

Design and Evaluation of the Battery Thermal Management System for Electric Vehicles Under Complex Environmental Conditions

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KEYWORDS		This research develops a cooling system controller for the battery thermal management system (BTMS) of electric vehicles using the proportional-integral-derivative (PID) technique, replacing the traditional relay switching mechanism commonly used in existing systems. The BTMS is designed to include some main components: an electronic control circuit, a coolant re-circulation pump, temperature sensors, a coolant piping system, and a coolant storage tank. The cooling liquid used is a mixture of water and ethylene glycol (EG) in a 5:5 ratio. This research evaluates the efficiency of integrating a PID controller into the BTMS under three scenarios, consisting of ambient temperature 25°C (normal), 45°C (hot), and 10°C (cold), respectively. The response capability of the system is tested with initial battery temperatures of 30°C, 45°C and 55°C, respectively. The simulation results demonstrate that the system reliably maintains the set temperature in every scenario, while the energy consumption is different. The research is also compared with recent published studies, thereby enhancing its scientific competitiveness. These findings highlight the essential role of the designed controller in achieving flexible, sustainable, and effective thermal management, and in maintaining optimal battery efficiency under real-world driving conditions.
Electric vehicles;		
BTMS;		
Lithium-ion cell;		
FTP-75 drive cycle;		
PID controller.		

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1. Introduction

The term “electric vehicles” emerged in the 1930s in England, the United States, and France. However, due to technological limitations and the significant development of internal combustion engines, electric vehicles did not attract sufficient attention during this period. In the 1970s, the energy crisis along with the dramatic increase in fossil fuel prices promoted the transition to green energy sources [1], [2]. The expanded use of conventional vehicles has led to increased emissions, energy shortages, and environmental pollution [3], [4]. Therefore, the development of electric vehicles is considered a necessary solution to resolve the limitations of traditional transportation [5]. If the internal combustion engine is known as the “soul” of conventional vehicles, the battery can be recognized as the “heart” of electric vehicles. The battery not only supplies energy for vehicle operation but also affects overall efficiency, lifespan, driving range, charging time, and ownership cost throughout the vehicle’s life cycle. As a result, optimizing the battery operating cycle is a key factor in improving reliability, enhancing efficiency, and limiting overheating issues.

Lithium-ion batteries have become widely adopted thanks to their high energy density, extended lifespan, and strong stability. However, they are highly sensitive to thermal changes and perform best only between 20°C and 40°C [6]. Cold environments raise internal resistance, while extreme heat accelerates aging and lowers overall efficiency [7]. Therefore, the BTMS plays an important role in electric vehicle systems by managing the battery temperature and keeping it evenly distributed across the cells [8]. When discharging, these batteries produce heat mostly from two sources: irreversible Joule heating caused by current passing through internal resistance, and entropic heat from electrochemical reactions. Of these, Joule heating is the primary contributor [9]. Available battery cooling techniques include air cooling, phase change material (PCM) cooling, and liquid cooling [7]. Among these options,

liquid cooling is highly recommended because of its excellent efficiency, rapid thermal response, and ability to reduce the risk of thermal instability [9]–[11].

Several recent studies [7], [12] have applied BTMSs controlled by relay on/off switching mechanisms for pump operation. However, this method still has limitations due to the settling time of the motor. To overcome this issue, this research presents the integration of a PID controller into the BTMS to enhance control capability, improve stability, and increase the operational efficiency of electric vehicles. The key contributions of this research are summarized as follows:

- Analysis of the FTP-75 driving cycle applied to an electric vehicle model combined with resistive forces during vehicle operation to ensure that the simulation conditions closely reflect real-world driving conditions.
- Investigation and analysis of the operation of the BTMS model with different ambient temperature conditions to evaluate BTMS efficiency, thereby highlighting the importance of BTMS in electric vehicle operation.
- Evaluation of the effectiveness of applying a PID controller to control the pump operation in the BTMS, along with comparative analysis, demonstrating that the PID controller significantly improves the stability and flexibility of the BTMS.

The structure of this research is organized as follows. Section 2 presents the configuration and modeling of the BTMS and describes the methods and implementation of the fundamental simulation platform in MATLAB/Simulink. Section 3 demonstrates the main results and discussions of the research, including three scenarios of BTMS under different ambient temperature conditions and verifies the results. Finally, Section 4 summarizes the conclusions of the research.

2. Materials and Methods

In this section, system modeling is built based on MATLAB/Simulink, using a liquid cooling method for the electric vehicle battery. The pump operates in suction and discharge modes to circulate the coolant through the cooling plate installed on the battery pack. After that, the temperature of the coolant passes through a heat transfer system, which lowers its temperature for the next cycle. Using the FTP-75 driving cycle and a water–EG mixture in a 5:5 ratio (Table 4), this study investigates the impact of different ambient temperatures. The system includes: the battery system, the cooling plate system, the coolant temperature regulation system, the coolant parameter configuration system, and the pump power controller, as shown in Figure 1.

