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Battery–Supercapacitor Hybrid Energy Storage System for Performance Optimization in Electric Vehicles

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Abstract: The growing demand for sustainable transportation has accelerated research in electric vehicle (EV) technologies, with energy storage systems playing a pivotal role in achieving higher efficiency and reliability. However, lithium-ion batteries, though advanced, face limitations during transient acceleration due to erratic load profiles and high-current peaks, resulting in voltage sag, heating, and accelerated degradation. This paper presents a microcontroller-based hybrid energy storage system (HESS) integrating a lithium-ion battery with a supercapacitor bank to mitigate these issues. The system adaptively manages power flow during acceleration using an ATMEGA328 microcontroller and an acceleration sensor to engage or disengage the supercapacitor via a ULN2003 relay driver. Experimental results demonstrate a 30% reduction in peak battery current and improved voltage and temperature stability, validating the hybrid system's effectiveness in enhancing battery longevity and overall EV performance.

Keywords: Electric Vehicle (EV), Hybrid Energy Storage System (HESS), Supercapacitor, Lithium-Ion Battery, Microcontroller, Load Leveling, Power Management.

I. INTRODUCTION

The advancement of electric vehicle (EV) technology is pivotal to the global transition toward sustainable transportation. A crucial aspect of this progress is the development of more efficient and durable energy storage systems that can extend cycle life and optimize power delivery. Despite continuous improvements in lithium-ion batteries, these systems face challenges under dynamic vehicular conditions characterized by erratic load profiles and frequent high-current demands during acceleration.

Such transient conditions lead to non-monotonic energy consumption, where rapid fluctuations in current output accelerate chemical aging and thermal degradation, resulting in reduced efficiency and premature cell failure. Conventional battery systems struggle to meet these short-duration, high-power demands, leading to issues such as voltage sag, increased heating, and reduced charge–discharge efficiency. A promising approach to overcome these limitations involves the integration of supercapacitors, which offer high capacitance, rapid charge/discharge characteristics, and superior cycle life. When combined with batteries in a hybrid energy storage system (HESS), supercapacitors can supply instantaneous current during acceleration, reducing stress on the battery and improving overall system responsiveness. Once the power demand stabilizes, the supercapacitors revert to a passive state, allowing the battery to resume its primary role. Recent research highlights that battery–supercapacitor hybrid systems can extend battery cycle life by 20–40% while enhancing voltage and thermal stability. Applications of such systems extend beyond EVs to grid balancing, rail transport, and hybrid renewable power networks. This paper focuses on implementing a microcontroller-controlled lithium-ion battery–supercapacitor hybrid system that dynamically optimizes power delivery based on real-time acceleration data. Experimental validation demonstrates improved battery protection, smoother power flow, and enhanced operational efficiency.

II. SYSTEM ARCHITECTURE

The proposed Hybrid Energy Storage System (HESS) consists of:

1) 12V lithium-ion battery,
2) Supercapacitor bank (series connection to achieve 12V, 100F, 3V units),

3) Microcontroller (ATMEGA328) for real-time control and relay switching,
4) Relay driver circuits (ULN2003),
5) LCD display for system status monitoring,
6) Regulated power supply (IC 7805) for logic.

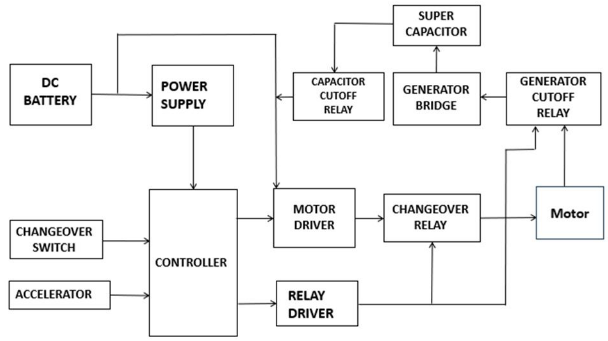

Fig: Super-Capacitor connected in parallel with battery and motor load

The proposed system connects a lithium-ion battery and a supercapacitor bank in parallel to supply power to a DC motor load. The ATMEGA328 microcontroller serves as the central control unit, receiving input from an acceleration sensor to detect dynamic driving conditions. Based on this input, the ULN2003 relay driver switches the supercapacitor in or out of the circuit as required.

