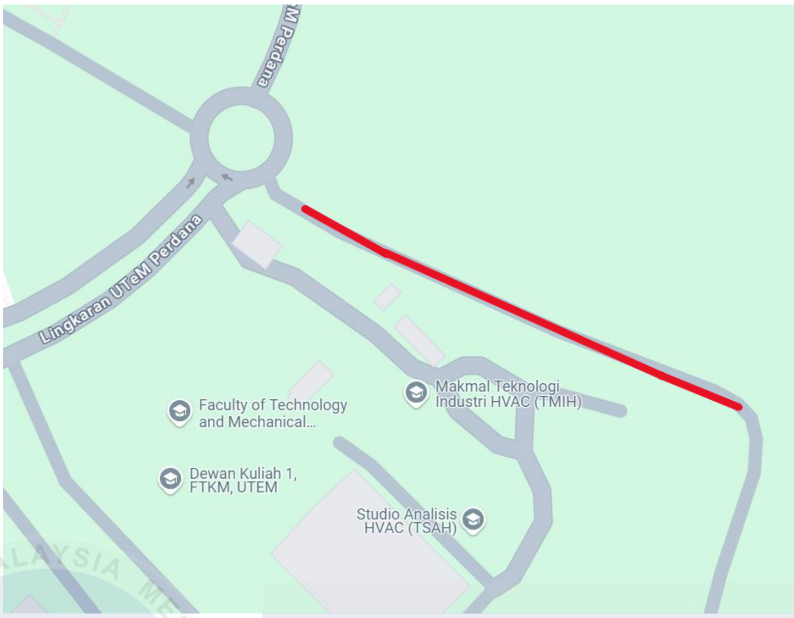

Figure 3.5 Route used for study.

3.9 Summary

This chapter presents the systematic investigation into the life monitoring of the motor generator and inverter in a hybrid vehicle using the Launch X431 Pro Scan Tool. Real-time data acquisition on various engine parameters by scan tool devices installed in a hybrid car under various driving conditions is included. The main focus of this research work lies in real-time monitoring of MG1 and MG2 torque, rotational speed (RPM), inverter temperature, and engine coolant temperature in Toyota Prius 3.

The process kick-started with brainstorming on project scope, formulating objectives, and designing the methodology. For precise and real data, the paper utilized a Launch X431 Pro Scan Tool that could easily analyse engine performance and hybrid system efficiency. The choice of the Toyota Prius 3 was largely because it could deliver detailed operational data and was well-known for advanced hybrid technology.

The chosen parameters were monitored in various speeds and modes of driving. These conditions gave quite comprehensive insight into the hybrid vehicle performance dynamic. Data collection was done on a controlled route near UTeM for consistency and reliability. Variations in performance across driving modes and speeds will be systematically analysed in order to understand the real-world behaviour of the Toyota Prius 3 hybrid system.

This chapter emphasized the integration of diagnostics tools and systematic data analysis to enhance hybrid vehicle performance, fuel efficiency and thermal management, contributing to sustainable automotive advancement.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis of the study, which investigates the operation of hybrid vehicle engines through data collected from a Toyota Prius 3. A Scan Tool, specifically the Launch X431 Pro, was employed to gather real-time data during test drives, providing valuable insights into the functioning of hybrid vehicles. The test drives allowed for a practical demonstration of how the Launch X431 Pro collects and interprets engine performance data. It is important to note that the findings are based on multiple test runs, with the results validated through real-time monitoring of the Toyota Prius 3's engine operations. This study serves as a foundation for addressing gaps in understanding the complexity of hybrid vehicle functionality.

4.2 Data Collection

This section presents the results and analysis obtained from tests conducted on a Toyota Prius 3 using the Launch X431 Pro Scan Tool. The data collected encompasses key parameters such as RPM, inverter temperature, torque, and engine temperature, providing detailed insights into the hybrid vehicle's performance under various driving conditions, including acceleration and deceleration. To ensure accuracy and reliability, tests were conducted at different speeds for each condition, enabling a more comprehensive understanding of the vehicle's behaviour. The route chosen is just beside FTKM building.

4.2.1 Engine Coolant Temperature (ECT)

4.2.1.1 Acceleration : Eco Mode

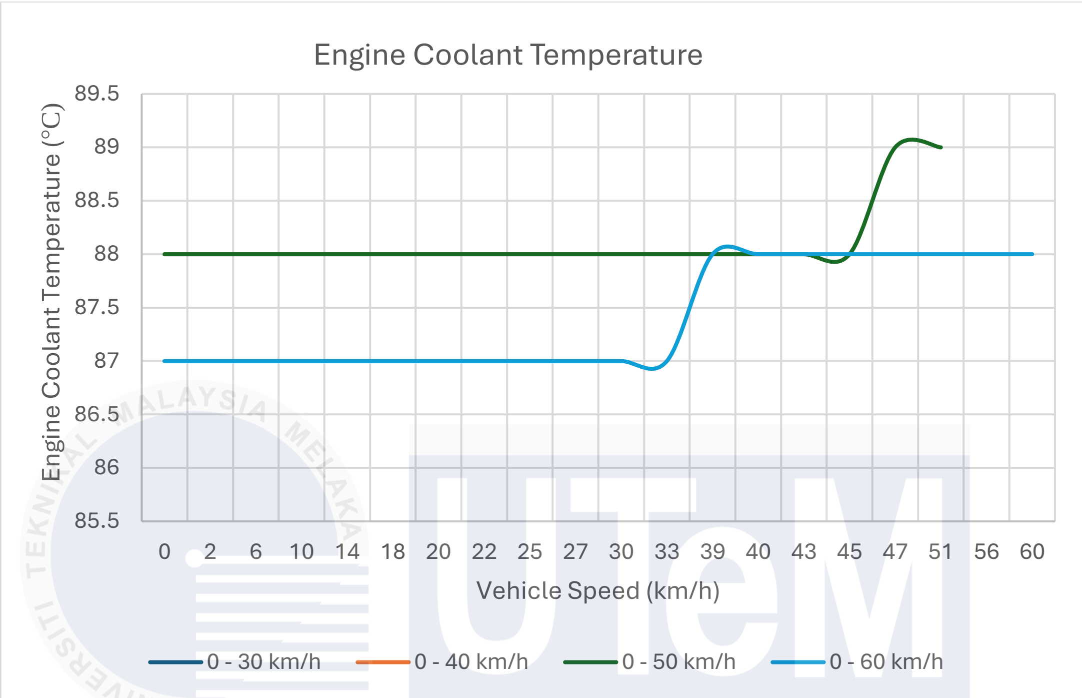

Figure 4.1 ECT during acceleration in Eco Mode.

The graph showing engine coolant temperature (ECT) against speed for Toyota Prius 3 in Eco Mode. At lower speeds (0-30 km/h), the ECT remains stable around 87°C. As speed increases (0-40 and 0-50 km/h), a slight rise in temperature but remain stable at 88°C. Beyond 50 km/h, a noticeable spike in ECT occurs, particularly in the 0-60 km/h profile, indicating that the engine takes on a more significant role, generating more heat as it prioritizes power over fuel efficiency. While Eco Mode optimizes efficiency by favouring electric motor usage, higher speeds require greater engine activity, leading to increased thermal stress. This highlights how the ECT is a reliable indicator of engine load and the balance between fuel efficiency and performance in hybrid vehicles.

4.2.1.2 Acceleration : Sport Mode

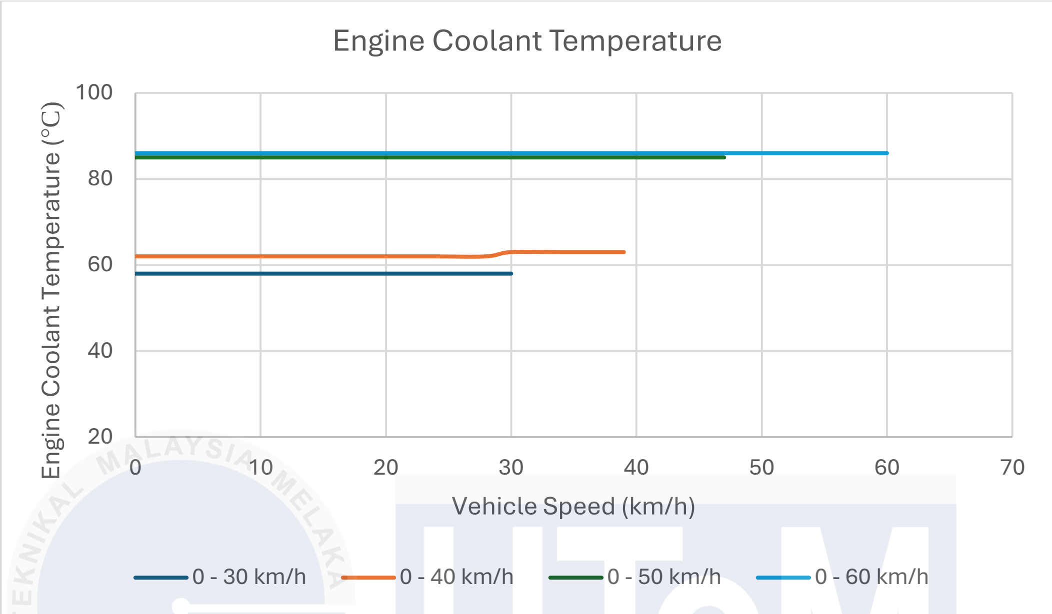

Figure 4.2 ECT during acceleration in Sport Mode.

The graph show the variation in engine coolant temperature in sport mode for a hybrid vehicle in different speed. It can be observed from the data that the temperature of the engine coolant is in good control and varies a little with different intervals of speed. At lower speeds, 0–30 km/h, the temperature is constant at 58°C, which reflects good cooling at low-load conditions. When the velocity increases to 40 km/h, the temperature slightly rises, reaching 62–63°C, demonstrating how the engine adapts to higher demands. At speeds of up to 50 km/h, the coolant reaches 85°C and maintains the same figure at 60 km/h, reaching 86°C throughout, indicating that the cooling system is strong enough for such high-performance conditions. In general, sport mode offers the same thermal regulation over all speed intervals with its cooling system, maintaining engine performance and preventing overheating.

Also, this graph clearly highlights discontinuities in engine coolant temperature trends, particularly between the 0-30 km/h to 0-40 km/h ranges and the 0-50 km/h to 0-60 km/h ranges. These inconsistencies are attributed to challenges encountered during the test runs for the 0-50 km/h and 0-60 km/h ranges, requiring repeated trials to obtain accurate data. Consequently, the temperature variations are not continuous because the test vehicle, a Toyota Prius 3, had been operating on the road for an extended period. This prolonged operation likely contributed to a gradual increase in engine coolant temperature over time, which reflect the graph.

