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Review Article

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Performance Improving Methods of Regenerative Braking System

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Abstract

Use of regenerative braking is to increase the range of electric vehicles (EVs) is an effective strategy. It is one of crucial tools of main attractiveness of electric vehicles. In electric and hybrid electric cars, regenerative braking is the most efficient and ecologically effective strategy to enhance energy economy and vehicle stability. It is a good approach for electric vehicles to enhance their operating range. Regenerative braking is the act of turning kinetic and potential energy held in a vehicle body when braking or driving downhill into electric energy and loading it in the battery. Several studies have been conducted to demonstrate various strategies for increasing the efficiency and driving range of electric cars through the use of regenerative braking. The main aim of this manuscript is to investigate some of these strategies and how they impact the overall performance of electric cars. Finally, the potential use of regenerative braking systems (RBS) is considered.

Keywords

Regenerative braking, Electric vehicle, Hybrid electric vehicle

Introduction

Due to rising environmental concerns and recent advancements in battery technology, electric cars have emerged as the utmost realistic options for the creation of low-emission and fuel-efficient automobiles. RBS is a good way to improve fuel economy in heavy traffic and cities for EVs and hybrid EVs. The use of RBS, which regulates electrical motors that act as producers to change kinetic or potential energy into electric energy [1-3]. High-tech gear including sensors, inverter circuits, and auxiliary storage devices can be hired to increase the efficiency of electric cars. These technologies may make EVs more complex but boost the overall cost of EV manufacture. As a result, specialists are seeking to remedy this issue by modifying RBS. An automobile slows downhill as the motor slows down. When we press down on the brakes, the automobile slows down and the motor runs in the opposite direction. When operating in the wrong way, the motor serves as a generator, charging the battery [4-6]. RBS allows the automotive to collect kinetic energy while decelerating, resulting in considerable fuel savings. According to studies, a standard braking system wastes around one-third to one-half of power plant's energy into heat during deceleration in urban driving scenarios [7-9]. This squandered energy was initially in the form of kinetic energy, or motion energy. Investigating techniques for the recuperation of this lost kinetic energy is thus visually beautiful, environmentally fulfilling, and stimulating. From a practical standpoint, capturing vehicle's kinetic energy can be accomplished through converting it to heat, mechanical, or electrical energy [10-13]. To maximize the proficiency and size of RBS recovery, sensible management approaches, energy recovery modes, and braking force circulation are required.

Parallel and serial strategies are the most common management methodologies. For former, motor regenerative braking may be used with standard friction braking without needing any changes to the frictional brake force. Before friction braking, motor regenerative braking is used, and it is accompanied by a change in frictional braking force [14-16].

Regenerative Braking System

RBS is a mechanism through which part of kinetic energy in automobile is transferred and stored in the battery during deceleration, figure 1. In a flat road surface area, RBS may not always perform. It is observed on roads where cars must apply brakes on speed breaker, pits in the road, and slopes where vehicles must apply brakes. It is observable only when a battery is entirely charged. Because braking must be affected by energy, mechanical brakes in EVs are required. EVs employ a mechanical brake to enhance roughness of wheel in order to decelerate [1]. From an energy-saving standpoint, mechanical brakes consume a lot of energy as kinetic energy of EV is transformed to electric energy. Kinetic energy lost while braking can be turned into electrical energy and stored in a battery. This energy will be stored in the battery if correctly handled and controlled without producing any problems with motor, drive, battery [3, 4].

Regenerative Braking in EV

TWhen an EV stops accelerating, the powertrain immediately involves an RBS to compensate for energy loss due to deceleration, transferring energy back to the motor, which now functions as a generator to replenish the battery [1]. As a result, the battery has a longer range because it is constantly recharged, and studies and research show that the use of regenerative braking reduces battery ageing significantly, which also plays a vigorous part in reduction of ownership costs because cost of replacing a battery is reduced, which is the key player for the reduction of the spread of EVs [1, 5].

Several researchers worked on the enhancement in efficiency and driving range of RBS for EV through various approaches. The past work done related to RBS in EV is described below:

To boost braking performance, a fuzzy RBS is presented. The fuzzy RBS successfully handles the dispersal of braking force between front and back wheels, as well as supply of friction and RBS force. Furthermore, fuzzy RBS is implemented and tested on the road with an LF620 prototype EV. Experiments reveal that it is possible to obtain maximum automobile braking energy recovery while maintaining brake safety. The powertrain's proficiency as well as components' proficiency has been enhanced, and the EV's maximum driving range per charge has been raised [17]. FLC technique was employed to address the complicated non-linear problem in the hybrid EV engine, electric motor, and accumulator cell. As a result, the energy rational distribution was achieved, and the system was resilient [18].