An LCD module displays real-time system parameters such as battery voltage, current, and acceleration levels. During rapid acceleration, the controller activates the supercapacitor bank to deliver the necessary surge current, thereby relieving the battery from instantaneous high-load stress. Once the acceleration phase concludes, the supercapacitor is disengaged to allow the battery to handle steady-state operation.

III. WORKING

The project integrates a lithium-ion battery with a supercapacitor in a hybrid energy storage system for an electric vehicle (EV). In this design, both energy sources are connected through relays controlled by a microcontroller. Under normal driving, the EV is powered by the Li-ion battery, which offers steady energy but limited peak power. When the accelerator is pressed suddenly, indicating a rapid increase in speed, the system uses sensor inputs and microcontroller logic to automatically switch the supply from the battery to the supercapacitor. The supercapacitor then delivers high power instantly to meet acceleration demands, reducing strain on the battery. This approach improves both efficiency and battery lifespan, as the supercapacitor handles peak loads and frequent charge-discharge cycles. Once the surge passes, the microcontroller switches back to battery supply for regular driving. The hybrid setup harnesses the high energy storage of the battery and the rapid response of the supercapacitor, resulting in better performance, increased range, and more sustainable operation for the EV.

IV. EXPERIMENTAL RESULTS

Experimental analysis confirms the advantages of the proposed hybrid system. Peak current drawn from the lithium-ion battery during acceleration decreased by approximately 30%, effectively reducing the

thermal and electrochemical stress on the battery. Correspondingly, battery voltage remained stable throughout transient operations, with minimal fluctuations observed. The reduced temperature rise further indicates improved energy efficiency and longer potential battery life.

V. DISCUSSION

The integration of supercapacitors into EV energy storage architectures offers a practical means to counteract performance degradation associated with transient load demands. The hybrid system's ability to level power fluctuations not only enhances battery longevity but also contributes to system stability and reliability. The microcontroller-based adaptive control ensures precise and timely engagement of the supercapacitor bank, resulting in optimized energy management across varying operational conditions. However, practical considerations such as cost, size, and energy density of supercapacitors must be addressed for large-scale adoption in commercial vehicles. Future research could explore advanced control algorithms and power electronic interfaces for further optimization.

VI. CONCLUSION

The presented lithium-ion battery-supercapacitor hybrid energy storage system demonstrates significant potential for improving electric vehicle performance. By intelligently distributing power between the battery and supercapacitor, the system reduces peak current stress, enhances thermal stability, and prolongs battery life. The experimental findings confirm the viability of this approach, paving the way for more efficient, reliable, and durable energy storage solutions in next-generation EVs.

REFERENCES

[1] F. Ju et al., "Review of structures and control of battery-supercapacitor hybrid energy storage system for electric vehicle," IEEE Int. Conf. Automat. Sci. Eng., 2014.
[2] G. Gu et al., "Development of hybrid super-capacitor and lithium-ion battery energy storage system," Int. J. Low-Carbon Technol., 2023.
[3] K. Singh et al., "Performance enhancement of electric vehicle using ultracapacitor-based hybrid energy storage system," J. Energy Storage, 2025.
[4] C.V.V.M. Gopi et al., "Review of battery-supercapacitor hybrid energy storage system for EV applications," ScienceDirect, 2024.
[5] M.S. Ramkumar et al., "A hybrid approach for enhanced performance and reduced battery degradation," J. Energy Storage, 2025.
[6] J. Zhang et al., "Supercapacitors for renewable energy applications: A review," IEEE Trans. Ind. Electron., 2015.
[7] US Patent, "Electrochemical supercapacitor/lithium-ion battery hybrid," 2008.
[8] Emobility-engineering.com, "Supercapacitor applications," 2023.