4.2.1.3 Deceleration: Eco Mode

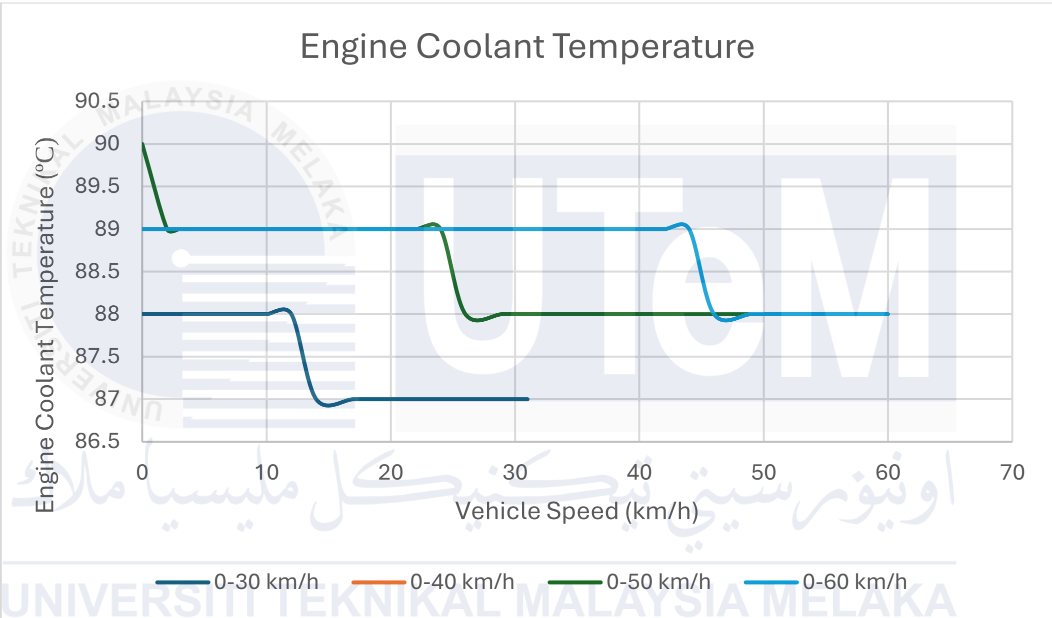

Figure 4.3 ECT during deceleration in Eco Mode.

The graphs represent the changes in engine coolant temperature as experienced by a hybrid vehicle when selecting deceleration in eco mode across various speed ranges within the test (0-30 km/h, 0-40 km/h, 0-50 km/h, and 0-60 km/h). It is interesting to note the characteristics of eco-mode deceleration, especially on performance issues related to thermal management in engines while coasting.

Under the 0-60 km/h deceleration, the coolant temperature keeps standing at 89°C for the high speeds, then drops to around 44 km/h, and then holds at 88°C for the rest of the deceleration period. The indication of drop in temperature therefore is likely to represent a transition phase in the operation of the hybrid powertrain, possibly denoting reduced engine load due to higher reliance on regenerative braking as the vehicle decelerates. In a way similar to the one above, this temperature keeps transitioning within the range of 88 to 89°C, seen in the temperature pattern that is consistent during deceleration, and is therefore indicative of a thermal management scheme that is the same from 0-50 km/h. As for 0-40 km/h the deceleration speed are stable at 89°C and for 0-40km/h, the engine coolant temperature transitioning within the range of 87°C to 88°C with the same pattern as higher speed of deceleration (0-60 km/h).

4.2.1.4 Deceleration : Sport Mode

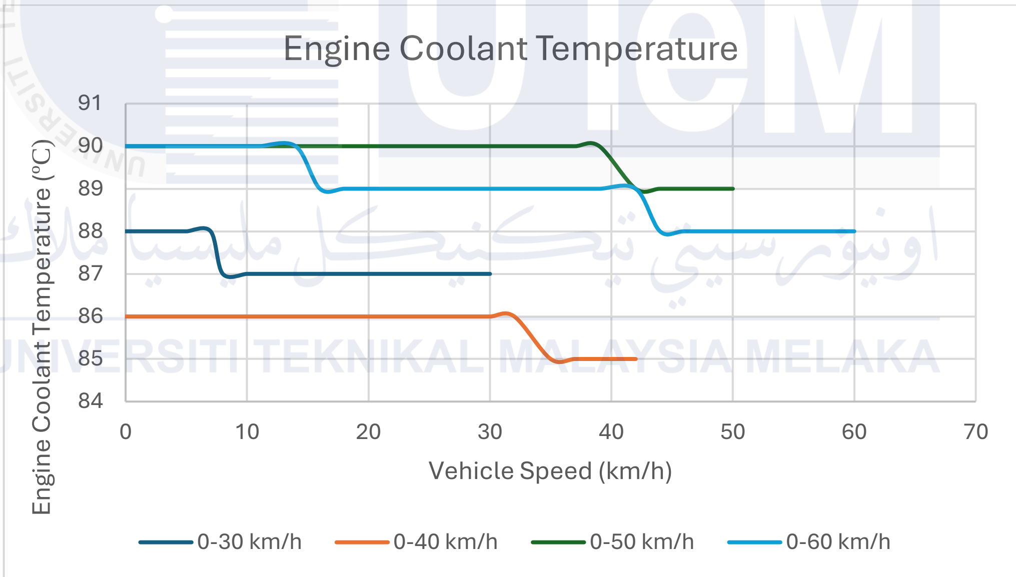

Figure 4.4 ECT during deceleration in Sport Mode.

The graph illustrates engine coolant temperature as a function of speed during deceleration in sport mode using a hybrid vehicle. The coolant temperature fluctuates between 85°C and 91°C across the speed ranges (0–30 km/h, 0–40 km/h, 0–50 km/h, and 0–60 km/h), with noticeable discontinuities between speed transitions. The 0–30 km/h range shows slight temperature decreases from 88°C to 87°C, while the 0–40 km/h range starts lower with 86°C and stabilizes after a drop. The 0–50 km/h and 0–60 km/h ranges begin at higher temperatures which is 90°C, then showing small declines as speed decreases in ranges of 89°C to 88°C. These variations reflect the dynamic behaviour of the hybrid vehicle's cooling system in sport mode, where increased engine load raises temperature during acceleration, and regenerative braking or reduced airflow impacts cooling during deceleration. The discontinuities may result from repeated tests or prolonged engine operation before data collection, indicating variability in cooling efficiency and test conditions. Overall, the coolant temperature remains within a stable operational range despite minor fluctuations.

4.2.2 MG1 and MG2 RPM

4.2.2.1 Acceleration : Eco Mode

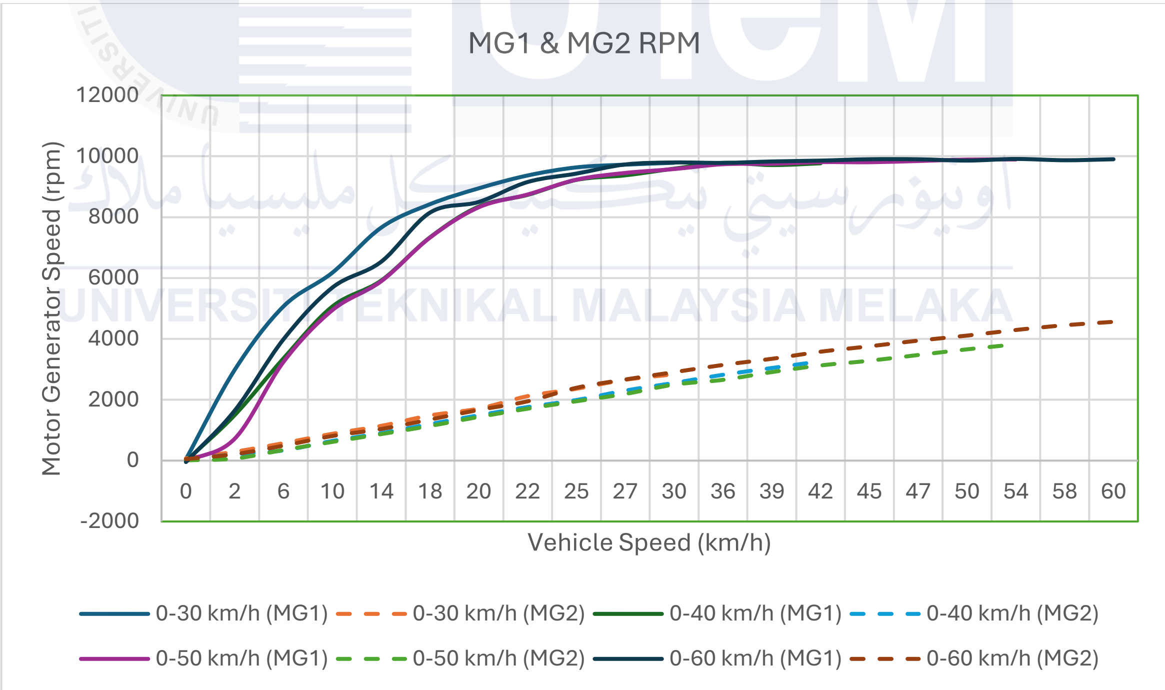

Figure 4.1 MG1 and MG2 RPM during acceleration in Eco Mode

In contrast, the MG1 and MG2 RPM graph for Eco Mode reflects a powertrain tailored for energy efficiency and smooth driving. There is a very contrast pattern of graph that differ between the Motor Generator 1 (MG1) and Motor Generator 2 (MG2). The RPM values rise more gradually compared to Sport Mode, indicating a conservative use of power. MG1 adjusts its RPM to optimize electricity generation for battery charging, while MG2 moderates its RPM to align with the speed requirements of eco-driving. The flatter curves at higher speed which is above 40 km/h emphasize the mode's focus on minimizing energy consumption and maintaining steady power delivery, ensuring a seamless and fuel-efficient driving experience.

