International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Hybrid Energy Storage-Based Regenerative Braking System for Electric Vehicles Using Supercapacitors and Buck-Boost Control

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A B S T R A C T

The rapid development in electric vehicle (EV) technology has been pushed with the aid of the global demand for cleanser and greater electricity-green transportation solutions. One critical element of enhancing the general performance of EVs is the implementation of regenerative braking structures (RBS), which convert the automobile’s kinetic strength all through braking into usable electrical electricity. This assignment specializes in the integration of a hybrid power garage machine, combining a conventional battery with a supercapacitor, to enhance the performance and performance of regenerative braking in electric powered automobiles. The proposed device uses a Buck-Boost DC-DC converter to intelligently manage electricity go with the flow between the battery, supercapacitor, and electric motor. The supercapacitor acts as a strength buffer, soaking up surprising surges of electricity for the duration of deceleration and releasing strength speedy throughout acceleration, which reduces the pressure at the battery and extends its lifespan. The AC inverter converts stored DC strength to AC for motor operation, even as the overall device guarantees smoother energy transitions and decreases electricity losses commonly observed in unmarried-source energy configurations. By employing this dual electricity source strategy, the regenerative braking device will become more powerful in capturing and reusing braking power, thereby growing the range and strength efficiency of the electric vehicle. The method supplied in this have a look at no longer only improves braking performance however also contributes to the sturdiness and sustainability of EV strength systems. Experimental consequences and simulations validate the advanced electricity recuperation price and highlight the sensible benefits of the usage of supercapacitors in hybrid storage configurations.

Keywords: Electric Vehicle, Regenerative Braking System, Supercapacitor, Battery, Buck-Boost Converter, Energy Recovery, Hybrid Energy Storage, Power Management, AC Inverter, Energy Efficiency

1. Introduction

The transition from internal combustion engine (ICE) cars to electric powered vehicles (EVs) is a vast step towards reducing environmental pollution and dependence on fossil fuels. However, the general performance and variety barriers of EVs continue to be key demanding situations. One promising way to cope with those demanding situations is the implementation of regenerative braking structures (RBS), which allow vehicles to recover and store kinetic energy that might in any other case be misplaced as heat for the duration of braking. This recovered energy can then be reused for the duration of acceleration, main to progressed electricity efficiency and extended driving range. While conventional RBS designs rely solely on battery garage, this technique faces boundaries in coping with fast fee and discharge cycles, that can degrade battery overall performance through the years. To conquer this, a hybrid energy garage system (HESS) is proposed, integrating a battery with a supercapacitor. Supercapacitors provide excessive electricity density, speedy fee/discharge talents, and longer cycle lifestyles, making them best for shooting short bursts of power all through braking and supporting high-electricity demands throughout acceleration. This paper gives a regenerative braking gadget that employs a Buck-Boost converter to manipulate strength float between the battery, supercapacitor, and electric motor. The system ensures that strength recovered all through braking is correctly controlled and disbursed, reducing losses and optimizing power utilization. The AC inverter helps easy operation of the electrical motor by using changing stored DC strength into AC power, similarly enhancing car performance. The proposed hybrid system now not most effective improves strength recovery but also contributes to better thermal control and decreased strain on the number one battery. By intelligently handling strength waft and leveraging the strengths of both power storage components, the gadget targets to provide a extra dependable, long lasting, and power-efficient solution for electric powered automobile applications. This research explores the design, implementation, and benefits of one of these machine, highlighting its capacity in current EV era.

2. Related Work

The Numerous research have been performed in current years to decorate the strength efficiency of electric vehicles (EVs) thru regenerative braking systems (RBS). Traditional regenerative braking systems commonly recognition on the usage of lithium-ion batteries as the only strength storage issue. While effective to some extent, those systems be afflicted by obstacles consisting of bad response to excessive modern-day variations, reduced battery lifespan, and inefficiencies all through high-strength charging and discharging. Researchers have consequently explored the combination of supercapacitors with batteries to conquer these challenges and offer greater robust strength garage solutions. Hybrid power garage structures (HESS) combining batteries and supercapacitors had been extensively investigated for their capacity to balance energy and electricity needs. For example, research have shown that supercapacitors can hastily absorb and release energy, making them best for short bursts of strength transfer, consisting of all through braking and acceleration events. This dual-electricity method enables to mitigate the thermal and electric strain on batteries, enhancing their lifespan and universal efficiency. Additionally, a few researchers have proposed fuzzy common sense or machine getting to know algorithms to manipulate strength waft intelligently between the battery and supercapacitor in actual-time driving situations. Moreover, the use of electricity electronics which include Buck-Boost converters and bidirectional DC-DC converters has been emphasized in numerous research works to control power go with the flow among the resources and the electrical drivetrain. These converters help in maintaining voltage degrees and efficaciously shifting power between the supercapacitor, battery, and motor. In combination with inverters and advanced manipulate strategies, the electricity electronics play a vital role in reaching stable and efficient operation of the regenerative braking machine. In comparison to single-supply structures, hybrid structures have validated progressed power healing costs, smoother car overall performance, and decreased operational losses. Although the integration of supercapacitors will increase machine complexity and value, the exchange-offs are justified via gains in electricity efficiency, battery health, and prolonged automobile range. The current work builds upon these findings by way of designing and simulating a regenerative braking device that integrates a supercapacitor-battery HESS controlled through a Buck-Boost converter, aiming to optimize energy utilization at some point of dynamic vehicle operations.