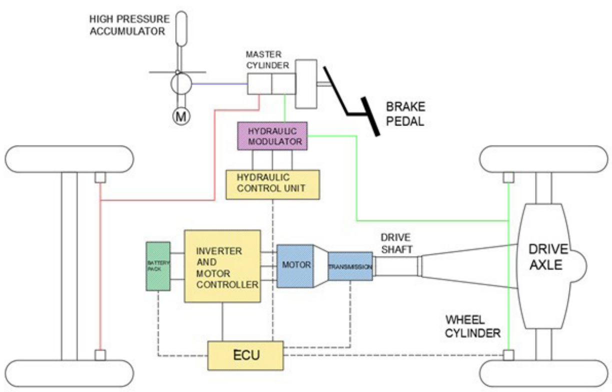

Figure 1: Schematic representation of RBS [1].

MDT regulator is presented to recover electric energy from kinetic energy and return it to motors' batteries. Cycle passes through ups and downs with positive, negative, and zero acceleration. Oscillations cause dissimilarities in load torque. A novel switching design has been added into the system to make electric energy with no need for the recommended method's mechanical adjustments. According to simulation findings, the improved switching pattern advances torque tracking signals and speed, as well as torque waves. When associating the state of charge designs of traditional and MDT regulator, suggested algorithm outperforms former and returns more energy to the batteries [19, 20].

An energy retrieval mode for an EV's RBS is proposed. The RBS setup is described, and its models are created. Imitation is used to test various adhesion situations. As demonstrated by the results, the given energy retrieval mode is successful and practicable, and a recommended control technique is appropriate [21]. To increase energy and expand the driving range of EVs, a single-pedal control approach is proposed. Theoretically, the capacity to recuperate energy is examined. The strategy for single-pedal control is based on single-pedal simulation and real-world driving scenarios [22].

It is presented a revolutionary electric braking approach based on brake pedal depression. To create this unique braking technique, many current braking approaches like single, two, and three switch topologies, as well as plugs, are merged. To arrive at this proposed approach, two crucial elements, namely stopping time and energy regeneration, are taken into account. Their performance is initially investigated using numerical modelling and experimentation. The suggested technique allows the vehicle to come to a complete stop at any speed while also allowing for energy recovery [23, 24].

For EVs, a new approach is being developed for managing the braking procedure of fully electrified RBS, which requires electric actuators as shown in figure 2. It keeps the wheel in a steady hold area without controlling the slip ratio, eliminating the time-consuming job of calculating an appropriate slip ratio orientation and the non-linear controller. The suggested technology not just prevents the wheels from fastening but can recuperate as much kinetic energy as possible via motor, that acts as producer while braking [25].

With no need of an extra ultracapacitor, converter or complex winding substitution, the suggested method simply alters switching logic of motor driver to suit box of energy regeneration electric braking. Some of pros of the suggested

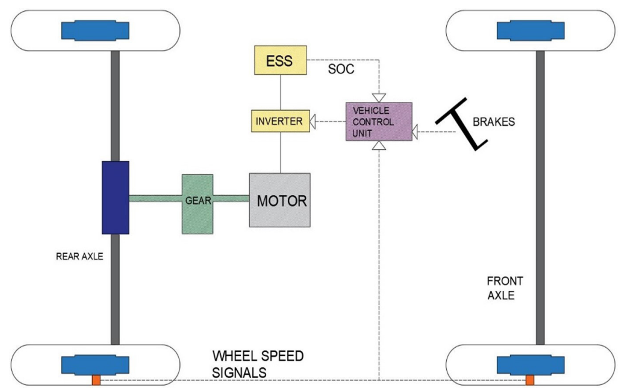

Figure 2: Fully electrified RBS system [25].

technique are: No necessity for a power converter, no need for an ultracapacitor to replenish the battery with braking energy, no need to adjust or build the motor winding precisely, motor driver (inverter) circuit structure does not need to be changed, smooth and controlled electric braking torque, improves the EV's protection, extends the range of the EVs [26, 27].