4.2.2.2 Acceleration : Sport Mode

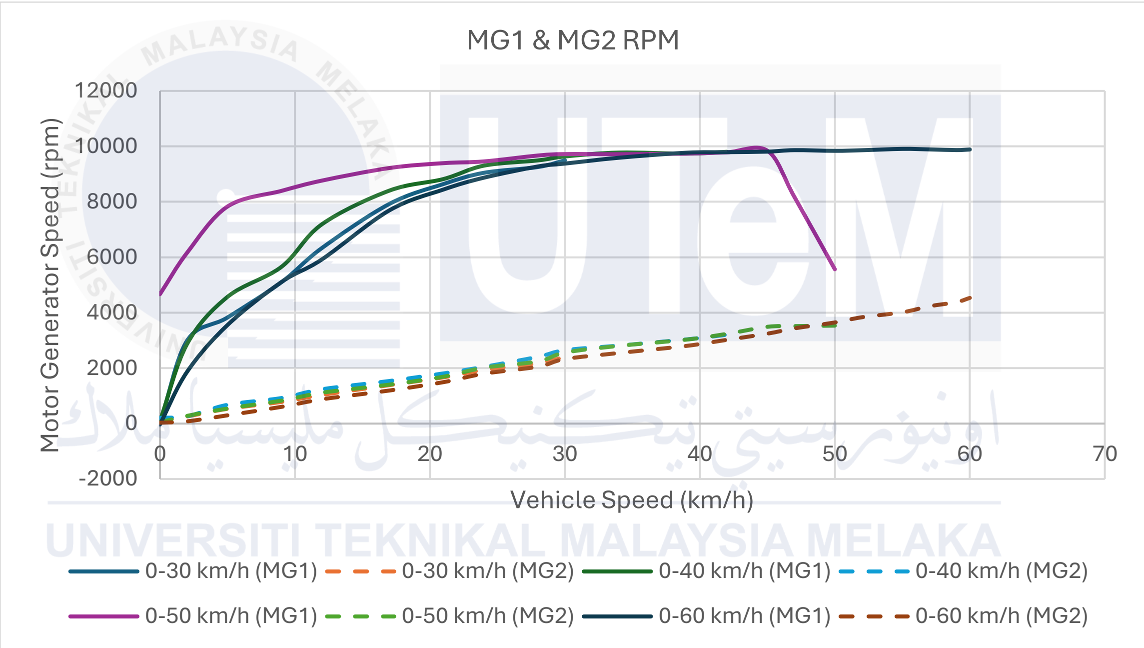

Figure 4.2 MG1 and MG2 RPM during acceleration in Sport Mode

The graph above shows a dynamic response of the hybrid powertrain optimized for high performance and rapid acceleration. As the vehicle speed increases, both MG1 and MG2 exhibit steady rise in RPM, reflecting their roles in delivering the maximum power output. MG1 is connected to the planetary gearset, adjusts its RPM to balance engine torque and electricity generation while MG2 is directly connected to the wheels, operated at speeds proportional to the vehicle's velocity. The sharp increase in RPM, especially at lower speed (0-40 km/h), demonstrates the aggressive acceleration characteristics of Sport Mode as the system prioritizes performance over energy efficiency.

The sudden decrease in RPM at 0-60 km/h in the graph is likely reflects a transition in the hybrid system's power delivery strategy. At this speed, the powertrain may shift from relying heavily on the MG2 to the internal combustion engine, reducing MG2 load and RPM. Additionally, the dip may result from speed-limiting calibration in sport mode to prevent overheating or excessive wear on components, shows that the hybrid system's response to maintain performance, efficiency and component protection during high-speed operation.

4.2.2.3 Deceleration : Eco Mode

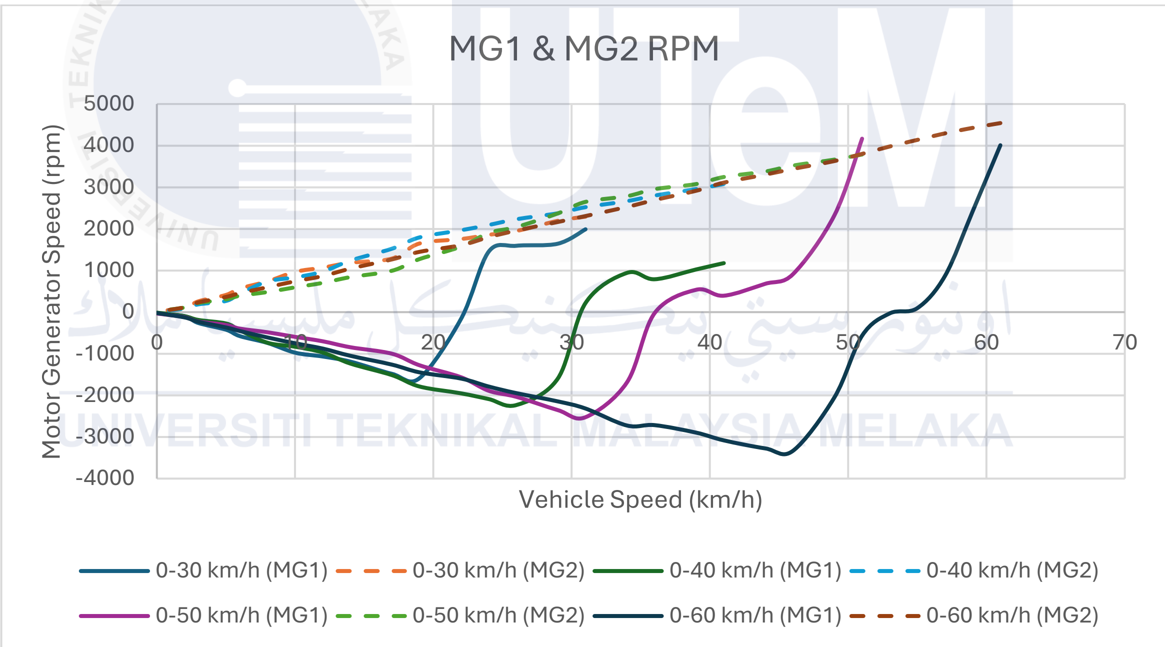

Figure 4.7 MG1 and MG2 RPM during deceleration in Eco Mode

The graph shows the distinctive pattern formed by these curves. During decelerations, MG2 which is directly connected to the wheels shows a gradual decrease in RPM reflecting the reduction in vehicle speed. At the same time, MG1 shows a varied RPM behaviour to optimise regenerative braking, converting kinetic energy into electrical energy stored in the battery. The curves show smoother transitions compared to sport mode, emphasizing energy recovery over abrupt power adjustments.

The RPM values also indicate the balance between power regeneration and maintaining a smooth driving experience. As the vehicle slows down through different speed ranges, the hybrid system coordinates the operation of MG1 and MG2 to ensure steady recovery while reducing mechanical wear. In Eco Mode, the powertrain prioritize in maximizes energy efficiency during deceleration, leading to more gradual decline in RPM and consistent regenerative braking performance.

4.2.2.3.4 Deceleration : Sport Mode

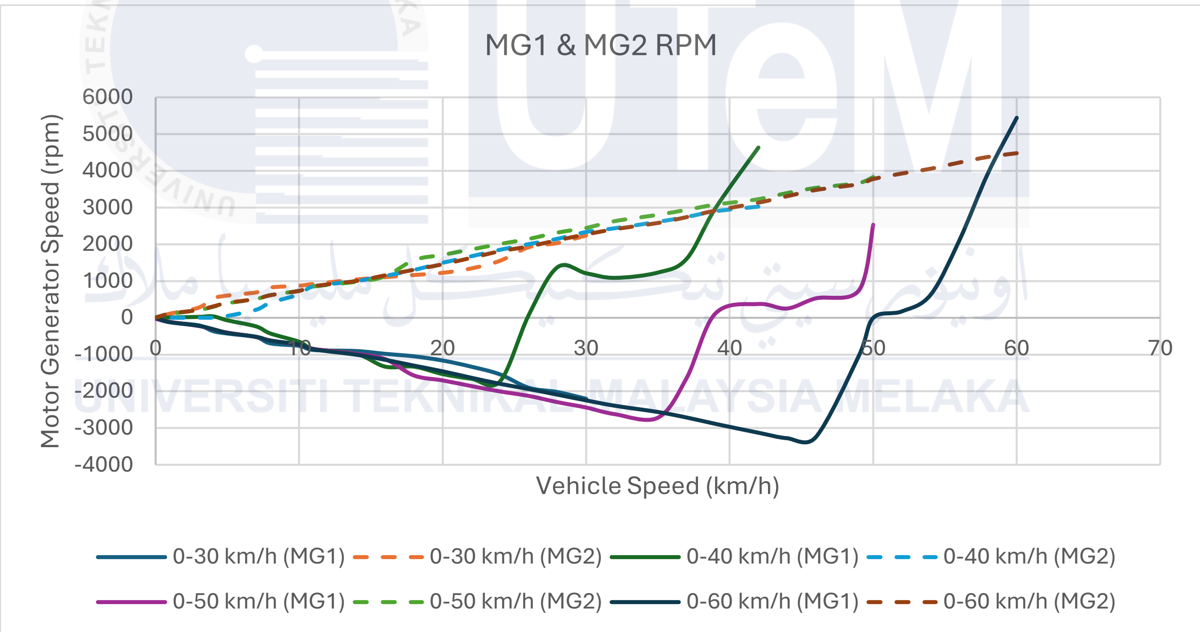

Figure 4.8 MG1 and MG2 RPM during deceleration in Sport Mode

The graph of MG1 and MG2 RPM for deceleration on Sport Mode highlights how the hybrid powertrain adjusts to recover energy and manage braking performance. During deceleration, MG2, which directly connected to the wheels reduces its RPM as the vehicle slows down, reflecting the decrease in speed. At the same time, MG1 which connected to the planetary gearset, shows varying RPM patterns to coordinate with the engine and generate electricity through regenerative braking.

The RPM curves for different speed ranges show distinctive behaviour, with sharp transitions and occasional fluctuations. These variations occur due to hybrid system's response to changes in braking intensity, load distribution and the need to balance power regeneration with smooth vehicle deceleration. In sport mode, the system prioritizes performance, so the deceleration profile may display sharper transitions as it maximizes energy recovery while maintaining control.

