Cylinder: Jurnal Ilmiah Teknik Mesin
Volume 11, Nomor 1, April 2025
ISSN 2252-925X (Online)

Thermal Behaviour of Electric Vehicle Battery Packs under NEDC and WLTP Driving Cycles: A GT-Suite Simulation Study

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ABSTRACT
This study examines the thermal behaviour of a $LiFePO_4$ battery pack in a converted electric vehicle using GT-Suite simulation. The base vehicle, a Toyota Avanza originally powered by a 1.3-litre engine, was retrofitted with a 60-kW synchronous AC motor and a 268.8 V, 40.32 kWh battery pack. Simulations were conducted under NEDC and WLTP driving cycles, both with and without passive cooling. Results showed that battery temperature peaked at 45.3°C (NEDC) and 71.6°C (WLTP) without cooling and was reduced to 36.6°C and 48.0°C respectively with passive cooling. Temperature spikes coincided with rapid acceleration and high-speed phases, highlighting the influence of discharge current on battery heating. These findings demonstrate the importance of thermal management in EV conversions and the effectiveness of passive cooling. Future work will focus on experimental validation and discharge current control via a battery management system (BMS) to ensure battery safety and longevity.

Keywords: Conversion; Electric Vehicle; GT-Suite; Simulation;

ABSTRAK
Penelitian ini menganalisis perilaku termal dari paket baterai lithium iron phosphate ($LiFePO_4$) pada kendaraan listrik hasil konversi dengan menggunakan perangkat lunak simulasi GT-Suite. Kendaraan dasar yang digunakan adalah Toyota Avanza dengan mesin 1.3-liter yang dikonversi menjadi kendaraan listrik, dilengkapi motor AC sinkron berdaya puncak 60 kW dan paket baterai sebesar 268,8 V dan 40,32 kWh. Simulasi dilakukan berdasarkan dua siklus pengujian standar, yaitu New European Driving Cycle (NEDC) dan Worldwide Harmonised Light Vehicles Test Procedure (WLTP), baik dalam kondisi tanpa sistem pendingin maupun dengan sistem pendingin pasif. Hasil menunjukkan bahwa suhu maksimum baterai mencapai 45,3°C (NEDC) dan 71,6°C (WLTP) tanpa pendinginan, yang kemudian menurun menjadi 36,6°C dan 48,0°C dengan pendinginan pasif. Peningkatan suhu terutama terjadi saat akselerasi cepat dan laju kendaraan tinggi, menunjukkan bahwa arus pelepasan memiliki pengaruh signifikan terhadap pemanasan baterai. Temuan ini menegaskan pentingnya sistem manajemen termal dalam konversi kendaraan listrik serta efektivitas strategi pendinginan pasif. Penelitian lanjutan direkomendasikan untuk validasi eksperimental dan pengendalian arus melalui sistem manajemen baterai (BMS) guna meningkatkan keselamatan dan masa pakai baterai.

Kata Kunci : Konversi; Kendaraan Listrik; Simulasi; GT-Suite

1. INTRODUCTION
The global demand for clean transportation solutions continues to rise each year, driven by increasing awareness of environmental sustainability. This urgency is reflected in the Paris Agreement of 2016, which set a primary objective of limiting the rise in global temperatures to 1.5°C [1]. In response to the targets outlined in the Paris Agreement, many governments worldwide have implemented strategies aimed at reducing the prevalence of internal combustion engine (ICE) vehicles and promoting the adoption of electrified vehicles (xEVs). The increasing uptake of electrified vehicles—including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery

electric vehicles (BEVs)—is largely propelled by regulatory frameworks and governmental initiatives designed to curb transportation-related emissions. A notable example is the establishment of Ultra Low Emission Zones (ULEZ) in the United Kingdom, which impose charges on vehicles that fail to meet stringent emission standards, thereby encouraging the transition to cleaner mobility options [2]. Furthermore, the UK government has enacted progressive legislative measures, including a ban on the sale of new petrol and diesel vehicles by 2030, with a further mandate that by 2035, only vehicles with zero tailpipe emissions—such as BEVs and fuel cell electric vehicles (FCEVs)—will be permitted for sale [2]. These policy interventions exemplify a broader global trend toward decarbonising the transport sector and accelerating the transition to sustainable, low-carbon vehicle technologies.