For RBS, an organized data-driven fault identification and diagnosis tactic is provided using PSAT software in both nominal and defective conditions. For data minimization, MPLS is approached, and for fault isolation, statistical and pattern recognition algorithms are used. The method given here shows great accuracy (100% fault classification accuracy using SVM, KNN, and PCA classifiers) as shown in table 1 and may be used to analyze faults in automotive system [28].

The effectiveness of a drive system with a power levelling function is determined by ultracapacitor conversion efficiency. The capacitor size and conversion power have been demonstrated to have a significant impact on ultracapacitor efficiency, the minor the capacitor, the lesser the efficiency. Following are some benefits of the proposed solution: The system's ride-through capability has been increased, system's functionality, particularly braking competence, is unrelated to the dependability of the mains, peak power of the mains is managed, and the mains drive effect is greatly decreased [29].

The functioning of an ultra-capacitor-based RBS for a DC motor has been simulated for various braking times. The action of regenerative braking was simulated for a braking period of 5 seconds. Based on the UC charging current, the motor appears to stop functioning after a certain amount of time. RBS and energy renewal from the UC to battery were seen in the current investigation [30].

Table 1: Overall classification accuracy [28].

Classification Algorithm	Classification Accuracy (%)
SVM (Support Vector Machine)	100
KNN (K-Nearest Neighbor) (k = 1)	100
KNN (k = 2)	100
KNN (k = 3)	100
PLS (Partial Least Square)	94.87
PCA	100
PNN	97.44

For EVs, the author has developed RBS mechanism. The system is constructed in MATLAB and SIMULINK and the identical drive circuit is implemented in hardware using a blend of fuzzy control and PID controllers. A control strategy is made for the system, figure 3. Regenerative braking is ensured by the combination of fuzzy control and PID control, which dynamically distributes electrical and mechanical braking force. PID has been shown to be quicker than fuzzy; when these two approaches are combined, desirable regenerative and mechanical brakes may be achieved. It can be easily used in BLDC motor and H-bridge inverter as the implemented system revolves synchronously. The control method for BLDC is revealed in figure 4 [24, 31].

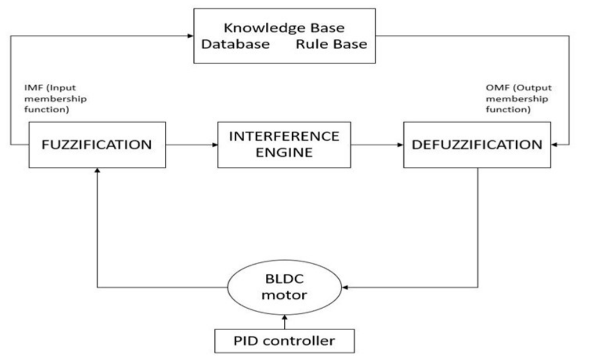

Figure 3: Basic configuration of control strategy [31].

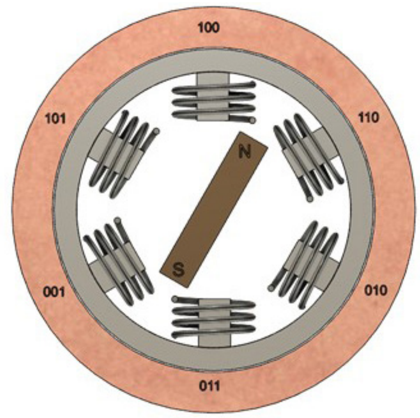

Figure 4: BLDC motor construction [24].

Conclusion and Future Scope

The purpose of RBS is to collect as much kinetic energy as possible and keep it as electrical energy. Various methods for increasing the efficiency of regenerative braking systems were presented in this review study. The basic goal of all these experiments, whether they are theoretical or practical, is to improve efficiency. RBS assist hybrid and electric cars in lowering consumption and lowering their carbon impact.

They can also extend the range of EVs and hybrid EVs, making them more practical for daily use. It can minimize wear of brake pads, increase driving range of EVs and reduce maintenance cost. They are only around 70% efficient at best, but after doing all of the trials, we can clearly identify some room for improvement or alternative techniques to improve efficiency.

This research solely focuses on the various methods for increasing the efficiency of regenerative braking. Various studies can be done on the same issue, such as alternatives to the RBS that are better and more efficient, or other ways in which this system might be implemented. Those methods can be implemented in real-time too to check if they are really effective for an EV or not. There are numerous ways to get the most out of this system.

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None.

Conflict of Interest

None.

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