

Comparative Simulation of Battery Cooling Methods in a Converted Automatic Transmission Electric Vehicle

Yosua Setiawan*¹, Mohd Farid², Adrian Sutjiadi³

^{1,3}Department of Mechanical Engineering, Atma Jaya Catholic University of Indonesia

²Automotive Development Centre, Universiti Teknologi Malaysia

E-mail: yosua.setiawan@atmajaya.ac.id

ABSTRAK

Studi ini dilakukan untuk mengetahui reaksi dari mobil listrik hasil konversi dari mesin pembakaran dan mengujinya dengan dua siklus mengemudi yaitu NEDC dan WLTP dengan menggunakan perangkat lunak GT-Suite. Hasil menunjukkan bahwa kondisi berkendara memiliki pengaruh signifikan terhadap temperatur baterai. Pada siklus NEDC, temperatur puncak mencapai 61°C tanpa sistem pendingin, yang kemudian menurun menjadi 50,7°C dengan pendinginan pasif dan 30,1°C dengan pendinginan aktif. Sebaliknya, siklus WLTP yang lebih dinamis menghasilkan beban termal yang lebih tinggi, dengan temperatur puncak mencapai 75,7°C tanpa pendinginan dan 66,5°C dengan pendinginan pasif, sementara pendinginan aktif mampu menurunkannya hingga 38°C. Hal ini mengindikasikan bahwa ketika arus keluar dari baterai tinggi, hal tersebut memicu kenaikan temperatur yang signifikan. Pendinginan secara pasif dapat mengurangi temperatur maksimum, tetapi itu belum cukup untuk membuat baterai berada di rentang temperatur yang aman. Penggunaan pendingin aktif menggunakan air membuat temperatur baterai berada di rentang temperatur yang aman.

Kata kunci :

Konversi; Kendaraan Listrik; Simulasi; GT-Suite

ABSTRACT

This study investigates the thermal behaviour of a converted electric vehicle battery pack under the NEDC and WLTP driving cycles using GT-Suite simulation. The results show that driving conditions significantly influence battery temperature. Under the NEDC cycle, the peak temperature reached 61°C without cooling, which decreased to 50.7°C with passive cooling and 30.1°C with active cooling. In contrast, the more demanding WLTP cycle produced higher thermal stress, with peak temperatures of 75.7°C without cooling and 66.5°C with passive cooling, while active cooling reduced it to 38°C. The findings indicate that rapid acceleration and high-speed operation increase discharge currents, leading to higher heat generation. Although passive cooling reduces thermal stress, it is insufficient to maintain safe operating temperatures under dynamic conditions, whereas active cooling provides effective thermal control.

Keywords :

Conversion; Electric Vehicle; GT-Suite; Simulation

1. INTRODUCTION

For the past ten years, the global transportation sector has undergone a transition to become more environmentally friendly through electrification. The beginning of this project was started because of the Paris Agreement in 2016 [1]. The fastest and easiest way to minimize or eliminate the emissions or tail pipe emissions is moving to electric vehicles.

Many governments around the world have created a policy to accelerate the adaptation of EV to the customer. Tax exemptions and road tax exemptions are the most common policies to accelerate the adaptation of EV. Countries such as Malaysia and Indonesia are implementing this exemption to promote and encourage peoples to buy EV Despite these advancements, the high upfront cost of EVs remains a major barrier, particularly in

developing countries such as Indonesia and Malaysia.

As an alternative to purchasing new EVs, converting existing ICE vehicles into electric vehicles has gained attention as a cost-effective and sustainable solution. EV conversion allows for the reuse of existing vehicle structures, reducing material waste and lifecycle emissions. This approach is particularly relevant in regions where older vehicles are still widely used. The cost to convert ICE vehicles to battery EV (BEVs) is considered low and viable than buying a new EV [2]. Converting ICE vehicles into battery electric vehicles BEVs also supports net-zero emission goals. This is because replacing existing ICE vehicles with newly manufactured BEVs would otherwise generate additional environmental burdens, particularly from emissions associated with the vehicle production process [3, 4].