Energy storage systems, specifically battery packs, are recognised as one of the most critical and sensitive components in the development of battery electric vehicles (BEVs). During the processes of charging and discharging, batteries inherently generate heat due to internal resistive losses and electrochemical reactions. If this heat is not properly managed, it can accumulate within the battery pack, significantly increasing the risk of thermal runaway—a hazardous phenomenon that can lead to fires or explosions. Thus, implementing an effective thermal management strategy is essential not only for ensuring operational safety but also for enhancing the overall reliability of the vehicle.

Beyond the imperative of safety, battery thermal management also serves a vital role in maintaining optimal performance conditions. It is widely recognised that lithium-based batteries, including lithium iron phosphate ($LiFePO_4$) chemistries, perform best within a temperature range of approximately 15°C to 35°C [3]. Maintaining the battery pack within this optimal temperature window helps minimise capacity fade, extend cycle life, and preserve the driving range and efficiency of the vehicle over time [4]. Deviations from this range, either due to overheating or overcooling, can accelerate battery ageing and diminish system performance.

To manage battery temperatures effectively, the implementation of a Battery Thermal Management System (BTMS) is necessary. A BTMS is designed to regulate the thermal environment of the battery by dissipating excess heat during operation and, if necessary, maintaining sufficient warmth under cold conditions. Thermal management approaches can generally be categorised into passive and active systems. Passive cooling relies on natural convection, conduction, and radiation, often utilising heat-dissipating enclosures or fins, and is attractive due to its simplicity and energy efficiency. In contrast, active cooling systems, such as forced air or liquid cooling, offer greater temperature control but at the cost of added system complexity and power consumption. Selecting an appropriate thermal management strategy is crucial, particularly for converted EVs, where space and system integration constraints may favour passive methods. Therefore, the development and evaluation of effective BTMS solutions are fundamental to achieving long-term durability, safety, and performance targets in battery electric vehicles.

One of the most practical and immediate strategies to reduce emissions from the road transport sector is the widespread adoption of battery electric vehicles (BEVs). Studies conducted by Hou, et al. [5] have shown that BEVs are capable of converting approximately 60% of the electrical energy from the grid into mechanical energy, significantly higher than internal combustion engine (ICE) vehicles, which achieve energy conversion efficiencies of only around 20% to 40%. However, the purchase price of new BEVs remains considerably higher than that of conventional ICE vehicles, and the development of new BEV models also entails substantial manufacturing costs [6]. As a result, converting existing ICE vehicles into electric vehicles presents a more economically viable and sustainable alternative. Vehicle conversions offer a cost-effective approach compared to designing and producing entirely new BEVs [7]. Moreover, converting ICE vehicles to BEVs can contribute to achieving net-zero emission targets, as scrapping large numbers of ICE vehicles to replace them with newly manufactured BEVs would otherwise increase the overall environmental impact due to the emissions associated with vehicle production [6, 8].

Most of the converted EV does not equip with a cooling system even though as mentioned above, cooling system is needed for safer and longer battery life. A major challenge with many existing converted electric vehicles (EVs) is the absence of a dedicated Battery Thermal Management System (BTMS) or effective heat dissipation measures. Without proper thermal regulation, batteries are more susceptible to accelerated performance degradation and an increased risk of thermal runaway, particularly during charging, discharging, or extended operation. As a result, battery lifespan can be significantly reduced, and critical safety risks associated with uncontrolled temperature rise remain largely unaddressed.

Simulation plays a crucial role in the development of battery thermal management systems (BTMS) for electric vehicle battery packs. It enables the prediction of cooling performance and system efficiency, significantly reducing both development time and associated research costs. ANSYS is widely utilised for simulating the thermal behaviour and cooling efficiency of battery systems. In parallel, GT-Suite has become a popular tool within the automotive engineering sector due to its comprehensive capabilities for simulating various automotive components and systems [9]. For instance, GT-Suite can model the dynamic thermal behaviour of an EV battery pack alongside the performance of its cooling mechanisms. A study conducted by Wang, et al. [10] demonstrated that simulation results closely matched experimental outcomes, confirming the effectiveness of simulation in predicting optimal cooling strategies. Therefore, simulation serves as an essential step in accurately understanding EV battery behaviour prior to real-world implementation.

In this study, two driving cycles will be used. New European driving cycles (NEDC) and Worldwide harmonized Light vehicles Test Procedure (WLTP). Both of the driving cycles were choosen because they are the most popular driving cycles in the world, espescially for EV to evaluate their range of driving. This simulation will evaluate and do thermal comparison between battery pack that equipped with cooling system and does not equipped with cooling sytem.