The battery cooling process uses a liquid coolant to absorb heat from the battery pack. After cooling the battery, this liquid becomes hot and must be cooled down again by a refrigeration system so it can be reused in the next cycle. A controller and a valve manage the flow of this coolant [7]. Because this entire refrigeration process requires electricity to run, it is considered a parasitic power loss for the BTMS.

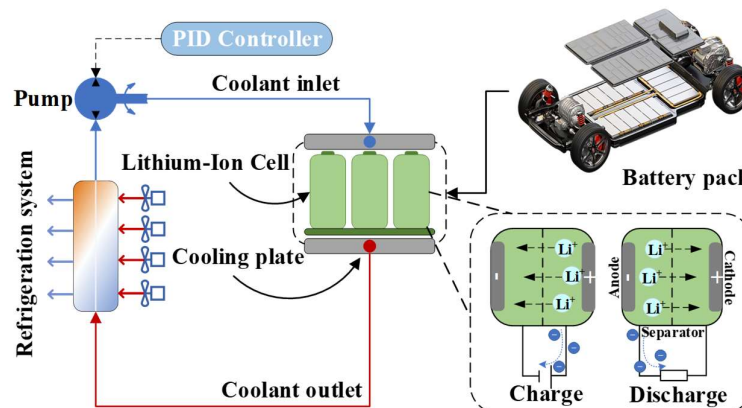


Figure 1. Liquid cooling system model.

2.1. Vehicle Model

This research considers a mid-size electric vehicle with its main parameters listed in Table 1 [13].

Table 1. Electric Sedan parameters.

Parameter	Symbol	Unit	Value
Overall mass	m	kg	1620
Frontal projected area	A	m^2	2.62
Rolling resistance coefficient	C_{rr}	-	0.0075
Rolling radius	r	m	0.345
Aerodynamic drag coefficient	C_d	-	0.363
Motor efficiency	η	%	85
Air density	ρ	kg/m^3	1.25

All resistive forces acting on the vehicle can be estimated based on the vehicle mass and its speed, obtained from the driving cycle. The resistive forces which have an impact on EV operation are shown in Figure 2 [7], [9], [14].

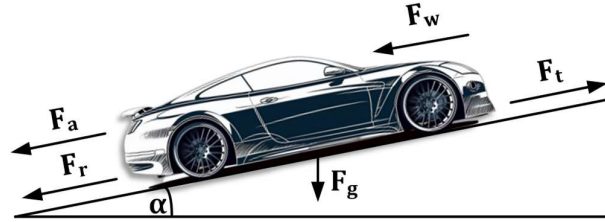


Figure 2. Resistive forces during EV operation.

$$F_t = F_g + F_w + F_a + F_r \quad (1)$$

The overall resistive force (F_t) consists of rolling resistance (F_r), uphill resistance (F_g), aerodynamic drag (F_w) and acceleration (F_a). This equation is given below:

$$F_t = mg \sin(\alpha) + \frac{1}{2} \rho A C_d (v + v_{wind})^2 + \lambda m \frac{dv}{dt} + \mu_{rr} mg \cos(\alpha), \quad (2)$$

where μ_{rr} is the rolling resistance coefficient; m is the vehicle mass (kg); α describes the road gradient (deg), g is the gravitational acceleration (m/s^2); ρ is the air density (kg/m^3); A is the frontal area of vehicle (m^2); v_{wind} is the wind speed (m/s); v is the vehicle speed (m/s); λ is the inertia coefficient, dv/dt is the vehicle acceleration (m/s^2).

The motor power and the battery discharge current are given as follows:

$$Power = \frac{F_t v}{\eta_m}, \quad (3)$$

$$I_b = \frac{Power}{V_b}, \quad (4)$$

where F_t is the required force for vehicle operation (N); η_m is the electric motor efficiency; I_b is the battery discharge current (A); V_b is battery voltage (V).

2.2. Battery model

The battery pack used in this research is formed by connecting 4 modules in series including 20 cells, in which the input current is provided according to the FTP-75 driving cycle. The battery model is demonstrated in Figure 3.

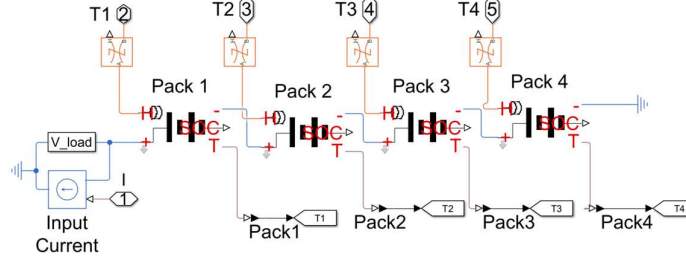


Figure 3. Battery model in Simulink.

The battery pack parameters are shown in Table 2 [7], [12]:

Table 2. Battery pack parameters.