Many converted electric vehicles (EVs) are not equipped with an adequate cooling system, despite the well-established importance of thermal management for ensuring battery safety and longevity. A significant limitation in such conversions is the lack of a dedicated Battery Thermal Management System (BTMS) or effective heat dissipation mechanisms. In the absence of proper thermal regulation, battery systems are more prone to accelerated degradation and an elevated risk of thermal runaway, particularly during charging, discharging, and prolonged operation. Consequently, battery lifespan may be substantially shortened, while critical safety concerns associated with uncontrolled temperature increases remain insufficiently addressed.

Simulation plays a pivotal role in the design and development of BTMS for EV battery packs. It enables accurate prediction of thermal behaviour and cooling performance, thereby reducing development time and research costs. Computational tools such as ANSYS are widely used to analyse thermal characteristics and evaluate cooling efficiency in battery systems. Similarly, GT-Suite has gained prominence in the automotive engineering field due to its capability to simulate integrated vehicle

systems. For example, GT-Suite can model the transient thermal behaviour of battery packs in conjunction with cooling system performance [5]. Wang, et al. [6], demonstrated that simulation results show strong agreement with experimental data, highlighting the reliability of simulation methods in determining optimal cooling strategies. Therefore, simulation is a critical step in understanding battery thermal dynamics prior to practical implementation.

In this study, two standard driving cycles will be employed: the New European Driving Cycle (NEDC) and the Worldwide Harmonized Light Vehicles Test Procedure (WLTP). These driving cycles are selected due to their widespread use in evaluating vehicle performance, particularly in assessing EV driving range. The simulation aims to perform a comparative thermal analysis between battery packs equipped with a cooling system and those without, in order to quantify the impact of thermal management on battery performance and safety.

2. METODOLOGI PENELITIAN

This study builds upon the author's prior work on converting an internal combustion engine (ICE) vehicle into a battery electric vehicle (EV), using the Toyota Avanza as the base platform. The Toyota Avanza was chosen due to its widespread use and accessibility in Indonesia, making it a suitable representative for practical EV conversion applications. The original vehicle configuration featured a 1.3-litre petrol engine coupled with an automatic transmission, delivering 93 horsepower and 120 Nm of torque. To achieve comparable performance in the electrified configuration, an appropriate electric propulsion system was selected. A three-phase synchronous AC motor was implemented, offering a peak power of 60 kW, a continuous rated power of 33 kW, and an efficiency of approximately 95%. The motor is capable of producing a maximum torque of 220 Nm and operating at speeds up to 12,000 rpm. The detailed specifications of the converted

EV, including motor and battery parameters, are presented in Table 1.

Table 1. Toyota Avanza converted car specifications

Vehicle Parameter	Values	Unit
Vehicle Gross Weight	1250	<i>kg</i>
Aerodynamic drag coefficient	0.3 [7]	
Frontal Area	2.23 [7]	<i>m²</i>
Final Drive Gear Ratio	5.125	
Motor Voltage	260-410	<i>V</i>
Max Torque	220	<i>Nm</i>
Peak Power	60	<i>kW</i>
Battery Pack Rated Voltage	268.8	<i>V</i>
Battery Pack Capacity	40.32	<i>kWh</i>

Based on these specifications, a comprehensive vehicle model was developed in GT-Suite. The model, illustrated in Figure 1, was initially constructed using the built-in electric vehicle template provided by the software. This template served as a baseline framework, which was subsequently modified to accurately reflect the characteristics of the

converted vehicle. In particular, the final drive ratio was adjusted to match the original differential configuration of the Toyota Avanza, ensuring consistency in drivetrain behaviour relative to the baseline vehicle.

Following the development of the GT-Suite model, a passive cooling module and active cooling using liquid were integrated into the simulation. This module incorporated convection nodes and temperature probes to simulate thermal behaviour within the battery system. The convection nodes were used to represent heat transfer processes, defined primarily by the convective heat transfer coefficient and the effective surface area. In this study, the convective heat transfer coefficient was differentiated based on whether the battery pack was equipped with a passive cooling system, active cooling system or not, while the surface area parameter was determined by the battery enclosure design and the contact between the liquid cooling plate and the batteries for passive and active cooling system respectively.