2. RESEARCH METHODOLOGY

This research builds upon the author's previous work involving the conversion of an internal combustion engine (ICE) vehicle to an electric vehicle (EV), using the Toyota Avanza as the base platform. The Toyota Avanza was selected due to its widespread popularity and availability in Indonesia, making it a representative model for practical conversion studies. The specific vehicle variant utilised was equipped with a 1.3-litre petrol engine paired with an automatic transmission, originally producing 93 horsepower and 120 Nm of torque. To match the original vehicle's performance characteristics in its electrified form, an appropriate electric propulsion system was selected. A three-phase synchronous AC motor was employed, delivering a peak power output of 60 kW, a continuous (rated) power output of 33 kW, and an operational efficiency of approximately 95%. The motor provides a maximum torque of 220 Nm and is capable of operating at rotational speeds up to 12,000 rpm. Key specifications of the converted electric vehicle, including motor and battery pack parameters, are summarised in Table 1.

Table 1. Toyota Avanza converted car specifications

Vehicle Parameter	Values	Unit
Vehicle Gross Weight	1250	kg
Aerodynamic drag coefficient	0.3 [11]	
Frontal Area	2.23 [11]	m^2
Final Drive Gear Ratio	5.125	
Motor Voltage	260-410	V
Max Torque	220	Nm
Peak Power	60	kW
Battery Pack Rated Voltage	268.8	V
Battery Pack Capacity	40.32	kWh

Based on the specifications outlined in Table 1, a detailed vehicle model was developed within GT-Suite. The constructed model is depicted in Figure 1. The simulation was initiated using GT-Suite's built-in electric vehicle (EV) template, which provided a foundational framework for the modelling process. However, several key parameters were modified to accurately replicate the performance characteristics of the converted electric vehicle. Notably, the final drive ratio was adjusted to align with the stock differential configuration of the original Toyota Avanza, ensuring that the drivetrain dynamics were consistent with the baseline vehicle.

After the model was created in GT-Suite, a passive cooling module was added to the simulation model. Inside the passive cooling system there were convection node and temperature probe. Convection node was used to model the heat transfer during the simulation. Figure 2 shows the convection node options in GT-Suite that consists of Convective heat transfer and surface area. In this research the convective heat transfer coefficient was determined by the battery pack that equipped with cooling system and was not equipped with cooling system. As for the surface area, depends on the battery enclosure design.

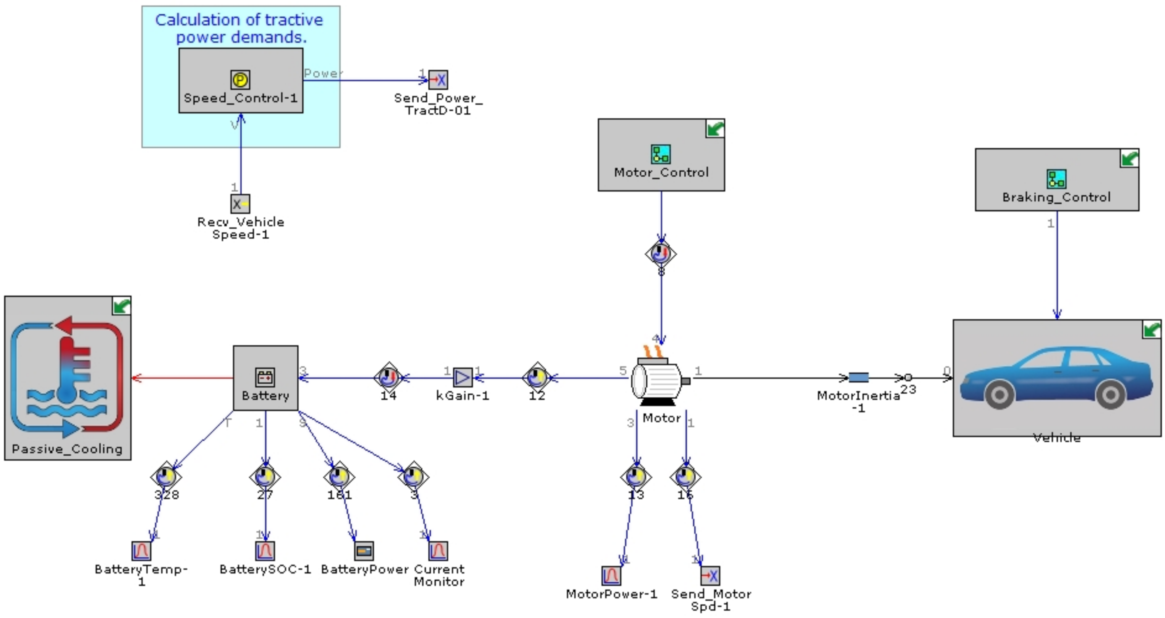

Figure 1. Map of Toyota Avanza in GT-Suite with passive cooling system.