Parameter	Unit	Value
Cell capacity	Ah	28
Pack charge limit voltage	V	420
Pack cut-off voltage	V	350
Nominal pack voltage	V	380
Pack weight	kg	250

The battery model uses a single R-C equivalent circuit that describes the physical behavior of the battery with high precision while maintaining a simple structure, suitable for EV applications. The model parameters, including OCV, R_0 , R_1 , and C_1 are determined as functions of the state of charge and temperature [15]. The diagram of this circuit is shown in Figure 4.

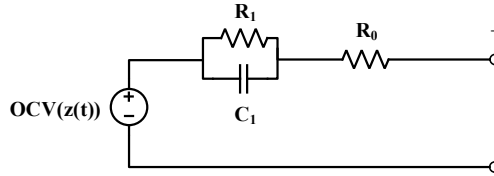


Figure 4. A single R-C equivalent circuit.

A bottom cooling plate with circulating coolant maintains a stable temperature for the battery pack. All cells are assumed to be uniform and generate internal heat, while their structural impacts on the overall thermal behavior are negligible. Because temperature differences within the pack are sufficiently small under normal conditions, they are ignored. Therefore, the temperature of every cell is considered equal and is represented by the average cell temperature. The battery temperature rise is described by Equation (5) which models the heat transfer of homogeneous materials [16]–[18].

$$m_{cell}c_{p_{cell}} \frac{dT_{cell}}{dt} = -\frac{T - T_a}{R_T} + Q_{gen}, \quad (5)$$

$$Q_{gen} = I^2 R_{int} - IT \frac{d_{OCV}}{dT}, \quad (6)$$

where R_{int} is the battery resistance (Ω); T is the battery temperature ($^{\circ}\text{C}$); d_{OCV} / d_T is the entropic coefficient; I is the battery discharge current (A).

2.3. Cooling plate and heat exchanger model

In this cooling system, the heat generated within the battery is transferred away by the flow of coolant circulating through the cooling pipes inside the cooling plate. The cooling system structure consists of internal cooling pipes that prevent direct contact between the battery surface and the coolant, thus eliminating the risk of short circuits. When the coolant flows through the pipes to the battery area, heat from the battery is conducted through the cooling plate and transferred to the coolant. As a result, the battery temperature is decreased, while the coolant goes to the cooling unit to be cooled and prepared for the next battery cooling cycle. The efficiency of the cooling plate heat exchanger mainly depends on the coolant mass flow rate, the amount of generated heat, temperature distribution, the specific heat capacity of the coolant, and the coolant inlet temperature [12], [19], [20]. Cold plate parameters are shown in Table 3

Table 3. Cold plate parameters.

Parameter	Unit	Value
Mass	kg	20
Specific heat (c_p)	J/kgK	910
Area	m^2	0.5
Thickness	mm	1
Thermal conductivity	W/mK	205

The cooling plate Simulink model and its thermal layout are shown in Figure 5.

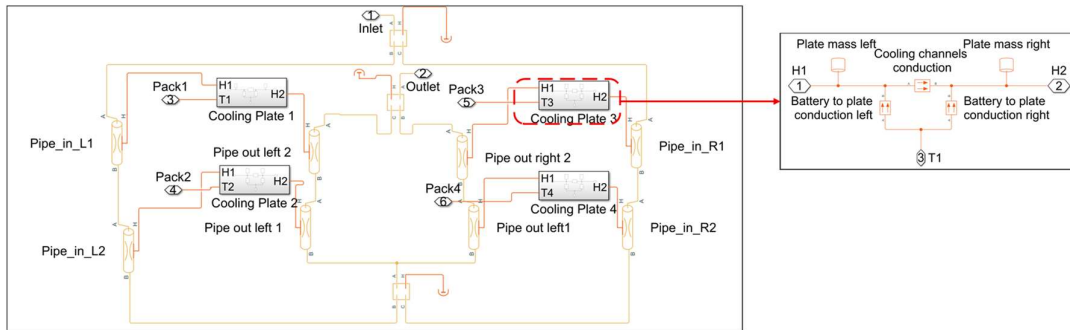


Figure 5. Cooling plate model.

2.4. Coolant

The BTMS controller dynamically adjusts the coolant flow rate based on real-time battery temperatures. To maintain the target set-point, it increases pump speed during high-heat events like fast charging or uphill driving, and reduces it when temperatures are stable. This adaptive strategy prevents unnecessary pump operation, thereby improving cooling efficiency, saving energy, and ensuring effective thermal management across various operating conditions [21], [22]. The parameters and model of the coolant are provided in Figure 6 and Table 4.

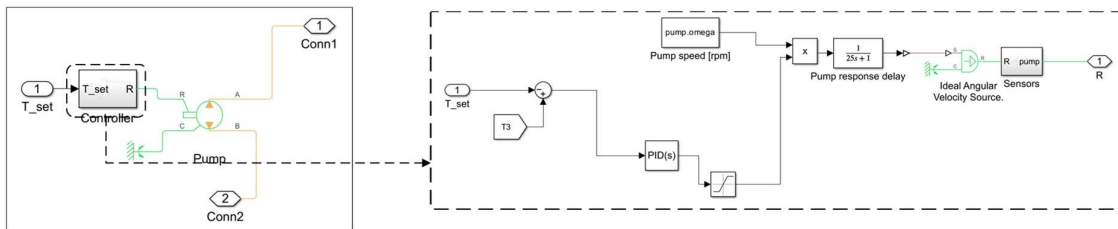


Figure 6. Pump controller model.

