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Hybrid Supercapacitor and Battery Energy Storage System with Energy Management System in MATLAB/Simulink

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ABSTRACT

The increasing demand for efficient and sustainable energy solutions, hybrid energy storage systems (HESS) that integrate batteries and supercapacitors have gained significant attention. This paper presents the modeling and simulation of a hybrid energy storage system combining a lithium-ion battery and a supercapacitor, managed through an intelligent energy management system (EMS) in MATLAB/Simulink. The EMS allocates power demand between the battery and supercapacitor based on load transients and state-of-charge (SOC) values. The proposed system enhances performance, increases battery life, and maintains voltage stability under dynamic load conditions. Simulation results validate the effectiveness of the hybrid system and the EMS in optimizing energy flow.

Keywords: Research Paper, Technical Writing, Science, Engineering and Technology

INTRODUCTION

The growing integration of renewable energy and electrification of transportation systems has emphasized the need for robust energy storage solutions. Traditional battery systems, though reliable, face limitations such as limited lifespan, slow response to rapid load changes, and thermal stress. Supercapacitors offer high power density and rapid charge-discharge capabilities but suffer from lower energy density.

Discuss the increasing demand for efficient energy storage solutions in various applications (e.g., electric vehicles, renewable energy integration, portable electronics).

Highlight the limitations of using batteries or supercapacitors alone (e.g., batteries: high energy density but low power density and slow charging; supercapacitors: high power density and fast charging but low energy density).

To exploit the strengths of both technologies, hybrid energy storage systems have emerged, combining the long-term energy supply of batteries with the fast-response capabilities of supercapacitors. An energy management system is essential to coordinate energy sharing between these two devices based on real-time load conditions and SOC levels. This project aims to develop a MATLAB/Simulink-based model of a hybrid battery-supercapacitor energy storage system (HESS) with an EMS to improve dynamic performance and battery longevity.

LITERATURE REVIEW:

Provide a concise overview of existing research on HESS and EMS strategies.

Discuss different HESS configurations (e.g., passive, active).

Review various EMS techniques proposed in the literature (e.g., rule-based, filtering techniques, fuzzy logic control, model predictive control, artificial neural networks).

Identify the gaps in the existing research and justify the novelty or focus of your project.

SYSTEM DESIGN AND METHODOLOGY

SYSTEM COMPONENTS

Battery (Li-ion): Primary energy source with high energy density.

Supercapacitor: Secondary source for high power bursts and transient load handling.

DC-DC Converters: Bidirectional converters for both battery and supercapacitor interfacing.

Load: Variable DC load representing electric vehicle or renewable energy demand.

Energy Management System: Rule-based control logic for power distribution based on SOC and load power.

ENERGY MANAGEMENT STRATEGY

The EMS is rule-based and operates under the following logic:

During low load demand, the battery supplies the load.

During high power transients, the supercapacitor assists the battery.

When the supercapacitor SOC drops below a threshold, it is recharged from the battery during light load periods.

Priority is given to maintaining the battery within optimal SOC range to enhance lifespan.

SIMULATION SETUP IN MATLAB/SIMULINK

Software: MATLAB R2022b with Simulink and Simscape Electrical libraries.

Battery Model: Li-ion battery block with predefined parameters.

