DYNAMIC HYBRID THERMAL MANAGEMENT SYSTEM FOR LITHIUM- ION BATTERY

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Introduction:
Lithium-ion batteries are central to the growth of electric vehicles, offering high energy density and long cycle life. Yet, their performance and safety are highly sensitive to temperature. Excessive heat during charging and discharging can reduce efficiency, shorten lifespan, and in extreme cases, cause thermal runaway.

Traditional cooling methods often fall short. Passive cooling systems are energy-efficient but slow to respond under heavy loads, while active cooling systems are effective but consume significant power and add complexity. A dynamic solution is needed - one that adapts intelligently to changing conditions.

The proposed Dynamic Hybrid Thermal Management System (DHTMS) integrates passive and active cooling strategies with intelligent control algorithms. By combining phase change materials, liquid cooling ducts, and adaptive switching logic, the system ensures uniform temperature distribution, minimizes hotspots, and dynamically adjusts to real-time operating conditions. This approach enhances battery safety, prolongs lifespan, and supports the broader vision of sustainable mobility.

Objectives:

Our project set out to:

- Create a cooling system that is modular, adaptable, and efficient.
- Develop smart algorithms that can switch cooling modes automatically.
- Build a working prototype to prove that our ideas are practical, not just theoretical.

Methodology:

1. The project began with a study of existing battery thermal management systems to identify gaps and opportunities. Custom cell holders were designed using CAD tools, allowing space for cooling ducts that conventional holders

lack. A battery pack of 42 cylindrical cells (6P × 7S configuration) was assembled, delivering 25.9 V and 15 Ah capacity.
2. Cooling ducts were fabricated from aluminium to maximize heat transfer, while a coolant mixture of distilled water and ethylene glycol circulated through the ducts with the help of a pump. A Peltier module was integrated to provide both heating and cooling functions, ensuring adaptability to different climates.
3. The control system was built around a Raspberry Pi 4, supported by NTC thermistors, MCP3008 ADC, CP2102 USB-UART converter, and a DALY BMS module. This setup enabled real-time monitoring of temperature, voltage, and current, while ensuring protection against electrical risks. Hardware prototypes were then tested under controlled conditions to validate the design.

Results & Conclusions:

1. The hybrid cooling system demonstrated uniform temperature distribution across the battery pack, reducing hotspots that typically threaten safety. Relay-based switching confirmed that the control algorithm could adapt dynamically, activating passive or active cooling as required.
2. Hardware testing validated the effectiveness of the design. The conclusion drawn is that hybrid cooling, when combined with intelligent control, offers a practical and scalable solution for enhancing battery safety, extending lifespan, and improving EV performance.

Project Outcome & Industry Relevance:

The outcome of the project is a validated prototype of a Dynamic Hybrid Thermal Management System that can be scaled for electric vehicles. Its relevance to industry lies in addressing critical challenges of battery overheating, safety risks, and reduced lifespan. By integrating PCM with liquid cooling and intelligent algorithms, the system offers a cost-effective, energy-efficient solution adaptable to diverse EV platforms. This innovation aligns with the automotive industry’s push toward safer, more reliable, and sustainable EV technologies, while also being applicable to renewable energy storage systems.

Working Model:

- Brought theory into practice, with custom hardware, sensors, and control logic.
- Demonstrated how the hybrid cooling system performs under real-world conditions.
- Validated the design by showing uniform temperature distribution and reduced hotspots.

Project Outcomes and Learnings:

1. The system demonstrated uniform temperature distribution across the battery pack, effectively reducing hotspots that compromise safety. Adaptive switching

between passive and active cooling modes was achieved through intelligent control, ensuring responsive operation under varying thermal loads. Hardware testing confirmed the reliability and scalability of the design, making it suitable for integration into electric vehicle platforms. Overall, the outcome contributes to safer, longer-lasting, and more efficient battery technology.

2. The project provided valuable exposure to practical aspects of engineering, including CAD design, 3D printing, and fabrication. It highlighted the importance of interdisciplinary knowledge by combining electrical, mechanical, and thermal engineering principles into a single system. Real-time monitoring and control emerged as critical elements in ensuring battery safety and efficiency. The experience emphasized the role of collaboration and persistence in overcoming technical challenges during design and implementation. Most importantly, the work reinforced the understanding that engineering solutions are not limited to technical performance but also play a vital role in enhancing safety, sustainability, and societal impact.

Future Scope:

Future development can focus on integrating AI-based predictive algorithms to anticipate thermal anomalies before they occur. Scaling the system for larger EV battery packs and renewable energy storage units is a natural extension. Lightweight materials and advanced PCMs could further improve efficiency and reduce system weight. Integration with IoT platforms could enable remote monitoring and predictive maintenance, while industry partnerships may refine the design for mass production, ensuring affordability and reliability. Beyond EVs, this technology has potential applications in aerospace, defence, and stationary energy storage systems where battery safety is critical.

The project serves as a foundation for next-generation battery thermal management solutions that combine adaptability, efficiency, and safety, contributing to the global transition toward sustainable energy and mobility.