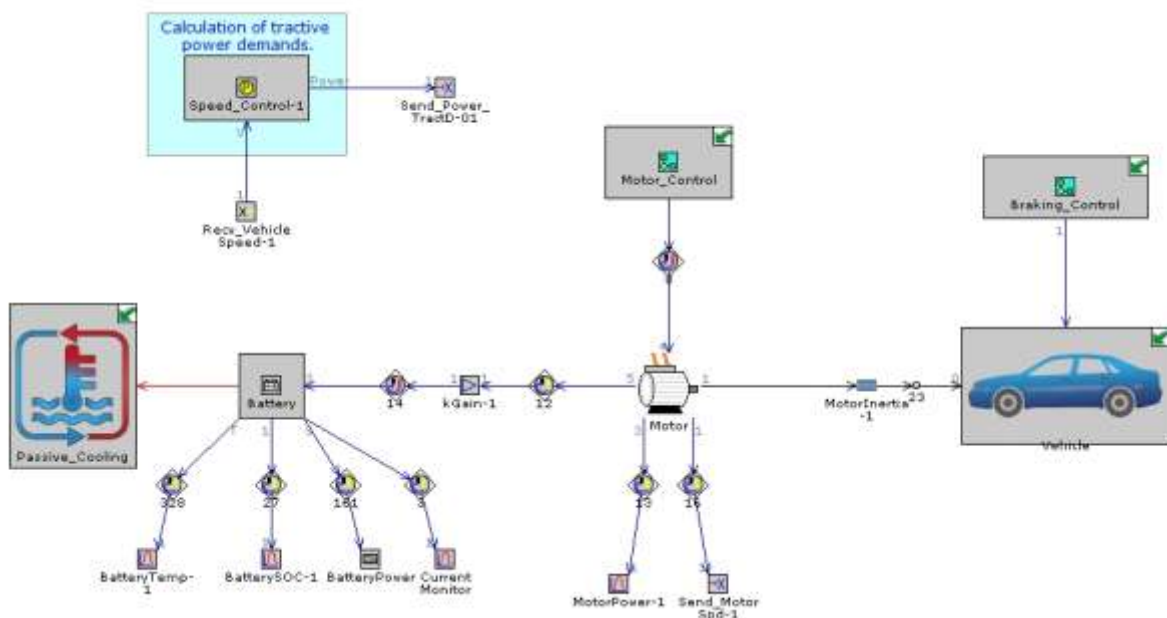


Figure 1. Map of Toyota Avanza in GT-Suite with passive cooling system



Figure 2. ConvectionConn node in GT-Suite.

For the passive cooling configuration, the battery enclosure was designed to function as a large heat sink, as shown in Figure 3. Aluminium was selected as the enclosure material due to its favourable properties, including low density and high

thermal conductivity, which facilitate efficient heat dissipation. The enclosure design incorporated a total of 136 aluminium fins to increase the effective surface area and enhance convective heat transfer.

Meanwhile, the active cooling was using refrigerant R-1234a and the cooling system was using GT-Suite template for battery cooling with refrigerant. The model diagram of the cooling system shown in Figure 3. Meanwhile the cooling plate is located at the bottom of the battery pack, just like most brand new EV car. An active liquid cooling system using refrigerant was circulated inside the cooling plate as shown in Figure 4.