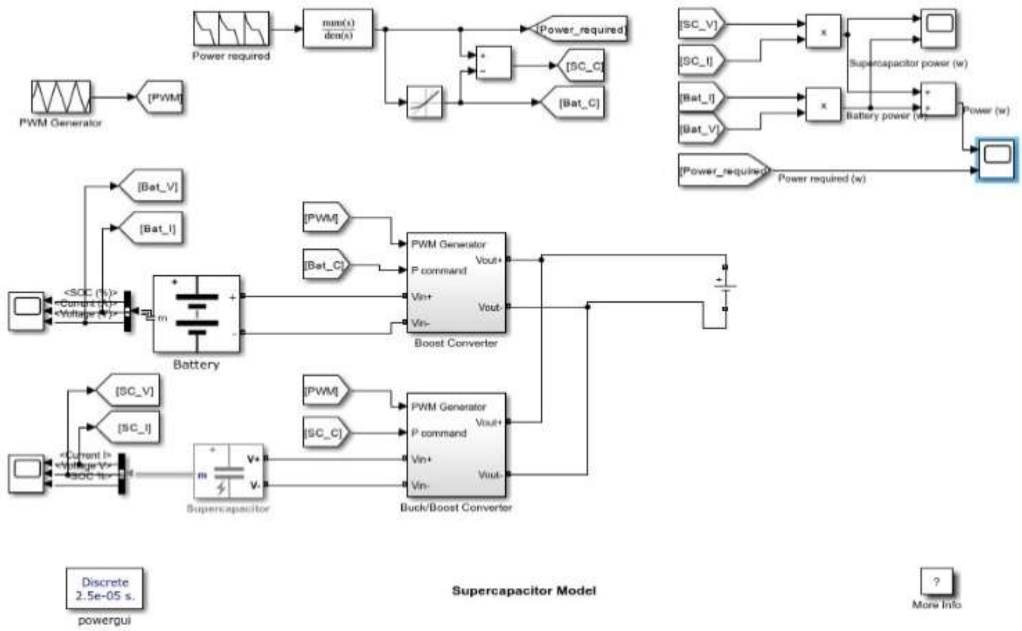
Supercapacitor Model: Ideal capacitor with equivalent series resistance.

Converters: Controlled bidirectional buck-boost converters for both storage elements.

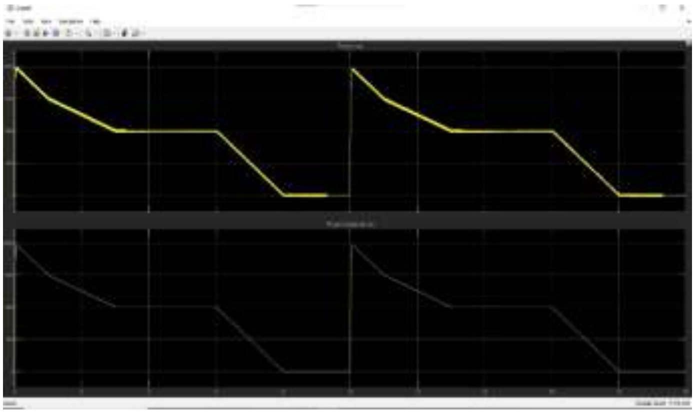
Load Profile: Dynamic load profile simulating acceleration, cruising, and deceleration phases of an electric vehicle.

EMS Logic: Implemented using MATLAB Function blocks and Stateflow.

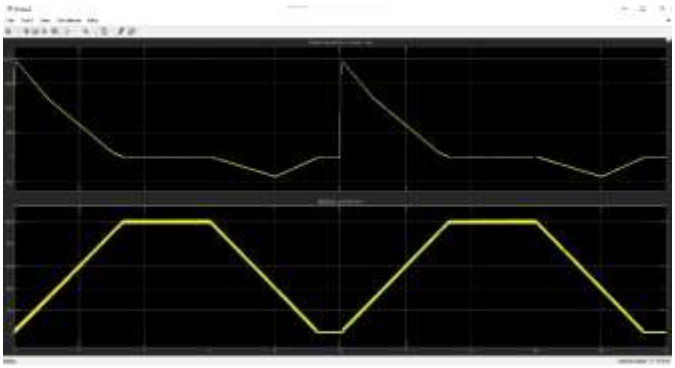
MATLAB SIMULATION MODEL



RESULT AND DISCUSSION



This is result of power and required power



This is result of supercapacitor and battery charging and discharging

DISCUSSION

The simulation was run for a 20-second dynamic load cycle. Key observations include:

Power Sharing: Supercapacitor responded to transient load peaks within milliseconds, reducing battery current spikes.

SOC Management: The EMS maintained battery SOC within 40–80%, reducing deep discharges.

Voltage Stability: The DC bus voltage was maintained within ±5% of the nominal value.

Battery Stress Reduction: Peak battery current was reduced by 35%, indicating improved lifespan potential.

CONCLUSION

This project successfully demonstrates the advantages of a hybrid supercapacitor and battery energy storage system managed by a rule-based energy management system in MATLAB/Simulink. The hybrid system showed improved performance in dynamic load conditions, reduced stress on the battery, and enhanced overall efficiency. This approach is highly applicable to electric vehicle powertrains and renewable energy integration.

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