4.2.3 MG1 and MG2 Torque

4.2.3.1 Acceleration : Eco Mode

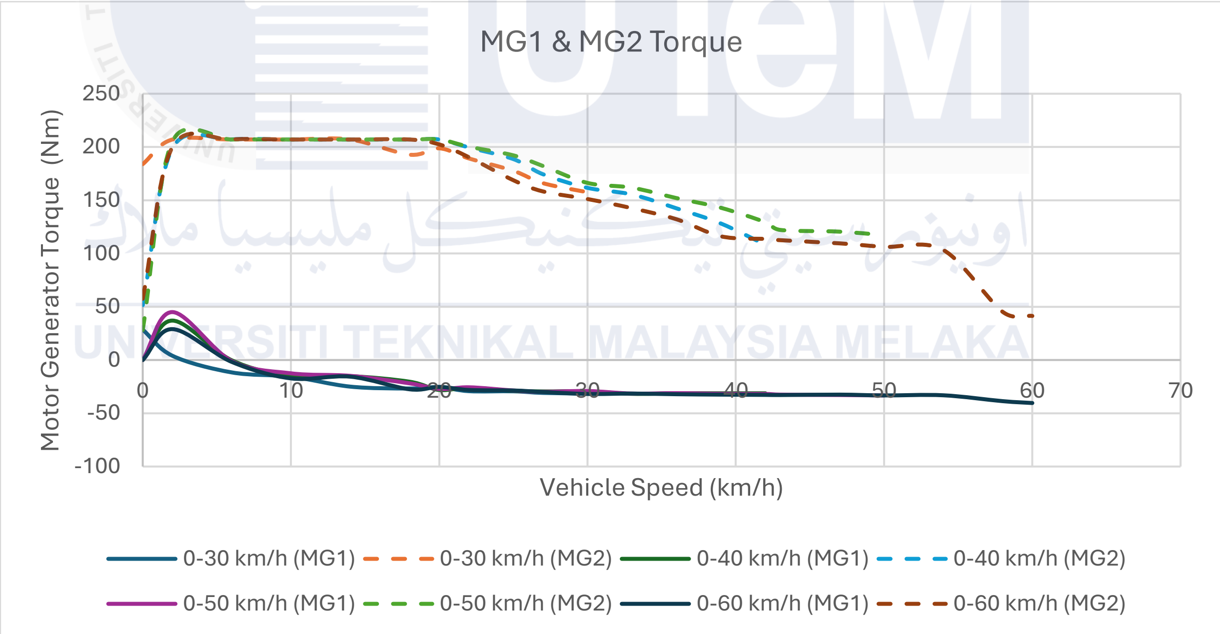

Figure 4.9 MG1 and MG2 Torque during acceleration in Eco Mode

The graph for eco mode acceleration shows a more conservative torque profile compared to sport mode. MG2 torque which is the upper curves still starts high but at a lower peak which is around 180-200 Nm and decrease more gradually as the speed increases. This reflects eco mode priority on efficiency over performance. While MG1 torque stays in a narrow negative range, indicating its primarily operating as generator to help maintain battery charge while providing smooth power delivery.

The torque drop is also present but less dramatic compared to sport mode. The drop occurs primarily due to the hybrid system's power transition strategy. Its normal to see if torque reading are higher at the beginning of the engine running and decrease by speed because, the engine need a high torque to overcome inertia and initiate movement. In the high-speed range, the torque decreases as speed increase. This reflects eco mode priority on efficiency over performance.

4.2.3.2 Acceleration : Sport Mode

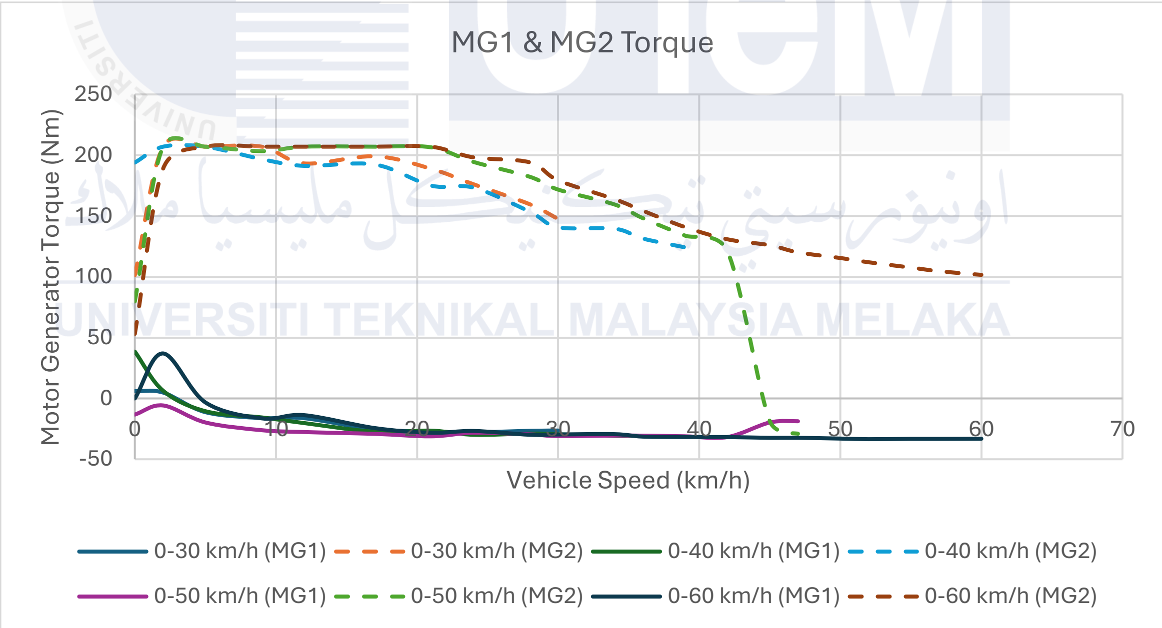

Figure 4.10 MG1 and MG2 Torque during acceleration in Sport Mode

In sport mode acceleration, the graph shows MG1 and MG2 torque behaviour with different acceleration rates. The upper curves represent MG2 torque which starts high which is around 200 – 220 Nm from 0 km/h and maintains this high torque until about 30 km/h. then gradually decreases as speed increases. Meanwhile, MG1 torque, the lower curves remain relatively low and steady, primarily acting to manage power split through the planetary gear set.

The sudden drop in MG2 torque around 40-50 km/h is particularly noticeable. This drop occurs when the system transition from pure electric drive to hybrid operation. Initially, MG2 provides high torque for a strong acceleration, but when the engine needs to engage for more efficient operation at higher speed, MG2 drop significantly. This transition represents the moment when the hybrid system shifts from primarily electric power to hybrid power.

4.2.3.3 Deceleration : Eco Mode

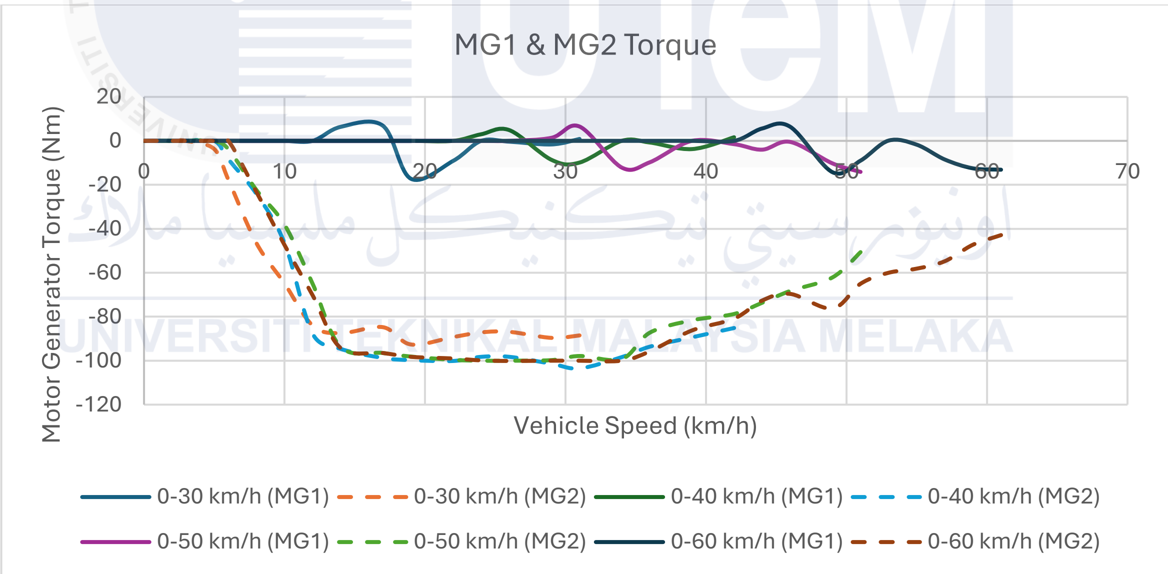

Figure 4.11 MG1 and MG2 Torque during deceleration in Eco Mode

During eco mode deceleration, the hybrid system has demonstrated a well-controlled regenerative braking strategy within a wide range of vehicle speeds from high (50-70 km/h), where both MG1 (upper curves) and MG2 (lower curves) maintain torques close to zero at their minimum values, which means light regenerative braking, to the mid-speed range (30-50 km/h), where a significant rise in negative torque up to -90 to -100 Nm takes place, representing the peak regenerative braking phase for the system. This gear change is even smoother compared to Sport mode, reflecting that eco mode has been cantered on comfort and efficiency.

Further deceleration in the lower speeds in a range of 10-30 km/h-the system gradually releases the regenerative braking force where the torque values decrease from -90 Nm back toward zero. This is clearly indicated in the data table by the smooth progression across all deceleration rates, with the greatest negative torque values concentrated in the mid-speed range before decreasing at lower speeds. Below 10 km/h, with very low speeds, torque values approach zero to ensure a very smooth and comfortable stop.

4.2.3.4 Deceleration : Sport Mode

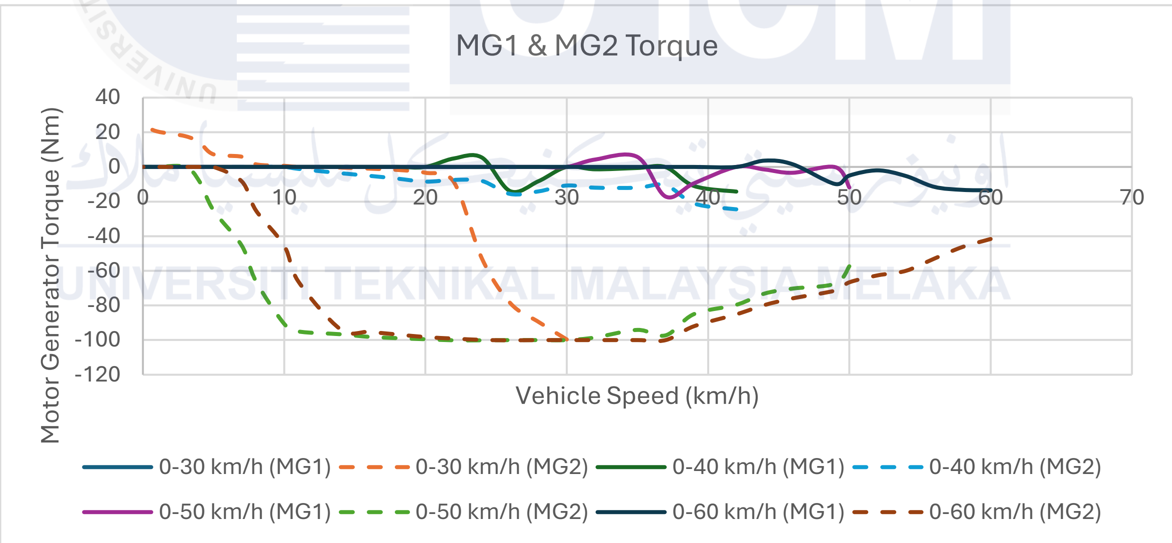

Figure 4.12 MG1 and MG2 Torque during deceleration in Sport Mode

In Sport mode, the graph shows clear behaviour patterns for both MG1 (upper curve) and MG2 (lower curves) during deceleration in different speed ranges. At higher speeds, between 0-50 km/h and 0-60 km/h, MG2 starts off with relatively modest negative torque values in a range of -20 to -40 Nm, indicating initial light regenerative braking. When the vehicle speed reduces to the mid-range, 0-30 km/h and 0-40 km/h, the negative torque of MG2 increases noticeably to attain a maximum regenerative braking force of -100Nm, showing the aggressive energy recovery of sport mode. During all this phase, MG1 shows almost zero torque magnitude since its main activity consists in controlling the operating mode of the planetary gear set.