Table 4. Properties of water and EG.

Properties	Symbol	Unit	Water	EG
Density	ρ	kg/m^3	999	1126
Thermal conductivity	λ	$W.m^{-1}.K^{-1}$	0.6	0.256
Viscosity	μ	$Pa.s$	1.002×10^{-3}	21×10^{-3}
Specific heat	c_p	$J.kg^{-3}.K^{-1}$	4185	2354

2.5. Boundary conditions

The interaction surface between the battery pack and the cooling plate is given as [7]:

$$m_{bat}c_{bat} \frac{dT_{bat}}{dt} = -k_{CP}A_{cp} \frac{dT_{CP}}{dx}, \quad (7)$$

where m_{bat} is the battery weight (kg); c_{bat} is the battery specific heat (J/kgK); T_{bat} is the battery temperature; k_{CP} is the cooling plate thermal conductivity (W/mK); A_{cp} is the contact area between the battery and cooling plate (m²); dT_{CP} / dx is the temperature gradient (K/m).

While one side of the cooling plate is in contact with the battery to absorb heat, the other side is responsible for transferring the heat to the environment. The boundary condition is shown below:

$$h_{amb}(T_{CP} - T_{amb}) = -k_{CP} \frac{dT_{CP}}{dx}, \quad (8)$$

where h_{amb} is the heat transfer coefficient (W/m²K), T_{amb} is the ambient temperature (°C) (in this research, it is considered $h_{amb} = 5 \text{ W/m}^2\text{K}$).

3. Results and Discussion

This research integrates a PID controller with the BTMS through three MATLAB/Simulink scenarios, using parameters from [7], [12]. To assess system reliability, these scenarios examine the effects of different ambient temperatures ($T_{env} = 25^\circ\text{C}$, 45°C and 10°C) using a 5:5 water and EG coolant mixture (the initial temperature of the coolant is assumed to be equal to the ambient temperature). Additionally, detailed energy consumption and performance criteria for each condition are provided below. For each scenario, the initial battery temperature is set to 30°C , 45°C , and 55°C , respectively, while the target temperature is maintained at $T_{set} = 20.5^\circ\text{C}$. This research uses the FTP-75 driving cycle to analyze vehicle speed and battery current as shown in Figure 7a and Figure 7b.

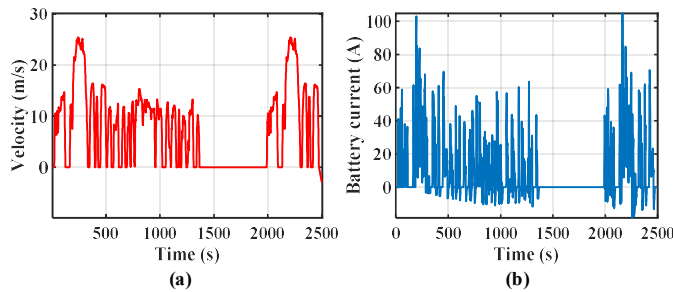


Figure 7. (a) Actual vehicle velocity profile; (b) Battery current of the FTP-75.

The pump operates at a rated speed of 4,000 rpm. The PID parameters selected are $K_p = 0.72$, $K_I = 0.1$, and $K_D = 0.92$, respectively. In addition, the settings for the PID controller are shown in Table 5.

Table 5. The PID controller parameters.

Parameter	State	Value
Saturation	Upper Limit	1
	Lower Limit	0
Anti-windup method	-	Clamping
Sampling time	-	0.01

3.1. Scenario 1: Evaluation of the system cooling effectiveness in a normal ambient temperature

In scenario 1, the ambient temperature is set to 25°C, suitable for the operational battery temperature range to assess the system operation under three initial battery temperature cases which are 30°C, 45°C and 55°C respectively.

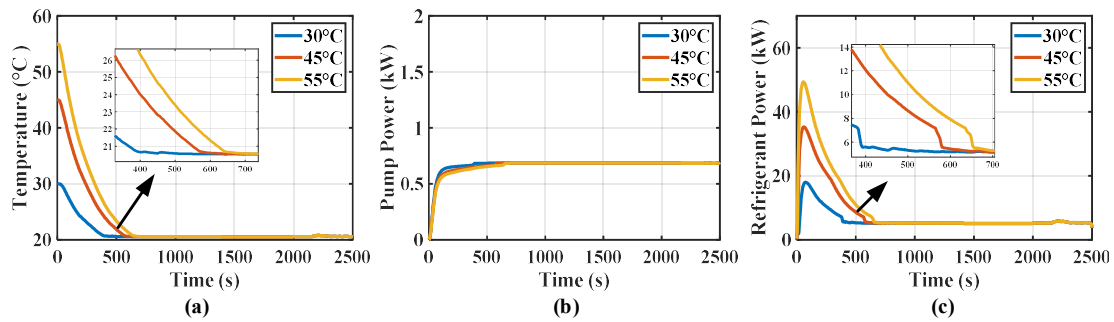


Figure 8. The BTMS response of scenario 1:

(a) The battery temperature; (b) The pump power; (c) The refrigerant power.

