

# A Review on Battery Thermal Management Systems in Electric Vehicles: Techniques, Challenges, and Machine Learning Advances

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*Abstract* – Due to the emergence of electric vehicles (EVs) and as an increasing number of applications rely on lithium-ion batteries, the efficient battery thermal management system (BTMS) has not been as important as now. In this paper, a detailed survey is done with regard to the different BTMS techniques, challenges, and also the recent developments of the field. It points out the major challenges encountered by EV batteries, especially the thermal problems that occur when they are driven at high-performance, rapid charging, and extreme weather. These include both the conventional and novel cooling technologies e.g. air cooling, liquid cooling, phase change materials (PCMs), as well as the new systems such as direct refrigerant cooling and hybrid systems which are compared in details. Also, the topic of the combination of machine learning (ML) and those of artificial intelligence (AI) into BTMS optimization is discussed, with the emphasis put on real-time optimization and predictive maintenance as well as fault detection. The relevance of the use of sustainable processes in the development of BTMS is also outlined in the paper along with focus on environmental friendly materials and chillers. Lastly, the directions of the future are given, where the increased efficiency, flexibility, and sustainability of the systems are needed to address the changing needs of the electric vehicle industry.

*Keywords* – Artificial Intelligence, Battery Thermal Management Systems, Cooling Techniques, Electric Vehicles, Machine Learning, Phase Change Materials, Sustainability.