While the vehicle continues with deceleration at lower speeds, below 0-30 km/h, the system starts to smoothly reduce the regenerative braking force for smooth stops. MG2 negative torque decreases from peak values back toward zero in order not to disturb vehicle stability during final deceleration. All of these are clearly visible in the very aggressive regenerative braking profile, deeper negative torque values, and sharper transitions in the torque curve compared to Eco mode. This can be clearly seen from the data table, where the torque values for MG2 become increasingly negative in the mid-speed range, then gradually reduce in magnitude as the speed approaches zero, while MG1 acts continuously for power distribution management via the planetary gear set.

4.2.4 MG1 and MG2 Inverter Temperature (IT)

4.2.4.1 Acceleration : Eco Mode

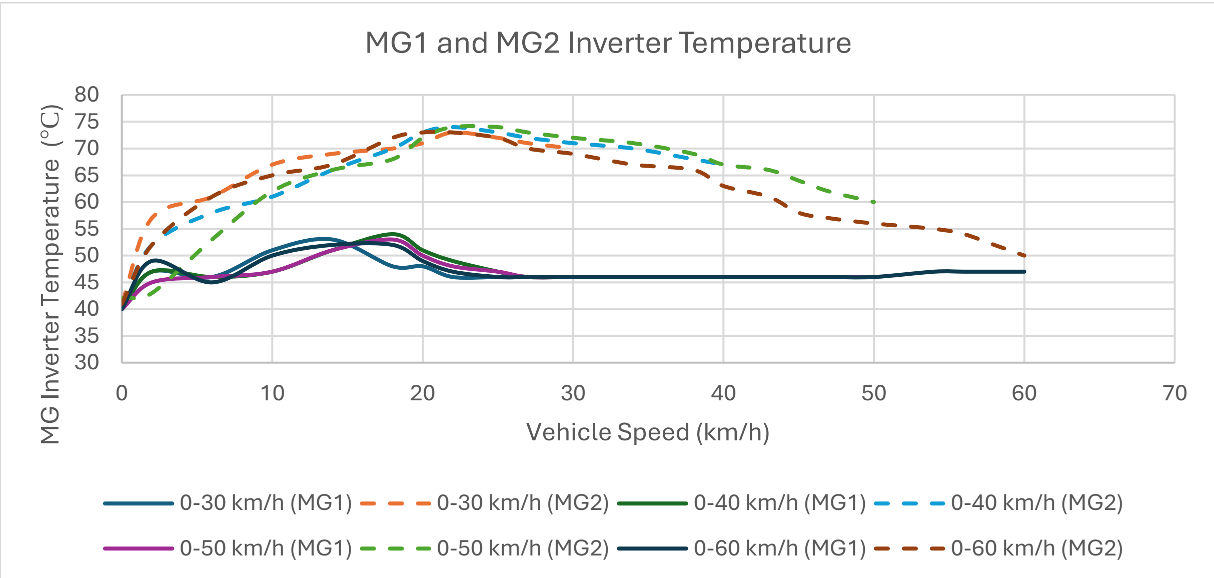

Figure 4.13 MG1 and MG2 IT during acceleration in Eco Mode

For acceleration in eco mode, the MG1 and MG2 inverter temperature rise more gradually compared to sport mode when reflecting the mode's focus on energy efficiency and moderate power delivery. At lower speed, below 0-10 km/h, the temperature increases are less pronounced as the system in a more conservative manner. Between 10-40 km/h, the inverter temperature reaches their peak values, but these peaks are lower than in sport mode, indicating reduced power demand and a more balanced load between MG1 and MG2. At higher speed, above 40km/h, the temperatures stabilize and decline slightly as speed increases, similar to the pattern observed in sport mode.

4.2.4.2 Acceleration : Sport Mode

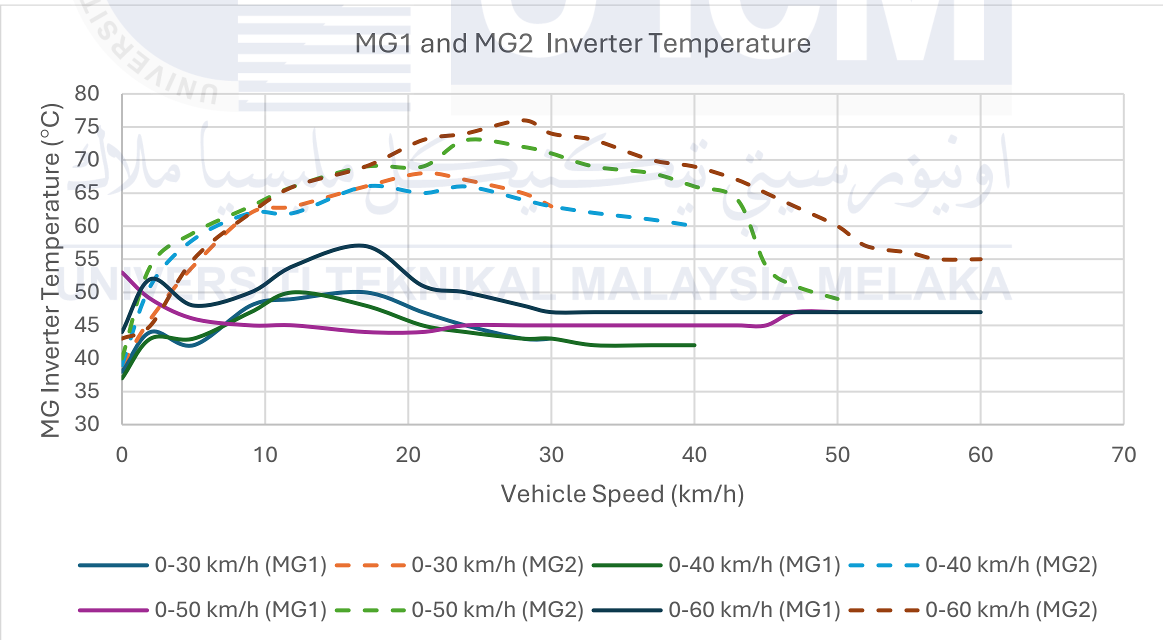

Figure 4.14 MG1 and MG2 IT during acceleration in Sport Mode

In sport mode, the MG1 and MG2 inverter temperatures show a dynamic response to the high-power demands of aggressive acceleration. At low speeds, 0-10 km/h, the temperatures rise steadily as MG2 provides the torque for rapid acceleration, while MG1 primarily manages power distribution. In the mid-speed range (10-40 km/h), the temperatures peak, with MG2 reaching approximately 68-74°C and MG1 around 66-70°C, reflecting the high energy flow required for maximum performance. MG2 experiences a sharper rise due to its primary role in propulsion, while MG1 supports power balancing within the planetary gear set. At higher speeds (40-60 km/h), the temperatures begin to stabilize and gradually decrease, with MG2 settling at 60-65°C and MG1 at 55-60°C, as torque demand reduces, and the system operates more efficiently. This pattern emphasizes the thermal load of sport mode and the importance of effective cooling to maintain inverter performance.

4.2.4.3 Deceleration : Eco Mode

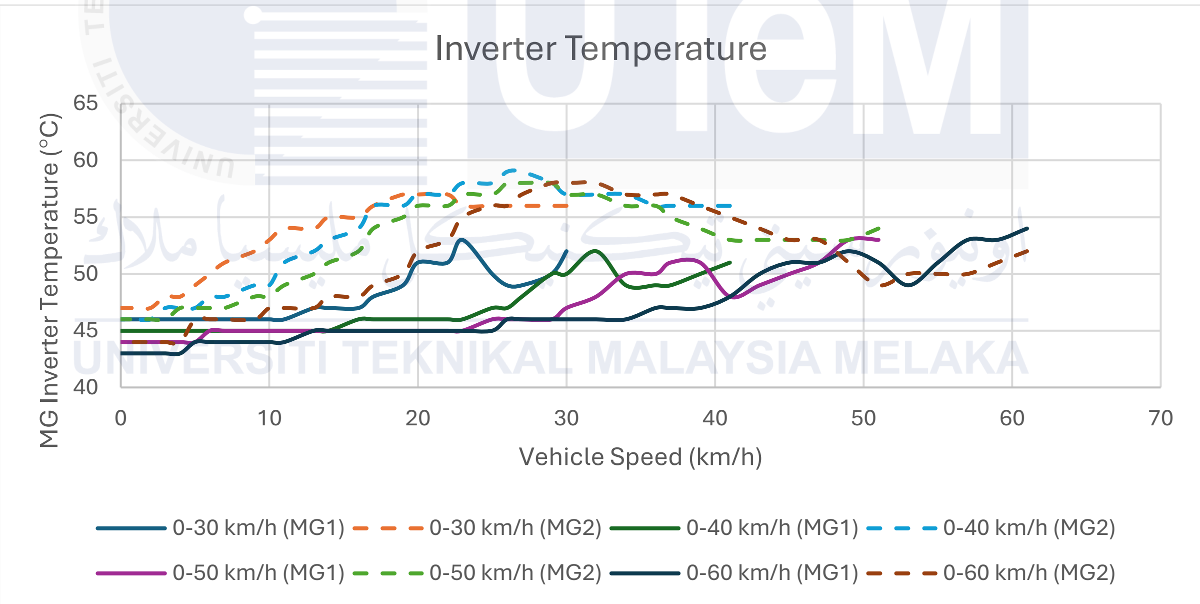

Figure 4.15 MG1 and MG2 IT during deceleration in Eco Mode

In eco mode deceleration, the inverter temperatures of MG1 and MG2 demonstrate a more gradual and controlled thermal behaviour compared to sport mode. Both motors start at similar temperatures around 45°C at low speeds, but as deceleration begins, MG2 inverter temperature shows a steady increase, reaching its peak of 55-58°C in the mid-speed range, 25-35 km/h. This progressive temperature rise aligns with eco mode's emphasis on smooth and efficient energy recovery, avoiding the sharp temperature spikes seen in sport mode.