Table 6. Evaluation criteria of scenario 1.

Evaluation criteria	Temperature		
	30°C	45°C	55°C
MAE	0.732°C	2.1824°C	3.1712°C
Settling Time	279.83 s	394.08 s	431.32 s
SSE	0.115502742°C	0.115502930°C	0.115503040°C

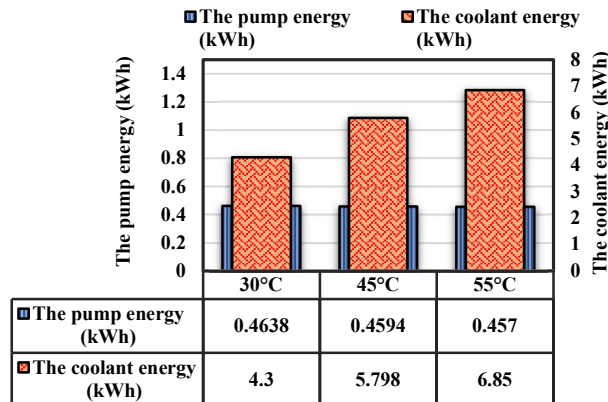


Figure 9. The pump and the coolant energy consumption system of scenario 1.

Remark 1: At an ambient temperature of 25°C, the BTMS equipped with a PID controller operates efficiently and stably. As shown in Figure 8a, the battery temperature closely tracks the 20.5°C set-point within the first 500 seconds and remains stable throughout the FTP-75 driving cycle, making the cycle's impact negligible once steady. Figures 8b and 8c illustrate that although the system demands high pump power during initial acceleration, the coolant power significantly drops and stabilizes around 5.2 kW to maintain the target temperature. Table 6 confirms this strong performance, showing a consistently low MAE, unchanged SSE, and settling times between 279.83 and 431.32 seconds across different conditions. Regarding consumption, Figure 9 indicates that while pump energy stays constant at 0.46 kWh, coolant energy increases from 4.3 kWh to 6.85 kWh as the initial battery temperature rises from 30°C to 55°C. These results show the long-term efficiency and reliability of the PID controller for BTMS.

3.2. Scenario 2: Evaluation of the system cooling effectiveness in a hot ambient temperature

In Scenario 2, the ambient temperature is set to 45°C to represent harsher environmental conditions than those in Scenario 1. The battery performance is then evaluated under this elevated ambient temperature. This scenario retains the same conditions of three initial battery temperature cases, which are 30°C, 45°C and 55°C respectively.

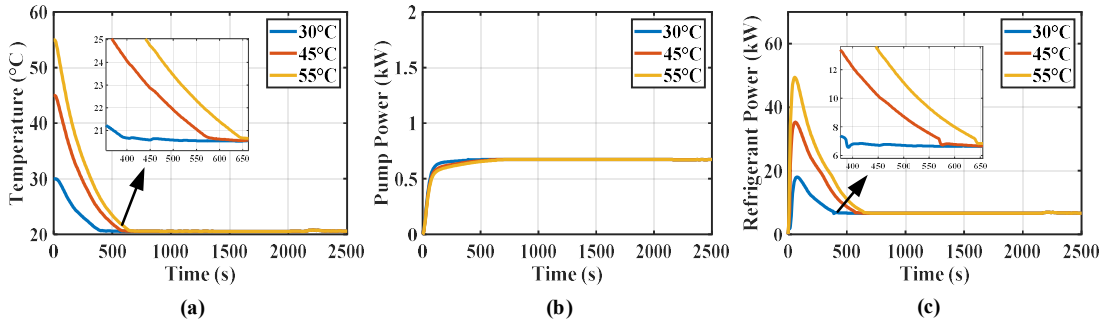


Figure 10. The BTMS response of scenario 2:

(a) The battery temperature; (b) The pump power; (c) The refrigerant power.

Table 7. Evaluation criteria of scenario 2.

Evaluation criteria	Temperature		
	30°C	45°C	55°C
MAE	0.7364°C	2.1907°C	3.1810°C
Settling Time	281.79 s	395.98 s	432.96 s
SSE	0.115531396°C	0.115531613°C	0.115531719°C

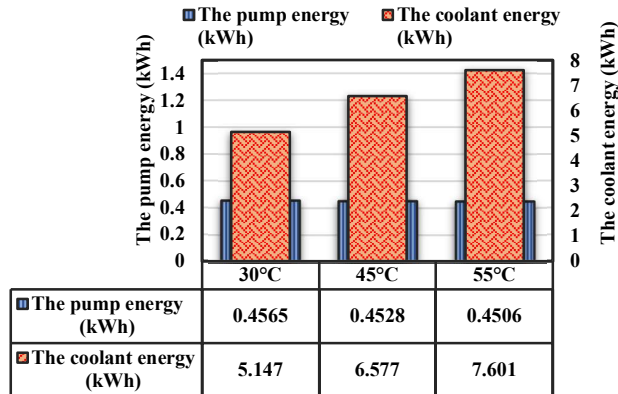


Figure 11. The pump and the coolant energy consumption system of scenario 2.

