Proceedings of the 13th World Congress on Mechanical, Chemical, and Material Engineering (MCM 2027)
August 17 – 19, 2027 – Prague, Czech Republic
DOI: 10.11159/htff27.001

Advanced Battery Management Systems: Real-Time State Monitoring, Safety Optimization, and Next-Generation Applications

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Abstract

As energy storage technology rapidly evolves with high-energy Lithium-ion, emerging solid-state batteries, and hybrid architectures integrated with fuel cells, robust safety control and accurate monitoring have become paramount for modern Battery Management Systems (BMS). Conventional BMS frameworks rely heavily on external electrical and thermal parameters—specifically voltage, current, and surface temperature. However, these traditional metrics often suffer from response latency, inaccurate state estimation, and insufficient early-warning capabilities for structural or thermal anomalies.

This presentation introduces an advanced, parallel-monitoring framework that augments traditional BMS controls with direct internal diagnostic sensing. By incorporating non-invasive ultrasonic and piezoelectric techniques, this smart monitoring system directly evaluates structural and material shifts within the battery architecture. This enables precise, real-time estimation of vital operational indicators. Compared to conventional surface-level diagnostics, this integrated approach provides accurate, early-stage anomaly detection, preventing catastrophic failures and optimizing energy utilization. This address will explore the fundamental principles, experimental validation, and real-world deployment strategies of this novel technique across high-impact sectors, including electric vehicles (EVs), electric maritime vessels, aerospace, renewable energy grid storage, high-density AI data centers, and physical AI platforms.