Throughout the deceleration process, MG1 inverter temperature maintains relatively stable values, showing slight variations between 45-50°C, while MG2 temperature follows a more pronounced but controlled curve. The different deceleration rates at 30 km/h until 60 km/h, show similar temperature patterns, with higher deceleration rates resulting in slightly elevated temperatures. As the vehicle approaches higher speeds (50-60 km/h), both inverter temperatures tend to converge around 50-55°C, indicating efficient thermal management that prioritizes component longevity and system stability.

From the graph, MG2 temperature graph is less smooth appearance compared to MG1 because MG2 acts as the primary motor for regenerative braking, requiring constant adjustments to brake force and energy recovery based on driving conditions. These adjustments create more variable thermal loads in MG2 inverter, particularly between 20-40 km/h where regenerative braking is most active. Meanwhile, MG1 steadier temperature profile reflects its simpler role of managing power distribution through the planetary gear set, experiencing more consistent loads during deceleration.

4.2.4.3 Deceleration : Sport Mode

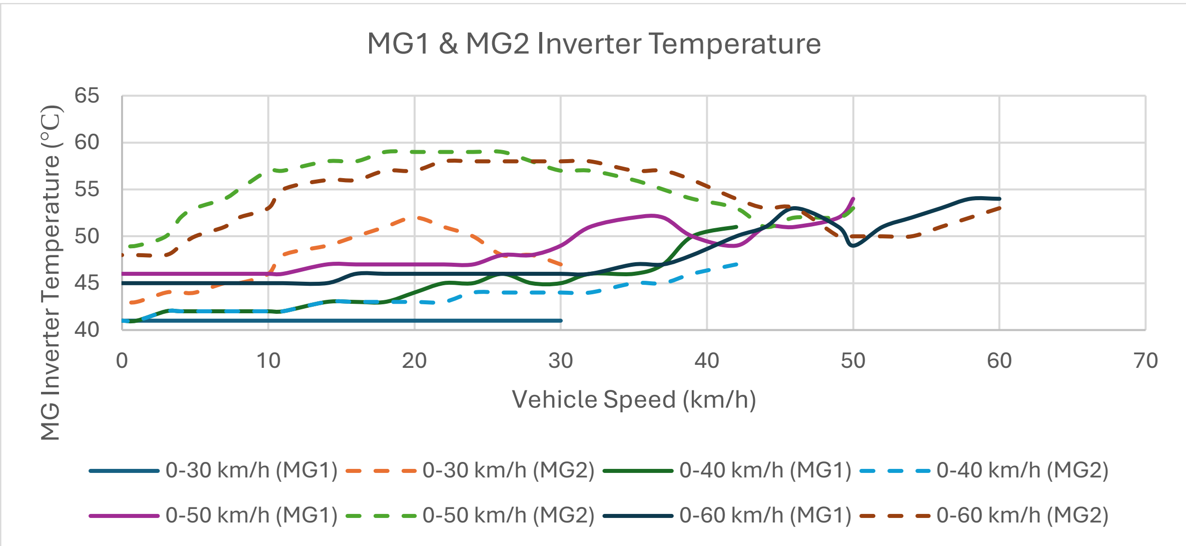

Figure 4.16 MG1 and MG2 IT during deceleration in Sport Mode

In the graph, the MG1 and MG2 inverter temperatures exhibit distinctive behaviours reflecting the aggressive regenerative braking strategy. At high speeds (50-60 km/h), both inverters start at relatively moderate temperatures around 45-50°C, but as deceleration progresses, they follow different patterns. MG1's temperature remains stable between 40-45°C throughout most of the deceleration process, indicating its consistent role in power management through the planetary gear set.

Meanwhile, MG2 temperature shows more dramatic changes, particularly in the medium speed range (20-30 km/h) where it reaches peak temperatures of 58-60°C. This higher temperature spike in MG2 directly correlates with the increased regenerative braking load characteristic of sport mode. The temperature variations are more pronounced at higher deceleration rates, showing how the sport mode's aggressive energy recovery strategy puts greater thermal stress on MG2's inverter. As the vehicle continues to slow down below 20 km/h, both inverter temperatures gradually decrease and converge around 45-50°C, demonstrating the system's thermal management capabilities even under sporty driving conditions.

4.3 Summary

The results and discussion of this study provide valuable insights into the operational characteristics of Toyota Prius 3 hybrid vehicle using the Launch X431 Pro Scan Tool to collect real time data during test drives. Key parameters such as RPM, inverter temperature, torque, and engine coolant temperature were monitored under various driving conditions and modes (Sport and Eco). The results show that engine coolant temperature, MG1 and MG2 RPM, MG1 and MG2 torque, also MG1 and MG2 inverter temperatures vary significantly between Sport and Eco modes, with Sport mode exhibiting higher temperatures and more aggressive performance characteristics. In contrast, Eco Mode shows more gradual increases in these parameters, reflecting focus on energy efficiency and smoother power delivery.

The findings highlight the importance of thermal management and efficient power distribution in hybrid vehicles to optimize performance and energy efficiency. By comparing the two driving modes, the research provides valuable insights into how hybrid vehicles can balance performance and efficiency, emphasizing the role of advanced monitoring tolls like the Launch X431 Pro in understanding and improving hybrid vehicle functionality. These results show how intricate the dynamics of hybrid vehicles are and how crucial it is to optimise driving styles and routes to maximize a better result.

CHAPTER 5

CONCLUSION

This study has successfully explored the use of the Launch X431 Pro Scan Tool to monitor and analyse the performance of Toyota Prius 3 hybrid vehicle under various driving modes and conditions. The research focused on collecting and interpreting real-time data for the key parameters such ad engine coolant temperature, motor generator of torque, RPM and inverter temperature. The results revealed significant variations between the Eco and Sport modes, highlighting the respective priorities on energy efficiency and performance dynamics.

Eco mode demonstrated a focus on optimizing fuel efficiency and reducing energy consumption, as seen in the smoother transitions and moderate values. In contrast, sport mode prioritized aggressive power delivery and dynamic performance. These findings underscore the importance of advanced diagnostic tools like the Launch X431 Pro Scan Tool in understanding the dynamic of hybrid systems and their ability to balance performance and efficiency.

Ultimately, this study aids in the development of more efficient and environmentally sustainable hybrid vehicles, advancing the automotive industry toward cleaner and more energy-efficient solutions. More broadly, this research enhances understanding of hybrid vehicle dynamics by emphasizing the importance of optimizing driving behaviours and route planning. Such insights will drive the creation of vehicle technologies that are both environmentally friendly and fuel-efficient.

RECOMMENDATION

Based on this study, there is only few parameters obtained which is engine coolant temperature, MG1 and MG2 of torque, RPM and inverter temperature. It only covers a tip of hybrid vehicles system specifically on Toyota Prius 3. To gain a deeper understanding of how hybrid system works in term of performance and efficiency, the future research can focus on expanding the range of parameters monitored in hybrid vehicles. For instance, monitoring fuel injection timing, throttle position and regenerative braking efficiency could reveal more about the interactions between the internal combustion engine and the electric motor. These parameters would allow to assess how hybrid vehicle systems balance power distribution under various driving conditions.

Besides, in this study, the Launch X431 Pro Scan Tool was used to monitor parameters like motor generator of torque, RPM, inverter temperature and engine coolant temperature. While this scan tool proved effective, there are many other advanced diagnostic tools available that might offer enhanced features. Tools like the OBDLink MX+ or professional-grade systems such as Bosch KTS may provide more access to proprietary hybrid vehicle system information, which can improve the depth of analysis. To ensure the best outcomes, future research should compare different type diagnostic tools which helps to oversee the best data collected for real-time monitoring in hybrid system. By finding and utilizing the most effective diagnostic equipment, future studies can ensure the collection of higher-quality data, leading to more robust conclusions and recommendations for improving hybrid vehicle technologies.

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APPENDIX

APPENDIX A Gantt Chart BDP 1

Task \ Week		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														
LogBook	P														
	A														
Chapter 1 : Introduction	P														
	A														
Chapter 2 : Literatire 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 B Gantt Chart BDP 2

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 C - Engine Coolant Temperature Data Table

APPENDIX C-1 Acceleration : Eco Mode

Speed (km/h)	Engine Coolant Temperature at different speed (°C)			
	0 - 30 km/h	0 - 40 km/h	0 - 50 km/h	0 - 60 km/h
0	87	88	88	87
2	87	88	88	87
6	87	88	88	87
10	87	88	88	87
14	87	88	88	87
18	87	88	88	87
20	87	88	88	87
22	87	88	88	87
25	87	88	88	87
27	87	88	88	87
30	87	88	88	87
33	-	88	88	87
39	-	88	88	88
40	-	88	88	88
43	-	-	88	88
45	-	-	88	88
47	-	-	89	88
51	-	-	89	88
55	-	-	-	88
57	-	-	-	88
60	-	-	-	88

APPENDIX C-2 Acceleration : Sport Mode

Speed (km/h)	Engine Coolant Temperature at different speed (°C)			
	0 - 30 km/h	0 - 40 km/h	0 - 50 km/h	0 - 60 km/h
0	58	62	85	86
2	58	62	85	86
5	58	62	85	86
9	58	62	85	86
12	58	62	85	86
17	58	62	85	86
21	58	62	85	86
24	58	62	85	86
28	58	62	85	86
30	58	63	85	86
34	-	63	85	86
36	-	63	85	86
39	-	63	85	86
42	-	-	85	86
45	-	-	85	86
47	-	-	85	86
50	-	-	-	86
52	-	-	-	86
55	-	-	-	86
57	-	-	-	86
60	-	-	-	86

APPENDIX C-3 Deceleration : Eco Mode

Speed (km/h)	Engine Coolant Temperature at different speed (°C)			
	0 - 30 km/h	0 - 40 km/h	0 - 50 km/h	0 - 60 km/h
60	-	-	-	88
59	-	-	-	88
57	-	-	-	88
55	-	-	-	88
53	-	-	-	88
50	-	-	88	88
49	-	-	88	88
46	-	-	88	88
44	-	-	88	89
42	-	89	88	89
39	-	89	88	89
36	-	89	88	89
34	-	89	88	89
31	87	89	88	89
29	87	89	88	89
26	87	89	88	89
24	87	89	89	89
22	87	89	89	89
20	87	89	89	89
19	87	89	89	89
17	87	89	89	89
14	87	89	89	89
12	87	89	89	89
10	87	89	89	89
8	88	89	89	89
6	88	89	89	89
5	88	89	89	89
3	88	89	89	89
2	88	89	89	89
0	88	89	89	89