Remark 2: This scenario evaluates the system under a harsh ambient temperature of 45°C. As illustrated in Figure 10a, the battery cooling time remains similar to Scenario 1; however, Figures 10b and 10c show that the warmer environment requires higher refrigerant power to ensure effective control, peaking at 7.55 kW at 550 seconds for an initial battery temperature of 45°C (7.47 kW compared with scenario 1). Moreover, Table 7 confirms that the MAE and settling time remain almost unchanged, demonstrating the strong adaptability of the PID controller. Regarding consumption in Figure 11, total energy rises significantly with higher initial temperatures up to 8.0516 kWh at 55°C, while pump energy stays constant at 0.45 kWh. Finally, refrigerant energy increases by about 10% compared to scenario 1, highlighting the major impact of ambient temperatures on BTMS energy efficiency.

3.3. Scenario 3: Evaluation of the system cooling effectiveness in a cold ambient temperature

Scenario 3 evaluates the thermal management system efficiency in contrast to scenario 2 by setting the ambient temperature to 10°C, which is outside the operating range of the EV battery. The scenario retains the same three initial battery temperature cases, which are 30°C, 45°C and 55°C respectively.

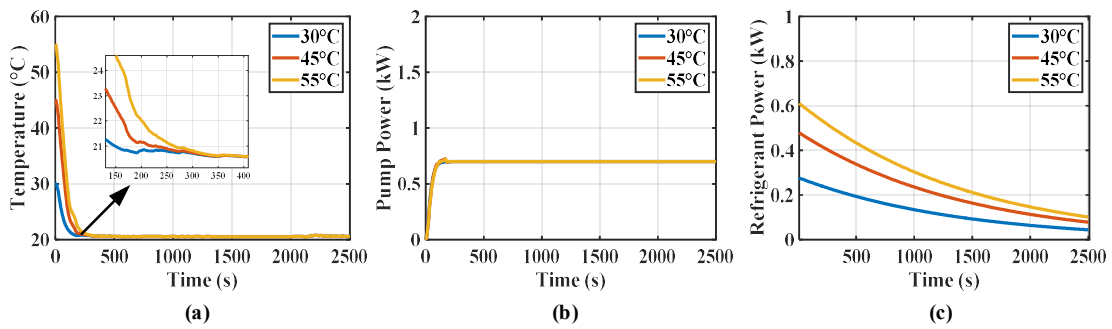


Figure 12. The BTMS response of scenario 3:

(a) The battery temperature; (b) The pump power; (c) The refrigerant power.

Table 8. Evaluation criteria of scenario 3.

Evaluation criteria	Temperature		
	30°C	45°C	55°C
MAE	0.3075°C	0.7948°C	1.1813°C
Settling Time	99.16 s	113.24 s	139.91 s
SSE	0.115530529°C	0.115530661°C	0.115530775°C

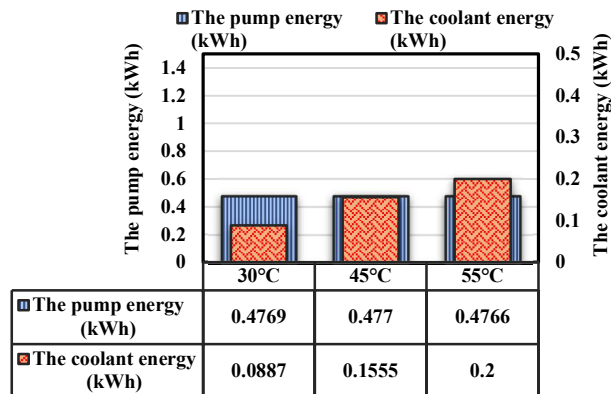


Figure 13. The pump and the coolant energy consumption system of scenario 3.

Remark 3: In scenario 3, the ambient temperature is set to a cold 10°C, which falls outside the normal EV battery operating range. As shown in Figure 12a, the cold air strongly assists the BTMS, causing the battery temperature to drop much faster than in other scenarios to reach the target. Consequently, Figures 12b and 12c indicate that the refrigerant power remains safely below 1 kW, saving energy and extending EV operation. Table 8 highlights excellent control performance with a consistently low MAE, stable SSE, and shorter settling times, specifically 99.16 seconds for an initial 30°C, and 139.91 seconds for 55°C. Figure 13 demonstrates a significant decrease in overall energy consumption, ranging from 0.5656 kWh to 0.6766 kWh depending on the initial temperature. The most significant point is that the cooling energy drops by over 95% compared to scenario 1 (from 4.3 kWh down to 0.2 kWh). These results clearly demonstrate the major impact of ambient temperature on BTMS energy use and overall efficiency.