3. Methodology

The proposed machine integrates a hybrid electricity garage gadget (HESS) comprising a lithium-ion battery and a supercapacitor, coordinated via a Buck-Boost DC-DC converter. The middle goal of the technique is to get better kinetic power for the duration of braking, save it efficiently the use of the hybrid gadget, and reuse it all through acceleration or regular force situations to improve the power performance and range of the electrical car (EV).

The device works in two primary modes: braking mode and driving mode. During braking, the electrical motor operates as a generator because of regenerative braking, converting kinetic power into electric electricity. This electricity is first directed to the supercapacitor because of its rapid charging functionality and excessive electricity density. The Buck-Boost converter regulates the voltage tiers and controls the electricity drift based totally on device call for. If the energy recovered exceeds the garage ability of the supercapacitor, the extra strength is redirected to the battery. In the driving mode, power stored in both the supercapacitor and the battery is furnished to the electric motor. The supercapacitor affords electricity at some stage in high-load conditions inclusive of acceleration or hill mountaineering, at the same time as the battery components energy during normal cruising conditions. This strength sharing reduces the weight at the battery, preventing rapid discharge and thermal degradation. The Buck-Boost converter helps bidirectional power flow and ensures that voltage levels are maintained as in step with the motor's operational necessities. A manage algorithm is implemented to display real-time driving situations, automobile pace, state of charge (SOC) of the battery and supercapacitor, and braking intensity. Based in this information, the algorithm comes to a decision the best distribution of strength between garage components and controls the converter for this reason. The system additionally consists of an inverter to convert saved DC electricity into AC for motor operation. This method now not simplest improves strength utilization and battery life however additionally contributes to smoother automobile dynamics and green braking performance.

4. Experimental Results

The proposed Hybrid Energy Storage System (HESS), including a lithium-ion battery and a supercapacitor (UC), became simulated the use of MATLAB/Simulink to evaluate its performance beneath numerous dynamic operating conditions. The device is designed to keep a DC bus voltage of 25V using a boost converter that elevates the battery voltage from 12V. The supercapacitor is charged up to 16.2V and serves as a electricity buffer, specifically in the course of high-temporary load conditions. A electricity limiter block guarantees that the battery gives you electricity only within its rated limits, and any excess brief energy call for is supplied exclusively by way of the UC.

A) Starting/Acceleration from Rest

At car startup, the motor studies high load torque due to static friction (stiction). This situation changed into modelled by making use of a 5 Nm load torque at 0 speed, which decreased to two Nm at zero.4 seconds. The simulation effects display that each the battery and the UC make a contribution to presenting the preliminary electricity demand. The UC discharges unexpectedly, with its State of Charge (SOC) losing to 83%, indicating its dominant function in handling the sudden energy requirement. The motor progressively hurries up and reaches regular-state velocity within 2.Five seconds. Once the consistent nation is accomplished, the battery will become the sole source of power for the motor, at the same time as the UC starts to recover.

B) Running on a Positive Ramp

To simulate an uphill using situation, a dynamic torque profile was implemented, growing from 2 Nm to four Nm between five.72s and eight.94s. As the motor torque lagged in the back of the increasing load torque, a velocity drop of about 25% became determined. The manage device replied by using drawing additional power from the UC, thereby protective the battery from surprising present day surges. During this temporary length, the UC discharged swiftly, attaining seventy two% SOC. Once the slope turned into cleared and the load stabilized, the battery resumed offering electricity to each the motor and the UC, which started recharging.

C) Regenerative Braking

At 14.Three seconds, a downhill situation turned into simulated by using applying a constant terrible dynamic torque of two Nm, representing gravitational assistance in vehicle movement. As the vehicle velocity improved, the motor transitioned into generator mode because of the reversal of modern. The kinetic electricity from the wheels become correctly transformed into electric electricity and saved inside the UC, main to a upward thrust in its SOC. This regenerative method additionally developed a braking torque, which successfully counteracted the acceleration caused by the slope. The consequences verify that the proposed device is capable of effectively shooting and reusing braking energy, therefore enhancing the general power performance of the car. Overall, the simulation results validate the effectiveness of the hybrid garage configuration. The UC correctly handles brief electricity needs, while the battery presents solid strength for the duration of everyday operation. This collaborative energy management effects in reduced battery strain, progressed device efficiency, and prolonged component lifestyles.

5. Conclusion of Experimental Results

The proposed regenerative braking machine the use of a hybrid energy storage configuration has demonstrated sizable upgrades in strength restoration, gadget performance, and aspect reliability for electric powered cars. By integrating a supercapacitor alongside a lithium-ion battery, the machine efficaciously addresses the restrictions of conventional unmarried-supply strength storage, specifically beneath transient operating situations including acceleration, mountain climbing slopes, and regenerative braking. Simulation results showed that the supercapacitor successfully handles excessive electricity needs during surprising load variations and provides immediately energy aid throughout startup and steep incline conditions. Additionally, it plays a crucial position in absorbing recovered power all through regenerative braking, thereby reducing the stress on the battery and enhancing the overall electricity management of the system. The use of a Buck-Boost converter enabled dynamic voltage control and bidirectional electricity flow between components, ensuring easy transitions and most efficient strength shipping. Overall, the hybrid strength garage device offers a promising answer to improve the performance, performance, and sustainability of electric automobiles. Future work might also consist of hardware implementation and checking out below actual using conditions to validate the machine's effectiveness and scalability in commercial EV packages.

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