Hybrid Energy Storage System for Enhancing Battery Lifecycle & Control in Electric Vehicles

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IEEE UCF Super State Racer

Abstract

Over the past decade, the automotive industry has began a major shift from a century's reliance on combustion engines to its electrical counterpart. Through this process, however, the carbon footprint caused by battery production for electric vehicles is detrimental to the environment and leads to increased costs due to degradation over time and material supply constraints. The rise of alternative energy storage resources such as ultracapacitors (UC) are considered to have several benefits to a typical EV design by being configured with the battery systems to alleviate its common limitations.

This research proposes a hybrid energy storage system (HESS) that puts the lithium batteries, typically seen in EVs, in parallel with a UC module. To maximize this topology's benefits, a processor hierarchy is implemented to switch between the two power systems depending on demand curves and sensory data. This design is centered on two factors: quicker response time to peak power demand and relinquishing peak current flow from batteries to the UC module. IEEE UCF's Super State Racer (SSR) project implements this design by converting a combustion go-kart to this proposed HESS configuration for enhancing back end control, and extrapolating results to the EV industry.

Energy Storage Mechanisms

Commercially developed beginning in the 1990s, lithium-ion batteries (LIB) are now used in many portable electronics and are the backbone of all industry-grade electric vehicles. Compared to other energy storage systems, their high energy density and low self-discharge make them premier candidates for high capacity EVs. Though LIBs have been floated as key to a transition away from fossil fuels, their use does not come without cost. The mining of the scarce metals and their usage in LIB production creates immense pollution, unjust global mining practices, and the disposal of LIB leads to detrimental environmental waste.

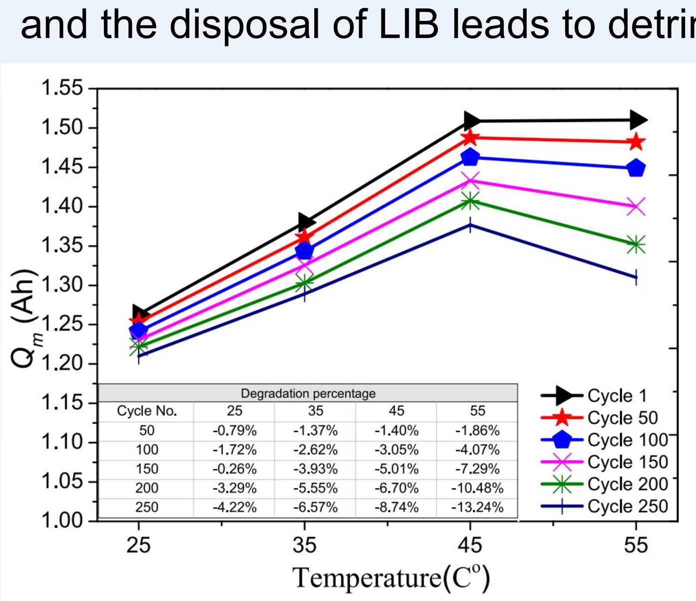

Figure 1. Degradation Data
Battery Cycles vs Charge Capacity for Different Temperature Thresholds (Leng)

Offsetting the negative effects of LIB production can take the form of keeping them in use as long as possible as well as using alternative energy storage for a portion of overall energy capacity. Battery degradation is common in many LIBs. Contributing factors include large current spikes leading to upper extremes of battery temperature and wide variation in power levels across the usage of the batteries.

Ultracapacitors have risen to popularity in recent years for their characteristic behavior in carrying a high specific energy - the rate in displacing charge - while LIBs have a high specific power - the ability to reliably store power with little deviation. UC's ability to counterbalance the limitations in performance of LIBs and their composition being made primarily of carbon allow for this energy storage component to be an ideal partner for LIBs. Past research from Vijaie University and Maxwell technology sight UCs ability to enhance the limitations of LIBs in EVs and in general through hybrid power systems.

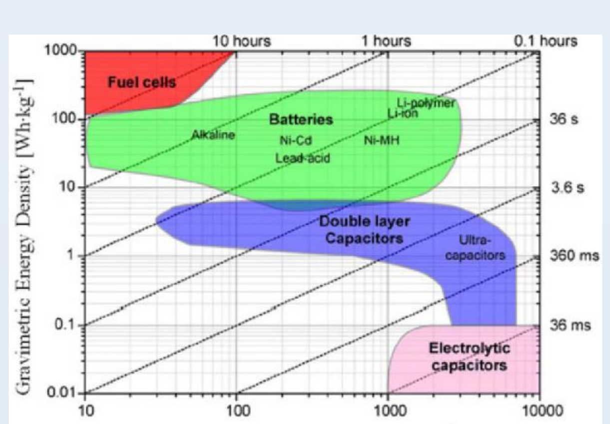

Figure 2: Power Density Vs. Energy Density of Energy Systems (Ostadi)

This research seeks to tackle the issues of power variability, efficient response to peak demand curves, and scarce element usage by implementing an ultracapacitor module - manufactured primarily from carbon - for a sizable portion of the SSR vehicle's overall energy capacity. Scaling these results, insight to the EV industry at large can be determined through extrapolated data. The HESS configuration hypothesized to have the most significant impact to these variables is discussed in the below section.