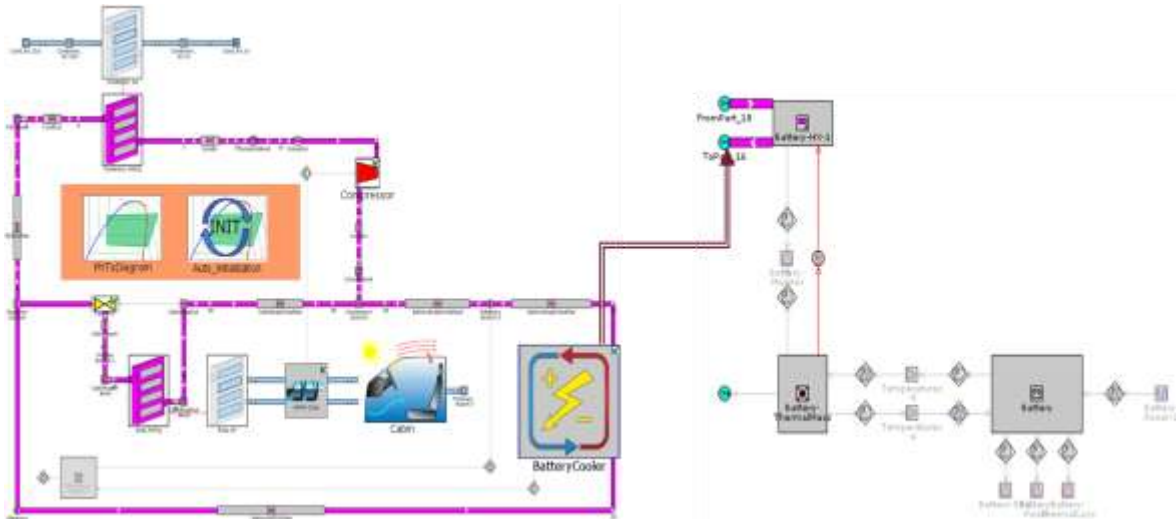


Figure 3. Diagram of the cooling system in GT-Suite.

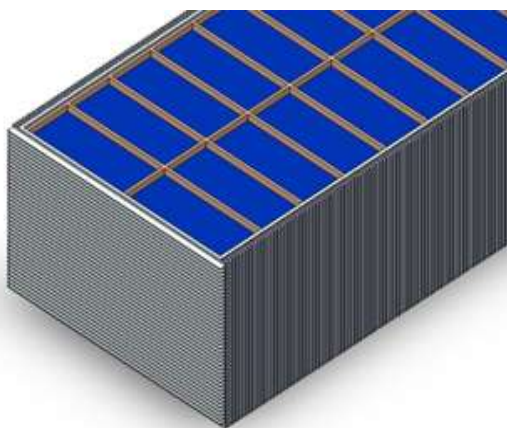


Figure 5. Battery enclosure design for battery pack that act as a heat sink.

3. RESULTS AND DISCUSSION

3.1. NEDC Driving Cycle

During the NEDC driving cycle, the vehicle achieved a maximum speed of approximately 120 km/h, as illustrated in Figure 1. The simulation results indicate that, in the absence of any cooling mechanism, the battery temperature reached a peak value of 61°C. When thermal management strategies were introduced, a substantial reduction in peak temperature was observed. Specifically, the implementation of a passive cooling system reduced the maximum battery temperature to 50.7°C, while the integration of an active cooling system further decreased it to

30.1°C, as shown in **Error! Reference source not found..**

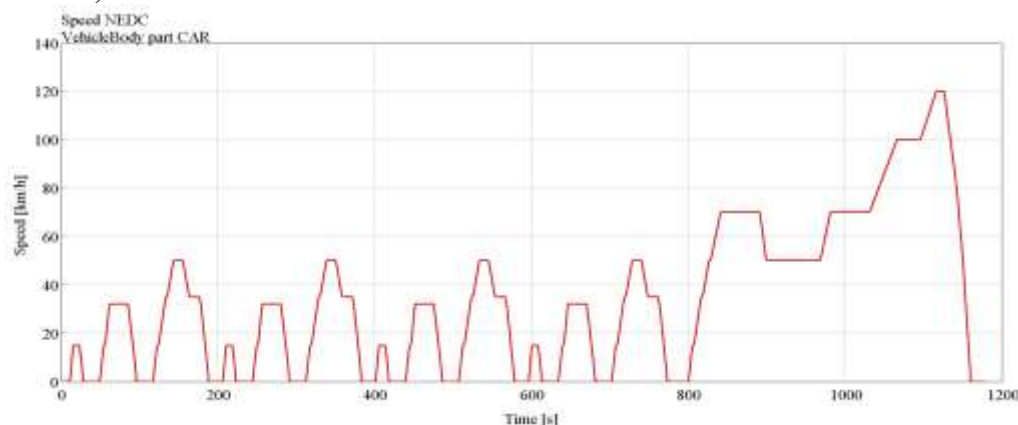


Figure 1. Speed graph of NEDC.