3.4. Model validation

To validate the reliability of the system, the results in this research are compared with two recent studies [7], [12]. The average initial battery temperature is set at 30°C equal to the ambient temperature, while the desired set-point temperature is 25°C, using water for the coolant and FTP-75 driving cycle to observe the system response process. The results in Figure 14 show that this study maintains a smoother and more stable battery temperature.

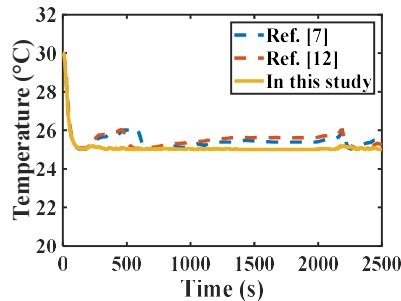


Figure 14. Comparison of results between the designed method and recent studies.

The key contribution of this research compared to references [7], [12] is the coolant pumping mechanism. Previous studies used an on/off relay system that abruptly starts and stops the pump based on temperature changes, such as the high heat generated during uphill EV driving. This repeated starting can negatively affect cooling speed. In contrast, this study employs a PID control strategy that runs the pump continuously throughout the driving cycle, ensuring a much more stable battery temperature. Although this continuous operation consumes a small amount of extra energy, it ensures reliable thermal regulation during real-world driving conditions.

4. Conclusions

This research has constructed and simulated a liquid-cooled BTMS in MATLAB/Simulink. The main contributions of this research include evaluating BTMS efficiency under three different ambient temperatures and investigating cases in which the initial battery temperature differs from the ambient temperature, in order to assess the system's response under real-world conditions. Furthermore, the research integrates a PID controller with the BTMS to ensure effective thermal management and maintain optimal battery performance. Considering scenarios in which the ambient temperature differs from the initial battery temperature provides a more realistic insight into BTMS operation and represents a necessary direction for the development of more advanced thermal management systems for electric vehicles. This comprehensive analysis offers an important scientific basis for optimizing BTMS control strategies, enhancing operational efficiency, safety, and battery lifespan in practical electric vehicle applications.