APPENDIX C-4 Deceleration : Sport Mode

Speed (km/h)	Engine Coolant Temperature at different speed (°C)			
	0 - 30 km/h	0 - 40 km/h	0 - 50 km/h	0 - 60 km/h
60	-	-	-	88
58	-	-	-	88
56	-	-	-	88
54	-	-	-	88
52	-	-	-	88
50	-	-	89	88
49	-	-	89	88
46	-	-	89	88
44	-	-	89	88
42	-	85	89	89
39	-	85	90	89
37	-	85	90	89
35	-	85	90	89
32	-	86	90	89
30	87	86	90	89
28	87	86	90	89
26	87	86	90	89
24	87	86	90	89
22	87	86	90	89
20	87	86	90	89
18	87	86	90	89
16	87	86	90	89
14	87	86	90	90
11	87	86	90	90
10	87	86	90	90
8	87	86	90	90
7	88	86	90	90
5	88	86	90	90
4	88	86	90	90
3	88	86	90	90
1	88	86	90	90
0	88	86	90	90

APPENDIX D - MG1 and MG2 RPM Data Table

APPENDIX D-1 Acceleration : Eco Mode

Speed (km/h)	MG1 & MG2 RPM at different speed							
	0 – 30 km/h		0 – 40 km/h		0 – 50 km/h		0 – 60 km/h	
0	-	-	-	-	-	-	-47	50
2	-	-	-	-	-	-	1647	211
6	-	-	-	-	-	-	3990	492
10	6176	882	5065	648	4945	615	5686	809
14	7656	1143	5917	905	5893	871	6535	1039
18	8426	1486	7337	1204	7329	1140	8150	1350
20	8949	1709	8350	1491	8326	1436	8501	1666
22	9371	2119	8733	1761	8745	1707	9156	1949
25	9636	2362	9225	1991	9232	1952	9432	2394
27	9726	2657	9375	2302	9453	2191	9732	2666
30	9788	2835	9594	2554	9581	2498	9797	2907
36	-	-	9748	2820	9740	2654	9783	3144
39	-	-	9712	3043	9754	2910	9830	3345
42	-	-	9770	3264	9809	3128	9859	3579
45	-	-	-	-	9805	3282	9903	3756
47	-	-	-	-	9846	3471	9902	3944
50	-	-	-	-	9892	3657	9860	4109
54	-	-	-	-	9896	3822	9912	4293
58	-	-	-	-	-	-	9870	4449
60	-	-	-	-	-	-	9903	4561

APPENDIX D-2 Acceleration : Sport Mode

Speed (km/h)	MG1 & MG2 RPM at different speed							
	0 – 30 km/h		0 – 40 km/h		0 – 50 km/h		0 – 60 km/h	
0	-6	82	91	207	4668	46	-31	31
2	2983	256	2862	262	6156	277	1860	81
5	3827	532	4570	677	7829	542	3553	298
9	5100	781	5654	921	8394	827	5106	604
12	6333	1034	7190	1238	8765	1114	5922	877
17	7925	1387	8405	1536	9220	1405	7693	1194
21	8641	1668	8821	1810	9395	1691	8443	1495
24	9046	1939	9305	2047	9457	2017	8870	1801
28	9255	2173	9494	2408	9670	2243	9275	2052
30	9500	2407	9635	2648	9722	2562	9379	2328
34	-	-	9777	2814	9718	2803	9590	2546
39	-	-	9738	3036	9740	3028	9772	2802
42	-	-	9805	3206	9785	3237	9791	3021
45	-	-	-	-	9843	3491	9810	3244
47	-	-	-	-	8180	3516	9864	3434
50	-	-	-	-	5566	3534	9839	3648
52	-	-	-	-	-	-	9861	3836
55	-	-	-	-	-	-	9909	4014
57	-	-	-	-	-	-	9891	4232
59	-	-	-	-	-	-	9866	4380
60	-	-	-	-	-	-	9887	4534

APPENDIX D-3 Deceleration : Eco Mode

Speed (km/h)	MG1 & MG2 RPM at different speed							
	0-30 km/h		0-40 km		0-50 km/h		0-60 km/h	
61	-	-	-	-	-	-	4009	4542
59	-	-	-	-	-	-	2425	4427
57	-	-	-	-	-	-	873	4296
55	-	-	-	-	-	-	97	4138
53	-	-	-	-	-	-	-30	3980
51	-	-	-	-	4167	3787	-566	3802
49	-	-	-	-	2327	3664	-2048	3630
46	-	-	-	-	911	3521	-3332	3441
44	-	-	-	-	681	3379	-3274	3304
41	-	-	1178	3080	395	3247	-3081	3111
39	-	-	1025	2956	537	3077	-2895	2916
36	-	-	790	2801	-22	2955	-2715	2693
34	-	-	943	2667	-1686	2786	-2724	2527
31	1990	2294	219	2522	-2524	2649	-2316	2309
29	1644	2194	-1594	2375	-2354	2372	-2145	2166
26	1594	1949	-2232	2232	-2035	2045	-1946	1960
24	1453	1858	-2088	2094	-1889	1904	-1788	1802
22	-161	1755	-1951	1967	-1565	1573	-1596	1608
19	-1585	1650	-1787	1796	-1277	1275	-1447	1449
17	-1482	1286	-1513	1524	-999	994	-1261	1267
14	-1189	1187	-1236	1239	-844	842	-1049	1046
12	-1066	1069	-971	974	-701	703	-876	866
10	-974	967	-831	834	-594	596	-748	742
8	-740	738	-735	737	-484	483	-609	598
6	-576	568	-435	444	-396	393	-453	455
5	-422	413	-273	269	-309	308	-368	365
3	-261	259	-188	187	-224	218	-230	234
2	-96	93	-99	90	-120	111	-126	116
0	-32	25	-12	5	-32	26	-22	8

APPENDIX D-4 Deceleration : Sport Mode

Speed (km/h)	MG1 & MG2 RPM at different speed							
	0 – 30 km/h		0 – 40 km/h		0 – 50 km/h		0 – 60 km/h	
60	-	-	-	-	-	-	5443	4480
58	-	-	-	-	-	-	3937	4378
56	-	-	-	-	-	-	2106	4225
54	-	-	-	-	-	-	627	4057
52	-	-	-	-	-	-	175	3927
50	-	-	-	-	2533	3831	-3	3776
49	-	-	-	-	745	3669	-1034	3637
46	-	-	-	-	529	3535	-3247	3479
44	-	-	-	-	253	3395	-3276	3308
42	-	-	4633	3026	376	3228	-3127	3133
39	-	-	2978	2899	116	3079	-2885	2917
37	-	-	1606	2745	-1638	2939	-2713	2740
35	-	-	1232	2612	-2718	2803	-2563	2581
32	-	-	1087	2438	-2622	2631	-2393	2413
30	-2204	2241	1213	2336	-2441	2447	-2247	2270
28	-2020	2034	1376	2150	-2295	2319	-2091	2111
26	-1904	1922	78	2005	-2125	2147	-1939	1943
24	-1540	1553	-1727	1851	-2003	2009	-1797	1811
22	-1330	1344	-1658	1675	-1857	1860	-1631	1633
20	-1162	1224	-1531	1496	-1703	1715	-1456	1456
18	-1048	1164	-1329	1302	-1569	1569	-1301	1308
16	-980	1107	-1329	1140	-1124	1131	-1143	1157
14	-904	1042	-983	1002	-982	981	-1005	1003
11	-876	921	-847	856	-847	850	-857	858
10	-763	872	-650	638	-735	738	-727	732
8	-695	824	-427	410	-617	616	-619	616
7	-524	692	-234	219	-519	511	-516	513
5	-428	606	-69	52	-403	397	-410	406
4	-362	526	40	7	-312	298	-309	309
3	-205	277	25	3	-222	211	-216	212
1	-122	114	10	1	-111	103	-118	115
0	-21	10	0	0	-28	16	-3	2

APPENDIX E - MG1 and MG2 Torque Data Table

APPENDIX E-1 Acceleration : Eco Mode

Speed (km/h)	MG1 & MG2 Torque at different speed							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
0	28.5	183.875	0	51.5	0	28.125	0	57.5
2	4	207	37	198.625	45	205.125	29	199.75
6	-11.625	207	-0.25	207	-1	207	-1.75	207
10	-15.625	207	-15	207	-12.5	207	-17.25	207
14	-25	207	-15.125	207	-14.875	207	-15.625	207
18	-26.75	192.75	-20.375	207	-21.875	207	-27.5	207
20	-25.5	198.75	-28.125	207	-27.25	207	-25.25	202.375
22	-29.25	189.25	-26	199.5	-25.625	200.25	-28.125	190.375
25	-29.375	177.625	-28.875	188.625	-28.625	192.125	-28.625	168.75
27	-30.875	166	-29.5	174.375	-29.875	182.125	-30	158.25
30	-31.5	157.5	-29.375	161.625	-29.125	166.25	-31.875	151.125
33	-	-	-31.75	155.375	-31.5	161.75	-31.5	142.5
36	-	-	-31.25	142.375	-31.125	152	-32.125	132.125
39	-	-	-31.25	128.125	-31.75	142.875	-32.5	116.125
42	-	-	-31.25	108.125	-31.875	129.375	-32.75	113.625
43	-	-	-	-	-32.5	122.125	-32.875	112.5
47	-	-	-	-	-32.875	120.5	-32.5	109.5
50	-	-	-	-	-33.25	117.25	-33.25	106.25
54	-	-	-	-	-	-	-33.125	103.25
58	-	-	-	-	-	-	-38.625	45.25
60	-	-	-	-	-	-	-40.375	41.35

APPENDIX E-2 Acceleration : Sport Mode

Speed (km/h)	MG1 & MG2 Torque at different speed							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
0	6	101.375	38.5	194	-13.25	79.75	0	53.125
2	4.875	206.875	6.375	207	-5.75	207	37	188.875
5	-11.25	207	-10.5	207	-19.75	207	-3.25	207
9	-16.125	207	-15.625	196.75	-26.125	203.375	-16.375	207
12	-16.25	193.25	-20.25	191.25	-27.625	207	-13.75	207
17	-25.375	199.125	-27.375	192.375	-29.125	207	-24.375	207
21	-27.25	188.875	-26.5	175	-31.125	206.5	-28.25	207
24	-27.875	176.125	-29.875	173.375	-28.25	194.5	-26.75	198.25
28	-26.625	159.625	-28.875	153.5	-29.5	182.25	-29.875	194.125
30	-26.375	147.5	-29.5	140.75	-31	171.75	-29.625	179.375
34	-	-	-30.75	139.625	-30.5	159.5	-29.375	163.875
36	-	-	-30.75	131.5	-30.625	148.25	-31.375	154.375
39	-	-	-31.375	124.25	-31.125	133.875	-31.75	140.875
42	-	-	-	-	-31.75	121	-31.75	130.875
45	-	-	-	-	-19.75	-18.625	-32.375	126
47	-	-	-	-	-18.75	-29	-32.375	120.125
50	-	-	-	-	-	-	-33	115.5
52	-	-	-	-	-	-	-33.5	112
55	-	-	-	-	-	-	-33.25	107.625
57	-	-	-	-	-	-	-33.25	104.625
60	-	-	-	-	-	-	-33.125	101.625