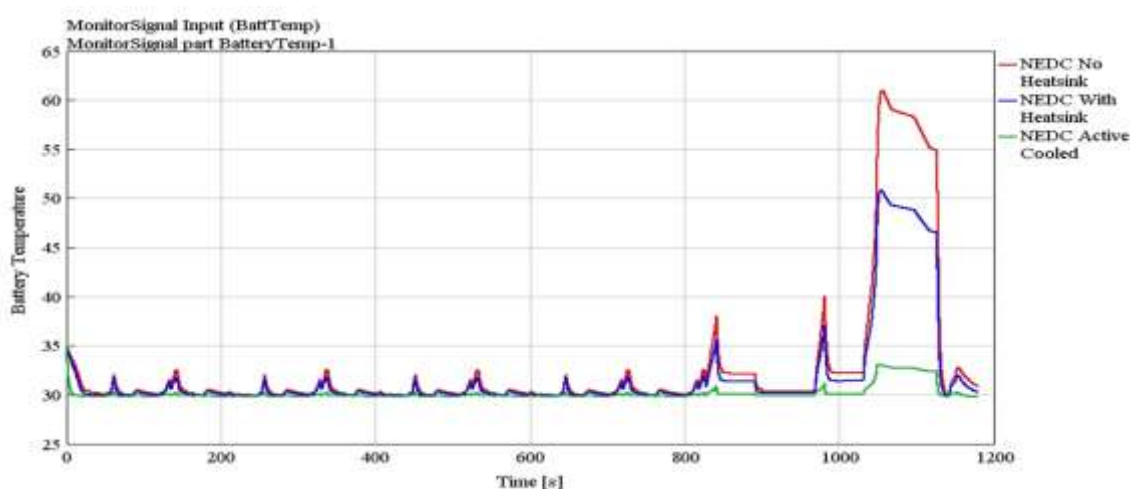


Figure 7. Battery temperature comparison using NEDC.

A comparison between the battery temperature profile and the NEDC velocity profile reveals a strong correlation between transient driving conditions and thermal response. The battery temperature increases significantly during rapid acceleration phases, particularly as the vehicle approaches its maximum speed. The temperature continues to rise and reaches its peak during subsequent deceleration and braking periods. This trend can be attributed to elevated charge and discharge rates associated with aggressive acceleration and regenerative braking, both of which intensify heat generation within the battery pack. These findings highlight the pronounced influence of transient load conditions on battery thermal behaviour, even within relatively moderate driving cycles such as the NEDC. Author has done some experimental during normal driving cycle and the car shown temperature around 30 to

35°C driving around 20-80 km/h for 30 minutes. When the car was under normal load not heavy load the battery temperature was very similar to the simulation result.

The results clearly demonstrate that even a passive cooling approach can effectively mitigate thermal stress within the battery system under standard driving conditions. However, the adoption of an active cooling system provides a significantly greater reduction in operating temperature, bringing it down to a safer level of approximately 30.1°C. Maintaining lower battery temperatures is essential for enhancing battery lifespan, ensuring operational safety, and sustaining overall performance during vehicle operation.

3.2 WLTP Driving Cycle

The WLTP driving cycle, which is more demanding and better reflects real-world driving conditions, is illustrated in Figure 6. In

comparison to the NEDC, the WLTP cycle imposed significantly higher thermal loads on the battery pack, as indicated by increased average and peak temperatures. Under this cycle, and without any thermal management system, the battery temperature rose markedly, reaching a maximum of 75.7°C. When a passive cooling system was introduced, the peak temperature decreased to 66.5°C. Although this reduction demonstrates the capability of passive cooling to mitigate temperature rise under high-load and dynamic operating conditions, the resulting temperature remains relatively high from a safety and durability perspective. A detailed comparison of the battery temperature profiles for both conditions is presented in Figure 7. Furthermore, the implementation of an active liquid cooling system resulted in a substantial

reduction in peak temperature to approximately 38°C.

The elevated average battery temperature observed during the WLTP cycle can be attributed to its higher maximum speeds and more aggressive, transient driving patterns leads to much higher current drawn from the battery. A comparative analysis of the vehicle speed and battery temperature profiles indicates that peak temperatures occur during periods of maximum acceleration and high-speed operation. This behaviour is primarily driven by increased discharge currents under high power demand, which intensify internal heat generation within the battery. The strong correlation between vehicle dynamics and thermal response highlights the necessity of incorporating realistic driving conditions into the design and evaluation of battery thermal management systems.