Acknowledgments

This research is the result of the collective efforts of all team members: Nguyen Cong Trang, Nguyen Hoang An, Vu Thanh Hung, and Nguyen Anh Khoa from Ton Duc Thang University.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- [1] C. C. Chan, "The state of the art of electric, hybrid, and fuel cell vehicles," *Proceedings of the IEEE*, vol. 95, no. 4, pp. 704–718, 2007, doi: [10.1109/JPROC.2007.892489](https://doi.org/10.1109/JPROC.2007.892489).
- [2] L. Szabo and V. Iulia, "A Brief History of Electric Vehicles," *Journal of Computer Science and Control Systems*, vol. 15, no. 1, Sep. 2022.
- [3] Y. Deng, C. Feng, H. Zhu, J. Chen, M. Wen, and H. Yin, "Effects of different coolants and cooling strategies on the cooling performance of the power lithium ion battery system: A review," *Applied Thermal Engineering*, vol. 142, pp. 10–29, 2018, doi: [10.1016/j.applthermaleng.2018.06.043](https://doi.org/10.1016/j.applthermaleng.2018.06.043).
- [4] E. Jiaqiang *et al.*, "Effect analysis on flow and boiling heat transfer performance of cooling water-jacket of bearing in the gasoline engine turbocharger," *Applied Thermal Engineering*, vol. 130, pp. 754–766, 2018, doi: [10.1016/j.applthermaleng.2017.11.070](https://doi.org/10.1016/j.applthermaleng.2017.11.070).
- [5] R. R. Kumar, C. Bharatiraja, K. Udhayakumar, S. Devakirubakaran, K. S. Sekar, and L. Mihet-Popa, "Advances in batteries, battery modeling, battery management system, battery thermal management, SOC, SOH, and charge/discharge characteristics in EV applications," *Ieee Access*, vol. 11, pp. 105761–105809, 2023, doi: [10.1109/ACCESS.2023.3318121](https://doi.org/10.1109/ACCESS.2023.3318121).
- [6] M. Lu, X. Zhang, J. Ji, X. Xu, and Y. Zhang, "Research progress on power battery cooling technology for electric vehicles," *Journal of Energy Storage*, vol. 27, p. 101155, 2020, doi: [10.1016/j.est.2019.101155](https://doi.org/10.1016/j.est.2019.101155).
- [7] S. Vikram, S. Vashisht, and D. Rakshit, "Performance analysis of liquid-based battery thermal management system for Electric Vehicles during discharge under drive cycles," *Journal of Energy storage*, vol. 55, p. 105737, 2022, doi: [10.1016/j.est.2022.105737](https://doi.org/10.1016/j.est.2022.105737).
- [8] M. A. Badran and S. F. Toha, "Employment of Artificial Intelligence (AI) Techniques in Battery Management System (BMS) for Electric Vehicles (EV): Issues and Challenges," *Pertanika Journal of Science & Technology*, vol. 32, no. 2, 2024, doi: [10.47836/pjst.32.2.20](https://doi.org/10.47836/pjst.32.2.20).
- [9] N. Napa, M. K. Agrawal, and B. Tamma, "Development of electro-thermal model for air cooling study of electric vehicle lithium-ion battery module operating in Indian conditions and drive cycle," *Applied Thermal Engineering*, vol. 240, p. 122233, 2024, doi: [10.1016/j.applthermaleng.2023.122233](https://doi.org/10.1016/j.applthermaleng.2023.122233).
- [10] A. G. Mohammed, H. Hasini, K. E. Elfeky, Q. Wang, M. A. Hajara, and N. I. Om, "Cooling effectiveness enhancement of parallel air-cooled battery system through integration with multi-phase change materials," *International Journal of Thermal Sciences*, vol. 201, p. 109030, 2024, doi: [10.1016/j.ijthermalsci.2024.109030](https://doi.org/10.1016/j.ijthermalsci.2024.109030).
- [11] S. Ma *et al.*, "Temperature effect and thermal impact in lithium-ion batteries: A review," *Progress in Natural Science: Materials International*, vol. 28, no. 6, pp. 653–666, 2018, doi: [10.1016/j.pnsc.2018.11.002](https://doi.org/10.1016/j.pnsc.2018.11.002).
- [12] A. Rahmani, M. Dibaj, and M. Akrami, "Design and simulation of battery thermal management systems for electric vehicles using MATLAB Simulink," *Journal of Energy Storage*, vol. 111, p. 115398, 2025, doi: [10.1016/j.est.2025.115398](https://doi.org/10.1016/j.est.2025.115398).
- [13] H. Liu, F. Chen, Y. Tong, Z. Wang, X. Yu, and R. Huang, "Impacts of driving conditions on EV battery pack life cycle," *World Electric Vehicle Journal*, vol. 11, no. 1, p. 17, 2020, doi: [10.3390/wevj11010017](https://doi.org/10.3390/wevj11010017).
- [14] O. D. Momoh and M. O. Omoigui, "An overview of hybrid electric vehicle technology," in *2009 IEEE vehicle power and propulsion conference*, Ieee, 2009, pp. 1286–1292. doi: [10.1109/VPPC.2009.5289703](https://doi.org/10.1109/VPPC.2009.5289703).
- [15] L. Zhang, H. Peng, Z. Ning, Z. Mu, and C. Sun, "Comparative research on RC equivalent circuit models for lithium-ion batteries of electric vehicles," *Applied Sciences*, vol. 7, no. 10, p. 1002, 2017, doi: [10.3390/app7101002](https://doi.org/10.3390/app7101002).
- [16] D. Bernardi, E. Pawlikowski, and J. Newman, "A general energy balance for battery systems," *Journal of the electrochemical society*, vol. 132, no. 1, pp. 5–12, 1985, doi: [10.1149/1.211379](https://doi.org/10.1149/1.211379).
- [17] T. Huria, M. Ceraolo, J. Gazzarri, and R. Jackey, "High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells," in *2012 IEEE international electric vehicle conference*, IEEE, 2012, pp. 1–8. doi: [10.1109/IEVC.2012.6183271](https://doi.org/10.1109/IEVC.2012.6183271).
- [18] J. Kim, J. Oh, and H. Lee, "Review on battery thermal management system for electric vehicles," *Applied thermal engineering*, vol. 149, pp. 192–212, 2019, doi: [10.1016/j.applthermaleng.2018.12.020](https://doi.org/10.1016/j.applthermaleng.2018.12.020).
- [19] M. Akbarzadeh *et al.*, "A novel liquid cooling plate concept for thermal management of lithium-ion batteries in electric vehicles," *Energy Conversion and Management*, vol. 231, p. 113862, 2021, doi: [10.1016/j.enconman.2021.113862](https://doi.org/10.1016/j.enconman.2021.113862).
- [20] L. H. Saw, A. A. O. Tay, and L. W. Zhang, "Thermal management of lithium-ion battery pack with liquid cooling," in *2015 31st Thermal Measurement, Modeling & Management Symposium (SEMI-THERM)*, IEEE, 2015, pp. 298–302. doi: [10.1109/SEMI-THERM.2015.7100176](https://doi.org/10.1109/SEMI-THERM.2015.7100176).
- [21] C. Pandya and D. Timbadia, "A detailed review on cooling system in electric vehicles," *International Research Journal of Engineering and Technology (IRJET)*, vol. 8, no. 06, 2021.
- [22] O. Kalaf, D. Solyali, M. Asmael, Q. Zeeshan, B. Safaei, and A. Askir, "Experimental and simulation study of liquid coolant battery thermal management system for electric vehicles: A review," *Int J Energy Res*, vol. 45, no. 5, pp. 6495–6517, Apr. 2021, doi: <https://doi.org/10.1002/er.6268>.

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