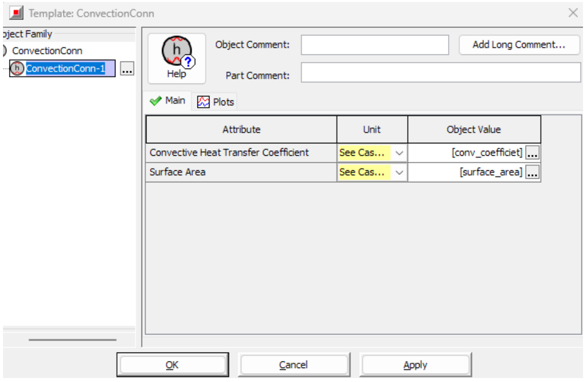

Figure 2. ConvectionConn node in GT-Suite.

Battery enclosure that was equipped with cooling system for battery pack was designed as a big heat sink as shown in Figure 3. The battery enclosure material was aluminium to ensure that the battery enclosure have light weight and good thermal conductivity to maximize the heat transfer phenomenon. The total number of fin was 136 fins and made out of aluminium.

In this study, two standard driving cycles were employed: NEDC and the WLTP. The NEDC represents a combination of urban and extra-urban driving conditions, allowing the vehicle to achieve a maximum speed of approximately 120 km/h over a total test duration of 1,180 seconds. In contrast, the WLTP cycle, which was developed to better reflect real-world driving behaviour, enables the vehicle to reach higher speeds, with a maximum of around 140 km/h, and extends over a longer period of 1,800 seconds. Compared to the NEDC, the WLTP cycle features more dynamic acceleration and deceleration patterns, higher average speeds, and a greater number of transient phases. These characteristics impose different thermal loads on the battery pack, making the use of both cycles valuable for assessing battery thermal performance under varying driving conditions.

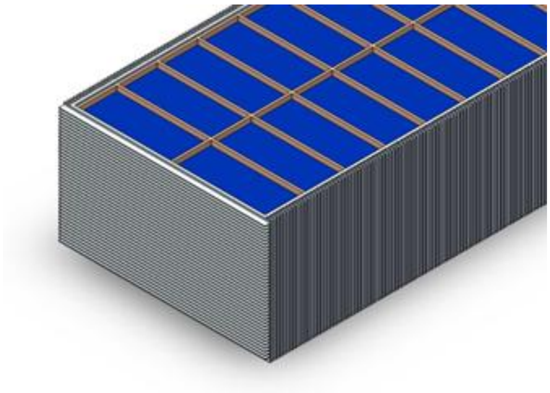

Figure 3. Battery enclosure design for battery pack that act as a heat sink.

3. RESULTS AND DISCUSSION

3.1. NEDC Driving Cycle

During the NEDC driving cycle, the vehicle was able to reach a maximum speed of approximately 120 km/h. The velocity profile of the NEDC cycle is illustrated in Figure 4. Based on the simulation results, the maximum battery temperature recorded during the NEDC cycle was 45.3°C in the absence of any cooling system applied to the battery enclosure. However, when a passive cooling system was integrated into the battery enclosure, the peak battery temperature was significantly reduced to 36.6°C as shown in Figure 5.

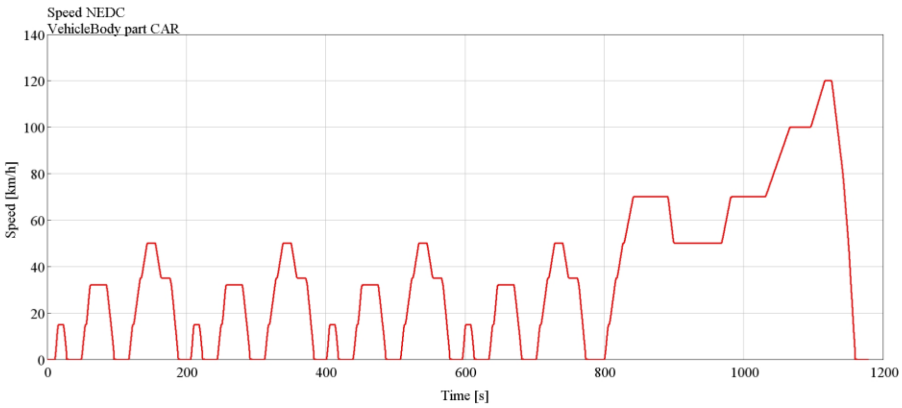

Figure 4. Speed graph of NEDC.