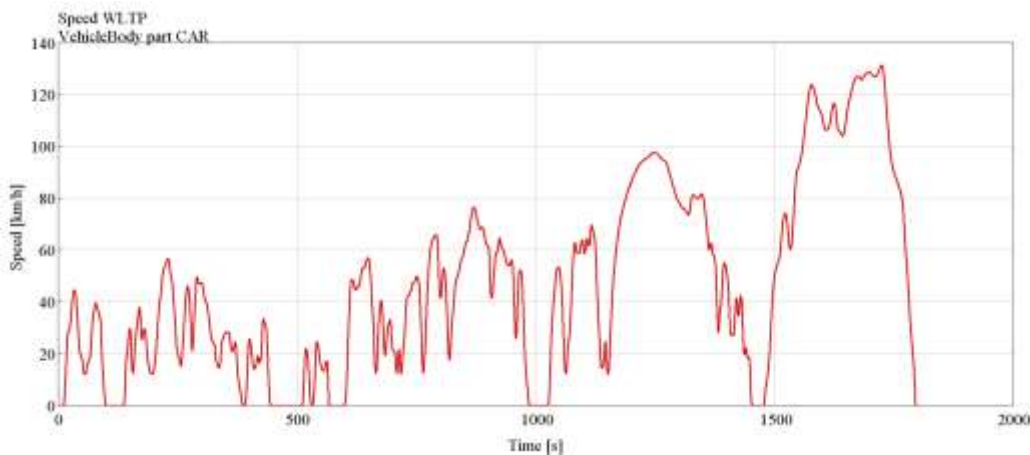


Figure 2. WLTP speed graph.