APPENDIX E-3 Deceleration : Eco Mode

Speed (km/h)	MG1 & MG2 Torque at different speed							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
61	-	-	-	-	-	-	-13.125	-42.875
59	-	-	-	-	-	-	-12.5	-47.25
57	-	-	-	-	-	-	-8.5	-54.75
55	-	-	-	-	-	-	-1.75	-58.125
53	-	-	-	-	-	-	0.125	-60
51	-	-	-	-	-14.125	-50.625	-9	-65
49	-	-	-	-	-10.25	-62.125	-14.25	-76.25
46	-	-	-	-	-0.5	-68.25	6.375	-69.625
44	-	-	-	-	-4	-73.625	5.625	-72.625
42	-	-	1.625	-85.125	-1.5	-78.75	0	-80.875
39	-	-	-3.75	-89.375	0	-81.625	0	-86.25
36	-	-	-0.75	-93.625	-9.75	-87.25	0	-95.75
34	-	-	0	-98.375	-12.125	-99.25	0	-100
31	0.875	-88.5	-9.875	-103.5	6.5	-97.875	0	-100
29	-1.625	-89.625	-8.625	-101.375	1.375	-99.75	0	-100
26	-0.375	-86.875	4.875	-98.25	0	-100	0	-100.125
24	0	-87.125	3	-98.25	0	-100	0	-99.875
22	-9.125	-89.25	0	-100.125	0	-99.625	0	-99
19	-17.25	-92.625	0	-99.75	0	-98.125	0	-98.25
17	6.875	-84.75	0	-98.75	0	-96.5	0	-96.5
14	6.375	-87.5	0	-94.625	0	-93.75	0	-94.25
12	0	-84	0	-87.75	0	-65	0	-70.25
10	0	-64.875	0	-46.5	0	-38.125	0	-47.375
8	0	-46.5	0	-24.125	0	-22.375	0	-23.25
6	0	-17.625	0	-8.375	0	-3.75	0	0
5	0	-3.75	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

APPENDIX E-4 Deceleration : Sport Mode

Speed (km/h)	MG1 & MG2 Torque at different speed							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
60	-	-	-	-	-	-	-13.5	-41.625
58	-	-	-	-	-	-	-13.25	-46.25
56	-	-	-	-	-	-	-11.5	-53
54	-	-	-	-	-	-	-5.25	-60
52	-	-	-	-	-	-	-2	-62.625
50	-	-	-	-	-11.875	-57.375	-5	-66.625
49	-	-	-	-	-0.125	-67.375	-9.875	-71.375
46	-	-	-	-	-3.375	-70.25	1.5	-75.875
44	-	-	-		-1.5	-73.125	3.625	-79.75
42	-	-	-14.25	-24.5	0	-79.625	0	-85.125
39	-	-	-11	-21.125	-9.5	-85	0	-92
37	-	-	-0.125	-10.5	-17.125	-97.25	0	-100
35	-	-	-0.625	-12	5.75	-94.125	0	-100
32	-	-	-1.375	-12	4.25	-98.5	0	-100
30	0	-99.625	0	-10.75	0	-100	0	-100
28	0	-89.5	-8.25	-14.125	0	-100	0	-100
26	0	-78.625	-14	-15.625	0	-100	0	-100.125
24	0	-53	5.375	-8.125	0	-100.125	0	-99.875
22	0	-8.625	4.875	-7.5	0	-100.125	0	-99.125
20	0	-3.375	0	-8.5	0	-99.5	0	-98.25
18	0	-1.75	0	-6.75	0	-98.875	0	-96.75
16	0	-1	0	-5.125	0	-98.125	0	-95.25
14	0	-0.375	0	-3.625	0	-96.625	0	-93.875
11	0	0	0	-1.125	0	-95	0	-66.125
10	0	0.625	0	0	0	-90.625	0	-45.5
8	0	1.5	0	0	0	-66	0	-25.125
7	0	5.875	0	0	0	-45.5	0	-8.375
5	0	7.25	0	0	0	-25.125	0	0
4	0	14.125	0	0	0	-8.375	0	0
3	0	17.75	0	0	0	0	0	0
1	0	20.5	0	0	0	0	0	0
0	0	24.25	0	0	0	0	0	0

APPENDIX F - MG1 and MG2 Inverter Temperature Data Table

APPENDIX F-1 Acceleration : Eco Mode

Speed (km/h)	MG1 & MG2 Inverter Temperature at different speed (ºC)							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
0	40	41	40	41	40	42	40	41
2	47	57	47	52	45	43	49	52
6	46	61	46	58	46	53	45	61
10	51	67	47	61	47	62	50	65
14	53	69	51	66	51	66	52	67
18	48	70	54	70	53	68	52	72
20	48	71	51	73	50	72	49	73
22	46	73	49	74	48	74	47	73
25	46	72	47	73	47	74	46	72
27	46	71	46	72	46	73	46	70
30	46	70	46	71	46	72	46	69
34	-	-	46	70	46	71	46	67
38	-	-	46	68	46	69	46	66
40	-	-	46	67	46	67	46	63
43	-	-	-	-	46	66	46	61
45	-	-	-	-	46	64	46	58
47	-	-	-	-	46	62	46	57
50	-	-	-	-	46	60	46	56
54	-	-	-	-	-	-	47	55
56	-	-	-	-	-	-	47	54
58	-	-	-	-	-	-	47	52
60	-	-	-	-	-	-	47	50

APPENDIX F-2 Acceleration : Sport Mode

Speed (km/h)	MG1 & MG2 Inverter Temperature at different speed (ºC)							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
0	38	39	37	39	53	40	44	43
2	44	46	43	51	49	54	52	45
5	42	54	43	58	46	59	48	55
9	48	62	47	62	45	63	50	62
12	49	63	50	62	45	66	54	66
17	50	66	48	66	44	69	57	69
21	47	68	45	65	44	69	51	73
24	45	67	44	66	45	73	50	74
28	43	65	43	64	45	72	48	76
30	43	63	43	63	45	71	47	74
33	-	-	42	62	45	69	47	73
37	-	-	42	61	45	68	47	70
40	-	-	42	60	45	66	47	69
43	-	-	-	-	45	64	47	67
45	-	-	-	-	45	54	47	65
47	-	-	-	-	47	51	47	63
50	-	-	-	-	47	49	47	60
52	-	-	-	-	-	-	47	57
55	-	-	-	-	-	-	47	56
57	-	-	-	-	-	-	47	55
60	-	-	-	-	-	-	47	55

APPENDI F-3 Deceleration : Eco Mode

Speed (km/h)	MG1 & MG2 Inverter Temperature at different speed (ºC)							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
61	-	-	-	-	-	-	54	52
59	-	-	-	-	-	-	53	51
57	-	-	-	-	-	-	53	50
55	-	-	-	-	-	-	51	50
53	-	-	-	-	-	-	49	50
51	-	-	-	-	53	54	51	49
49	-	-	-	-	53	53	52	51
47	-	-	-	-	51	53	51	53
45	-	-	-	-	50	53	51	53
43	-	-	-	-	49	53	50	54
41	-	-	51	56	48	53	48	55
39	-	-	50	56	51	54	47	56
37	-	-	49	56	51	55	47	57
36	-	-	49	56	50	56	47	57
34	-	-	49	57	50	56	46	57
32	-	-	52	57	48	57	46	58
30	52	56	50	57	47	57	46	58
29	50	56	50	58	46	58	46	58
27	49	56	48	59	46	58	46	57
26	49	56	47	59	46	58	46	56
25	50	56	47	58	46	57	45	56
23	53	56	46	58	45	57	45	55
22	51	57	46	57	45	56	45	53
20	51	57	46	57	45	56	45	52
19	49	57	46	56	45	55	45	50
17	48	56	46	56	45	54	45	49
16	47	55	46	54	45	52	45	48
14	47	55	45	53	45	51	45	48
13	47	54	45	52	45	50	45	47
11	46	54	45	51	45	49	44	47
10	46	53	45	49	45	48	44	47
9	46	52	45	49	45	48	44	46
7	46	51	45	48	45	47	44	46
5	46	49	45	47	44	47	44	46
4	46	48	45	47	44	47	43	44
2	46	47	45	46	44	46	43	44
1	46	47	45	46	44	46	43	44
0	46	47	45	46	44	46	43	44

APPENDIX F-4 Deceleration : Sport Mode

Speed (km/h)	MG1 & MG2 Inverter Temperature at different speed (ºC)							
	0-30 km/h		0-40 km/h		0-50 km/h		0-60 km/h	
60	-	-	-	-	-	-	54	53
58	-	-	-	-	-	-	54	52
56	-	-	-	-	-	-	53	51
54	-	-	-	-	-	-	52	50
52	-	-	-	-	-	-	51	50
50	-	-	-	-	54	53	49	50
49	-	-	-	-	52	52	51	50
46	-	-	-	-	51	52	53	53
44	-	-	-	-	51	51	51	53
42	-	-	51	47	49	53	50	54
39	-	-	50	46	50	54	48	56
37	-	-	47	45	52	55	47	57
35	-	-	46	45	52	56	47	57
32	-	-	46	44	51	57	46	58
30	41	47	45	44	49	57	46	58
28	41	48	45	44	48	58	46	58
26	41	48	46	44	48	59	46	58
24	41	50	45	44	47	59	46	58
22	41	51	45	43	47	59	46	58
20	41	52	44	43	47	59	46	57
18	41	51	43	43	47	59	46	57
16	41	50	43	43	47	58	46	56
14	41	49	43	43	47	58	45	56
11	41	48	42	42	46	57	45	55
10	41	46	42	42	46	57	45	53
8	41	45	42	42	46	55	45	52
7	41	45	42	42	46	54	45	51
5	41	44	42	42	46	53	45	50
4	41	44	42	42	46	52	45	49
3	41	44	42	42	46	50	45	48
1	41	43	41	41	46	49	45	48
0	41	43	41	41	46	49	45	48