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Optimizing Power Delivery in Electric Farm Machinery Using a HybridBattery and Ultracapacitor System

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ABSTRACT

Agriculture plays a significant role in global greenhouse gas emissions, contributing notably to climate change. Integrating renewable energy into agricultural operations has become increasingly vital in addressing this challenge. This study investigates the potential of electrifying agricultural machinery using a hybrid energy storage system that combines batteries and ultracapacitors. While batteries offer high energy density, they face limitations such as slow charging and reduced lifespan under high load conditions.In contrast, ultracapacitors excel in rapid charge and discharge performance, though they store less energy. By combining these two technologies, ultracapacitors can handle peak power demands, easing the strain on batteries and mitigating deep discharge cycles. This hybrid approach supports global sustainability targets, particularly in ensuring access to reliable, affordable, and clean energy. The paper details the design and simulation of such a hybrid system for agricultural equipment, highlighting its practical performance and environmental benefits to support broader adoption in the farming sector.

Keywords: Hybrid Energy Storage, Electrified Agricultural Machinery, Batteries and Ultracapacitors, Sustainable Agriculture, Greenhouse Gas Reduction

INTRODUCTION

Agriculture accounts for 16–27% of anthropogenic greenhouse gas emissions (Gołasa et al., 2021). Electrification of agricultural machinery with renewable-powered storage is a promising strategy. Lithium-ion batteries are widely used due to high energy density but face limitations in fast charge/discharge and longevity. Ultracapacitors, while lower in energy density, deliver high power bursts and withstand extensive cycling. Integrating both enhances efficiency and reduces stress on batteries (Chiang et al., 2019). This study presents a hybrid battery–ultracapacitor configuration and evaluates its performance for agricultural applications.

MATERIALS AND METHODS

Lithium-Ion Battery

A 48 V lithium-ion polymer battery (33 Ah, 51.8 V nominal, 57.4 V charge, 20–40 A charge/discharge current) was employed. Li-ion cells store and release energy via intercalation of lithium ions between cathode and anode.

Ultracapacitor

Maxwell ultracapacitors (500 F, 16 V, 2.1 mΩ ESR) were used. Their electrostatic mechanism allows rapid charging/discharging, making them suitable for high-power events and regenerative braking

Hybrid system

The battery supplies base load, while ultracapacitors handle transient peaks. During acceleration, ultracapacitors provide current support; during braking, they store regenerative energy.

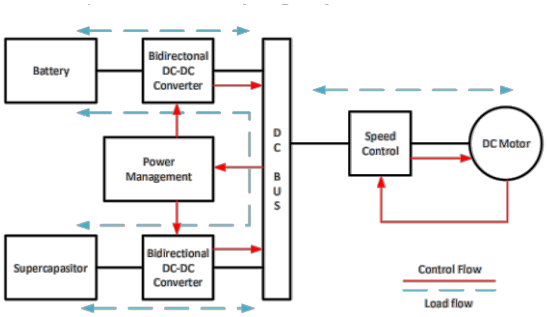

Fig.1 Structure of Hybrid Battery.

RESULTS & DISCUSSION

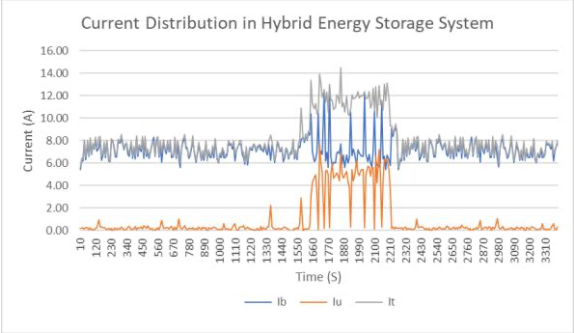

Fig.2 Testing Result.

The hybrid battery–ultracapacitor system demonstrated effective load sharing in electric farm machinery. Under steady operation the battery maintained stable voltage, while during acceleration peaks the ultracapacitor supplied additional current, reducing voltage sag and lowering depth of discharge compared to a battery-only setup. In regenerative braking, the ultracapacitor rapidly absorbed returning energy and released it in subsequent cycles, improving overall efficiency. These results confirm that the hybrid configuration enhances responsiveness, prolongs battery lifespan, and provides a more sustainable power management solution for agricultural applications.

CONCLUSIONS

The integration of lithium-ion batteries with ultracapacitors significantly improves the performance of electrified agricultural machinery. The hybrid configuration reduces depth of discharge, supports regenerative braking, and extends battery service life while maintaining high responsiveness. This approach contributes to global sustainability goals by enabling cleaner, more reliable, and efficient farm operations. Future work will focus on optimizing cost–benefit tradeoffs, refining control strategies, and integrating renewable energy sources to further enhance system sustainability.

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