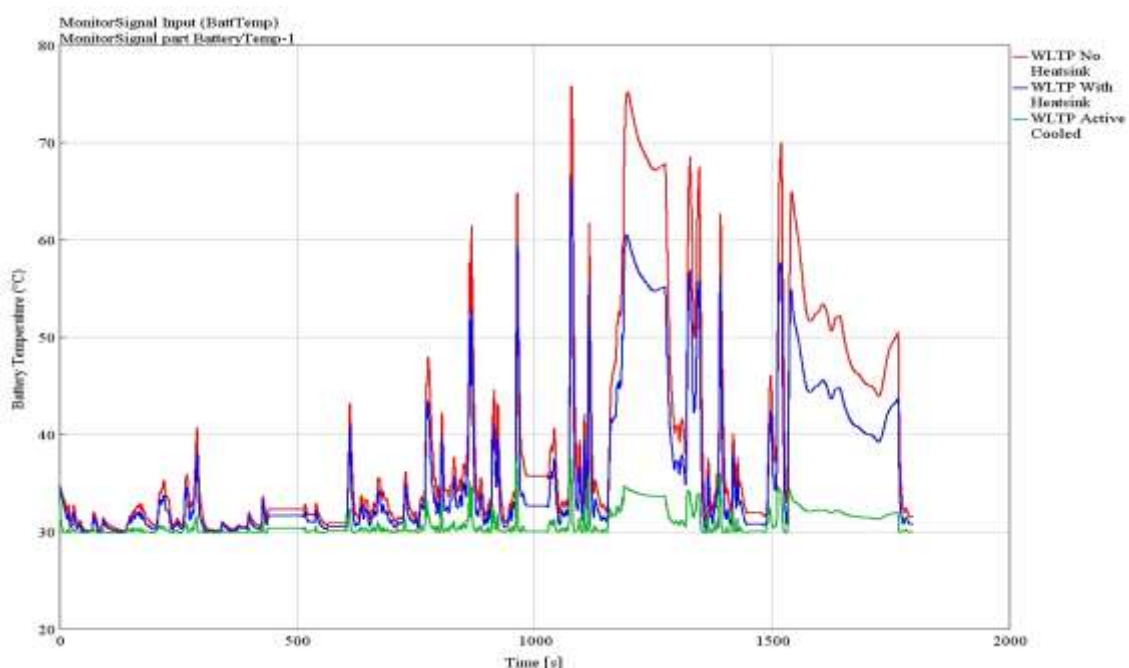


Figure 9. Battery temperature comparison using WLTP

CONCLUSION

This study examined the thermal behaviour of a converted electric vehicle battery pack under two standardised driving cycles, namely the NEDC and WLTP, using GT-Suite simulations. The results demonstrate that operating conditions have a significant influence on battery temperature. Under the NEDC cycle, a moderate thermal increase was observed, with a peak temperature of 61°C in the absence of a cooling system. The introduction of passive cooling reduced this value to 50.7°C, while active cooling further decreased the peak temperature to 30.1°C. In contrast, the more dynamic WLTP cycle imposed substantially higher thermal stress, resulting in peak temperatures of 75.7°C without cooling and 66.5°C with passive cooling. The application of an active cooling system significantly improved thermal regulation, reducing the peak temperature to approximately 38°C, which falls within a safer operating range.

The analysis indicates that high-speed operation and rapid acceleration phases lead to elevated discharge currents, which in turn increase heat generation within the battery pack. The observed correlation between vehicle dynamics—particularly speed and acceleration—and thermal response highlights the critical importance of effective battery thermal management systems, especially under realistic driving conditions. While passive cooling was shown to reduce thermal stress and improve overall safety, it was insufficient to maintain temperatures within an optimal range under more demanding conditions. In contrast, active cooling proved necessary to achieve safe and stable operating temperatures.

These findings reinforce the value of simulation tools such as GT-Suite in predicting battery thermal behaviour during the early stages of EV development, particularly for conversion-based applications where thermal management is frequently underdeveloped.

To enhance the validity of this work, future studies should incorporate experimental validation by comparing simulation results with real-world data. This

can be achieved through the integration of temperature sensors and current monitoring systems to capture in-situ thermal performance during vehicle operation. Additionally, since the present study primarily considers heat transfer within the battery pack and its cooling system, future investigations should also account for ambient temperature conditions surrounding the battery enclosure to enable a more comprehensive analysis of heat transfer mechanisms.

ACKNOWLEDGEMENTS

This study was supported by the research grant number Q.J130000.5009.10G04 under Universiti Teknologi Malaysia Flagship CoE/RG.

REFERENCES

- [1] G. Liobikienė and M. Butkus, "The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy," *Renewable Energy*, Article vol. 106, pp. 298-309, 2017, doi: 10.1016/j.renene.2017.01.036.
- [2] D. Pedrosa, V. Monteiro, H. Goncalves, J. S. Martins, and J. L. Afonso, "A Case Study on the Conversion of an Internal Combustion Engine Vehicle into an Electric Vehicle," in *2014 IEEE Vehicle Power and Propulsion Conference (VPPC)*, 27-30 Oct. 2014 2014, pp. 1-5, doi: 10.1109/VPPC.2014.7006994.
- [3] K. G. Logan, J. D. Nelson, C. Brand, and A. Hastings, "Phasing in electric vehicles: Does policy focusing on operating emission achieve net zero emissions reduction objectives?," *Transportation Research Part A: Policy and Practice*, vol. 152, pp. 100-114, 2021/10/01/ 2021, doi: <https://doi.org/10.1016/j.tra.2021.08.001>.
- [4] M. D. Santis and F. Regis, "Modeling, simulation, and techno-economic analysis of a retrofitted electric vehicle," in *2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 7-10 Sept. 2021 2021, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope51590.2021.9584594.

- [5] K. Muhammad Usman *et al.*, "Comparative Analysis of Experimental and Simulated Performance and Emissions of Compression Ignition Engine Using Biodiesel Blends," *IOP Conference Series: Materials Science and Engineering*, vol. 377, no. 1, p. 012136, 2018, doi: 10.1088/1757-899X/377/1/012136.
- [6] L. Wang, L. Wang, Y. Yue, and Y. Zhang, "Research on Thermal Management System of Lithium Iron Phosphate Battery Based on Water Cooling System," in *Proc. 2018 Chinese Automation Congress (CAC)*, 2018, pp. 341-349.
- [7] N. Xavier, "Calculating the Aerodynamic Drag Coefficient of a Toyota Avanza Car CAD Model Using CFD Analysis," in *Proc. 2023 31st Southern African Universities Power Engineering Conf. (SAUPEC)*, Jan. 2023, pp. 1-5, doi: 10.1109/SAUPEC57889.2023.1005780