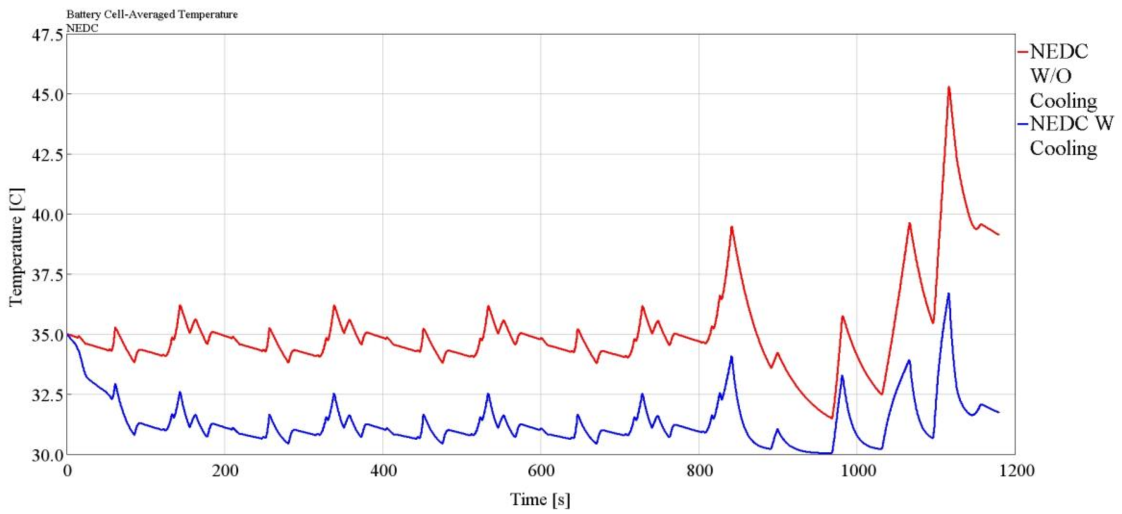

Figure 5. Battery temperature comparison using NEDC.

When comparing the battery temperature profile with the speed profile of the NEDC cycle, it was observed that the battery temperature began to rise notably during periods of rapid acceleration as the vehicle approached its maximum speed. The temperature continued to increase and reached its peak during the subsequent braking phases. This behaviour highlights the significant impact of high charge and discharge rates—experienced during aggressive acceleration and regenerative braking—on battery thermal dynamics. These results underscore the critical role of transient driving events in contributing to thermal stress within the battery pack, even under moderate driving cycles such as the NEDC.

This demonstrates that even a simple passive cooling strategy can effectively lower the thermal stress experienced by the battery pack under moderate driving conditions. Maintaining lower battery temperatures is critical for preserving the longevity, safety, and performance of the energy storage system during vehicle operation.

3.2 WLTP Driving Cycle

The WLTP driving cycle, which is more demanding and representative of real-world driving conditions, is illustrated in Figure 6. Compared to the NEDC, the WLTP cycle resulted in higher thermal stress on the battery pack, as evidenced by the increased average and peak temperatures. Under this cycle, and in the absence of a cooling system, the battery temperature rose significantly, reaching a maximum of 71.6°C. In contrast, when a passive cooling system was applied to the battery enclosure, the peak temperature was reduced to 48.0°C. This substantial difference demonstrates the effectiveness of passive cooling in mitigating thermal rise during high-load and dynamic driving conditions. A detailed comparison of battery temperature profiles for both scenarios is presented in Figure 7.

The increase in average battery temperature during the WLTP cycle can be attributed to the higher maximum speed and the more dynamic speed fluctuations throughout the driving sequence. When the vehicle speed and battery temperature profiles were analysed side by side, it was evident that the peak battery temperature coincided with periods of maximum acceleration and speed. This observation indicates that elevated discharge currents, particularly during high-power demands, play a significant role in increasing battery temperature. The correlation between vehicle dynamics and thermal behaviour underscores the importance of accounting for real-world load conditions when designing thermal management systems.