Hybrid Energy Storage System

A hybrid energy storage system topology can take many forms. Previous research explores several battery and UC system orientations that come with varying use cases and benefits. These take shape in the form of using UCs in series with batteries to sooth battery current variation, UCs used to intake back emf from excess charge, utilizing added voltage regulators to maximize efficient power consumption, etc. Trending across these designs is a goal of limiting variation in output from the batteries, a trait corresponding with degradation of cells. Ease in output variation is desired in the SSR design as well.

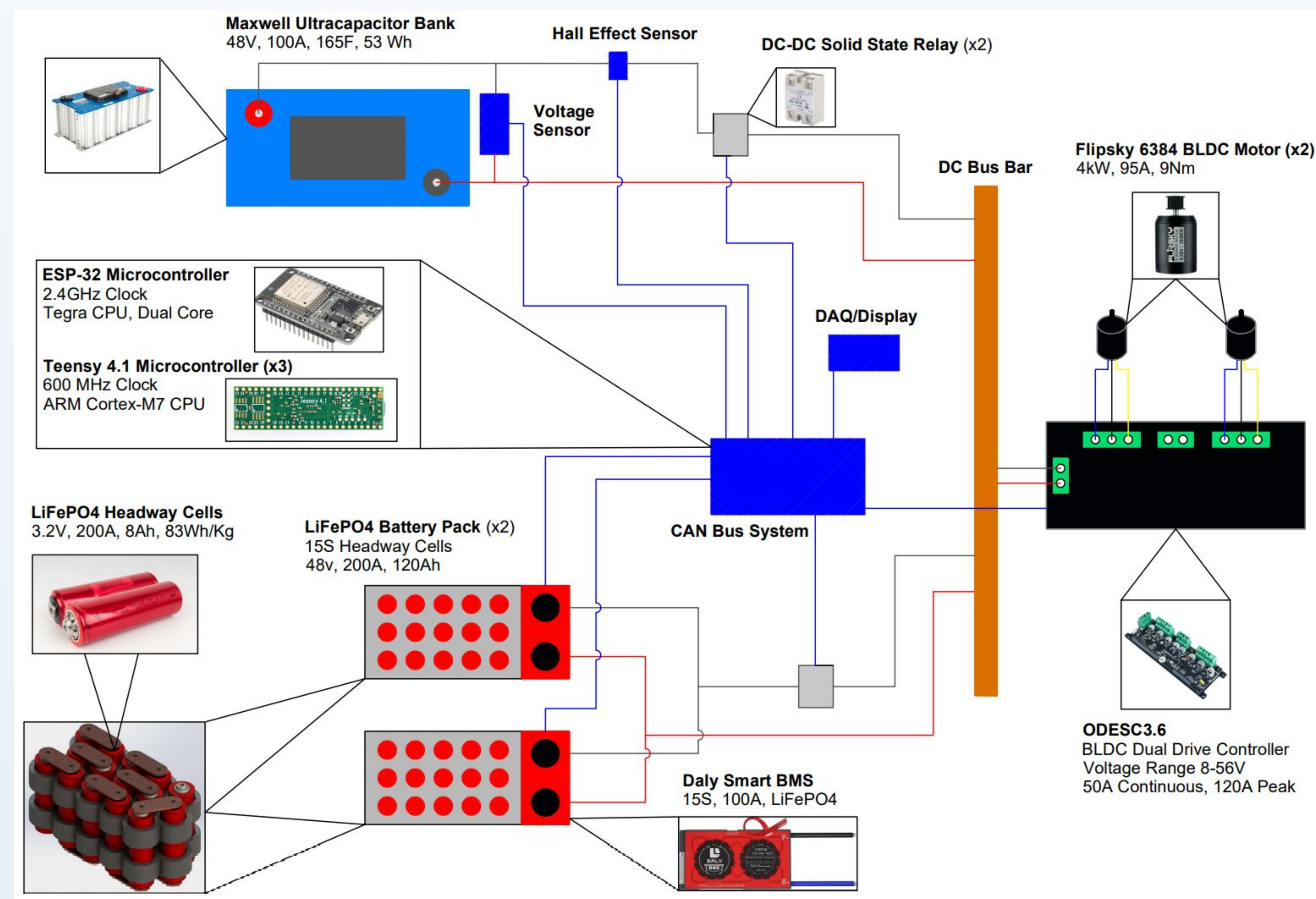

Figure 3. Super State Racer HESS Schematic

The Super State Racer HESS orientation, shown in Figure 3, places two lithium iron phosphate (LiFePO4) headway cell battery packs in parallel with each other. Each pack is then controlled by a smart battery management system (BMS) maintaining ideal conditions across the batteries, measuring voltage, current, & temperature data, and controlling the connection to the output current. Connected in parallel is the UC module that is in line with a solid state relay controlling switching. The DC bus bar, seen connecting both subsystems, drives the power needed for the dual-drive motor controller.