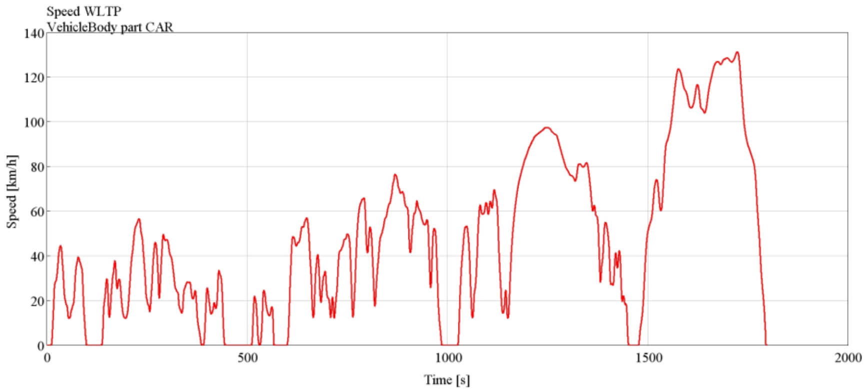

Figure 6. WLTP speed graph.

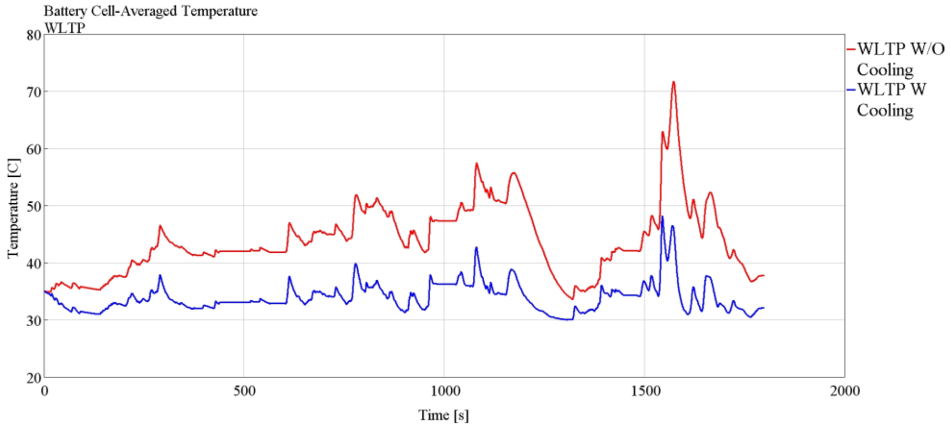

Figure 7. Battery temperature comparison using WLTP

CONCLUSION

This study investigated the thermal behaviour of a converted electric vehicle's battery pack under two standardised driving cycles, NEDC and WLTP, using GT-Suite simulation. The results revealed that driving conditions have a substantial impact on battery temperature. Under the NEDC cycle, a moderate increase in temperature was observed, with a peak of 45.3°C in the absence of a cooling system, which was reduced to 36.6°C with the application of passive cooling. In contrast, the more dynamic and demanding WLTP cycle resulted in significantly higher thermal stress, with peak temperatures reaching 71.6°C without cooling and 48.0°C with passive cooling.

The analysis showed that high-speed operation and rapid acceleration phases contribute to elevated discharge currents, which in turn raise battery temperatures. The correlation between peak speed, acceleration, and thermal response underscores the importance of effective thermal management, particularly under real-world driving conditions. The implementation of a passive cooling system proved effective in reducing battery temperature, thereby enhancing safety and potentially extending battery life. These findings support the use of simulation tools like GT-Suite for thermal evaluation during the early stages of EV design, especially in retrofitting applications where thermal management is often overlooked.

To further validate the findings of this study, experimental testing is recommended to compare real-world thermal behaviour with the simulation results. Future work should focus on implementing hardware-based validation using temperature sensors and current monitoring to assess thermal performance under actual driving conditions.

Since this study only cover heat transfer from battery pack to system during experimental work it is needed to measure the ambient temperature around the battery pack to investigate heat transfer phenomena more accurately. Furthermore, another active cooling system could be added to maintain the homogeneity in temperature distribution among other In addition, controlling the discharge current is essential for maintaining optimal battery temperatures and prolonging battery lifespan. This can be achieved through the integration of an intelligent Battery Management System (BMS), which can actively regulate current flow based on thermal and electrical feedback. The development and calibration of such control strategies will be crucial in enhancing both the safety and durability of battery systems in converted electric vehicles.

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