To enhance control over this system, a processor hierarchy centered around sensory input of power sources and motor demand curves will be used to switch between power supplies given a set of alterable parameters. Processors will examine the change in power demand from the motor and, based on a threshold percentage of the maximum consumption and current supply charges, will determine source switch states. By having alterable parameters for switching, results will examine best practices for longevity of the system and maximization of performance.

Simulation Model

Initial simulations will be used to model the charge and discharge patterns of the batteries and the UCs separately. Data accuracy is crucial as the model will be extrapolated for an industry-scale model. Providing evidence for the hypothesis that the implementation of a UC module and switching apparatus in a typical EV design can improve the lifecycle of the batteries is the primary goal of this research. This can be verified by a reduction in the variation of the battery power, which is one of the main causes of battery degradation. MATLAB simulations aim to develop accurate data on the validity of the HESS's impact on these factors.

To effectively model component characteristics such as the battery's transient voltage response, equivalent circuits that rely on experimental data are referenced from other research papers. Then constant and pulse discharge and random load tests will be used to assess the design efficacy. If these sample load tests show that the design reduces the variation of the battery power, this will indicate that the go-kart iteration will work similarly when subjected to real-world loads.

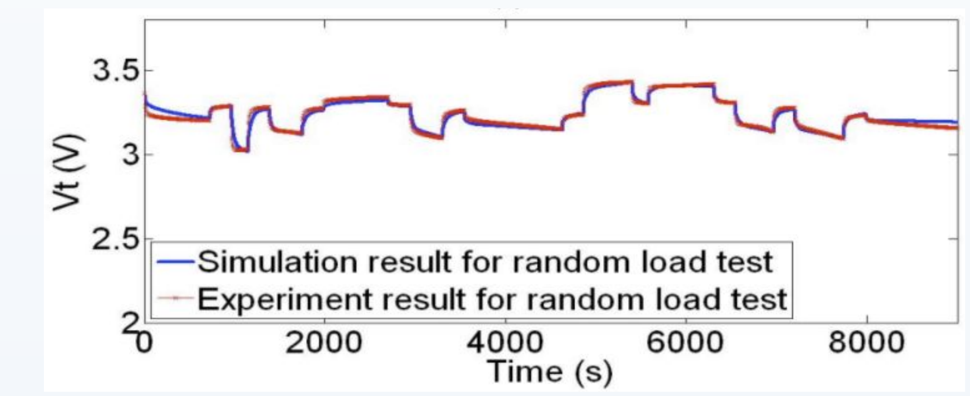

Figure 4. Past Simulation vs Experimental Data Correlation (Yao)

Super State Racer Project

The Super State Racer team within IEEE UCF has begun the conversion of a gasoline powered go-kart to the proposed HESS EV design. This initial version of the design seeks to build a cost effective prototype as a proof of concept for the switching apparatus and proper programmability discussed in the HESS section. Following the data received from this model and the confirmation of its functionality, two future paths will be taken by the team. To get as close as possible to the impact this topology would have on industry, the capacity of SSR version 2 will approach that of an industry grade vehicle and be put under tests against longevity and performance. Version 1 will continue to provide valuable knowledge to students through added research on its back end capabilities, and will be used to inspire the next great engineers.

Figure 5. Super State Racer Prototype Frame

References

L. W. Yao, J. A. Aziz, P. Y. Kong, and N. R. N. Idris, "Modeling of lithium-ion battery using MATLAB/Simulink" " in Proc. 39th Annual Conf. Ind. Electronics Society, 2013, pp. 1729–1734.

Kandler Smith; Matthew Earleywine; Eric Wood; Ahmad Pesaran. "Battery Wear from Disparate Duty-Cycles: Opportunities for Electric-Drive Vehicle Battery Health Management; Preprint.": 9 pp. 2012.

Mahdi Soltani; Jan Ronsmans; Shouji Kakihara; Joris Jaguemont; Peter Van den Bossche; Joeri van Mierlo; Noshin Omar. "Hybrid Battery/Lithium-Ion Capacitor Energy Storage System for a Pure Electric Bus for an Urban Transportation Application"; 19 July 2018. Department ETEC Mobility, Logistics and Automotive Technology Research Group (MOBI), Vrije Universiteit Brussel

Leng, Feng, et al. "Effect of Temperature on the Aging Rate of Li Ion Battery Operating above Room Temperature." Nature News, Nature Publishing Group, 6 Aug. 2015, https://www.nature.com/articles/srep12967.

V. Gevorgian (Vahan); E. Muljadi; Yusheng Luo; M. Mohanpurkar; R. Hovsapian; Vladimir Koritarov. "Supercapacitor to Provide Ancillary Services: Preprint.": 10 pp. 2017. https://www.nrel.gov/docs/fy18osti/68740.pdf$$D PDF.

Schupbach, Roberto M., and Juan C. Balda. "Design Methodology of a Combined Battery-Ultracapacitor Energy Storage Unit for Vehicle Power Management." UARK, 2003.

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