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ENERGY ENHANCEMENT OF ELECTRIC VEHICLES THROUGH REGENERATIVE BRAKING SYSTEM

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***Abstract*: Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) have been attracting a lot of attention for environmental issues and energy crisis. One of advantage of using foregoing vehicles is charging energy by regenerative brake. Regenerative braking systems (RBS) are a useful way to capture the energy lost while braking and at the same time lowering exhaust and brake emissions. The idea behind this process is to transform mechanical energy from a motor's kinetic energy into electrical energy. This paper, gives comprehensive information about regenerative energy system. Later, a case study of an electric vehicle conversion's electrical energy use in a real-world setting has been looked at. Such tests assess the energy usage of a vehicle's overall system whether it has regenerative braking or not. The absorbed capacity of regenerative energy is limited because of motor capacity and current limit of battery. This becomes serious issues the heavy weight vehicle such as bus and truck. To increase regenerative energy, large motor and battery are requested, which is difficult because of cost and limit of inverter capacity.**

With the advancement of energy regeneration technologies, the driving range of electric vehicles can be enhanced. Two boost approach, a unique energy regeneration strategy, is suggested in this paper for electric vehicles powered by brushless DC motors. Additionally, since this approach regenerates more energy than the single boost method, this method's energy regeneration efficiency has been greatly improved.

***Keywords:* Electric Vehicles, Regenerative Braking System, Regenerative Brakes, Brushless DC motor, Switched reluctance motor, Induction motor.**

I. INTRODUCTION

The number of automobiles is growing quickly along with the world population. Air pollution, global warming, and the quick depletion of petroleum resources are just a few of the serious environmental and health risks caused by car emissions. Additionally, the ensuing global energy crisis forces countries to use alternate energy sources and to extract the most energy possible from their existing resources. Electric cars (EVs) and hybrid electric vehicles (HEVs) can meet our current needs since they will ensure clean air, be energy efficient, and have novel uses for energy.[1]

EVs are vehicles that utilize electrical energy to supply the driving components. The overall mileage in a battery-powered electric vehicle depends on the battery's capacity, the driver's driving habits, and the effectiveness of the driving components. Increasing battery capacity would boost the mileage, although, it will also result in longer charging times and higher costs. Hence, the most realistic way to optimize the EV mileage is by increasing the efficiency of its driving components.[2]

The switching reluctance motor (SRM), which offers the benefits of a straightforward design, low price, high dependability, high power output, and good efficiency over a wide speed range, is currently one of the best solutions for powering EVs. [1] SRMs do, however, have the drawback of having high torque fluctuations, which have a direct effect on the vehicle's stability and comfort when braking.[3]

The dependency on batteries as the energy source for purely electric vehicles is another major drawback. This is because batteries have a high charging time, a low specific power, and it's inability to provide the vehicles' short-term power needs. [4] Thus, by recovering some of the braking energy, EVs use regenerative braking systems (RBS) to increase energy efficiency. Electric car brake systems may use a variety of brake technologies. As an illustration, some cars employ traditional friction brakes, which result in energy loss from the heating of the brake pads. The anti-lock braking system is a different type of brake system. This system employs an intermittent braking technique rather than continuous braking to slow or stop the vehicle as needed. This braking system performs better and is more efficient than the traditional brake system. [4] This paper focuses on making the system more efficient by using Regenerative Braking System in conjunction with the above specified braking systems.

II. REGENERATIVE BRAKING SYSTEM (RBS)

Regenerative braking, also known as energy recovery, is a braking technique that reduces the speed of a moving object or vehicle by turning its kinetic energy into electrical energy that can either be used right away or saved for later use. By converting the mechanical energy of the motor, it charges the battery.

A regenerative brake is achieved by using the traction motor which generates the negative torque in vehicle deceleration mode, it can convert the kinetic energy into the electric energy and it is charged to a battery, however, a general mechanical brake ingenerates the stopping force by overbearing brake disk to brake pad, the braking energy is converted into the heat and it is not reused. Then, the regenerative brake has little detriment and the running distance by one electric charge is increased by the regenerative brake. [3] However, the possible absorbed energy of the regenerative energy is limited because of the motor capacity and the current limit of the battery. As a result not only the regenerative electric brake but also the mechanical brake must be used. The trend becomes serious for the heavy weight vehicles, the bus and the truck and so on.

Fuel usage and pollutants are reduced in this method.

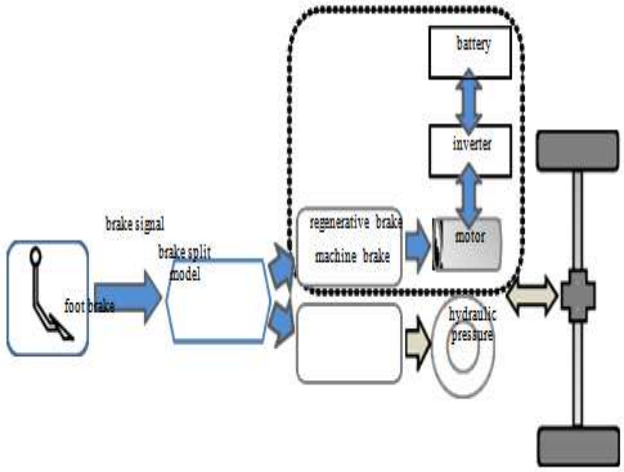

Fig. Braking System

Regenerative braking's benefit is its capacity to raise EV efficiency without requiring the addition of any components, notably for induction and permanent magnet electric motor.

2.1 CASE STUDY

The experiment below, carried out by the Indonesian Institute of Science, provides information on energy measurement and vehicle performance on an electric vehicle in a real-world scenario:[4]

Table 1: Specifications of retro fitted 1994 Toyota kijang Super EV. [5]

NAME OF COMPONENTS	SPECIFICATIONS
Electric Motor Type	Three Phase AC Induction
Electric Motor Maximum Power	52 HP
Electric Motor Maximum Torque	156 Nm
Electric Motor Maximum Rotation	6.500 rpm
Battery Type	Deep cycle lead acid
Battery nominal Voltage	96 Vdc
Battery Nominal Capacity	235 Ah
Charge Power	2.800 Watt (Single phase)
Other Features	400 W DCDC Converter, electro hydraulic power steering and electric vacuum brake.

2.1.1 Calculation of the Vehicle Energy Consumption

A Toyota Kijang Super automobile that ran on gasoline has been converted to run on electricity. [5] An electric motor with three phases has been installed to replace the original 1,500 cc gasoline engine, which was built in 1994. Other sections of the automobile, such as the fuel tanks and exhaust pipes, have been taken out and replaced with electric motors, batteries, motor controllers, and other parts used in electric vehicles. The vehicle now has an electric drive system, as shown in Table 1, which is a new specification. The flywheel and clutch were still employed, and there had been no modification in the gear ratio of this car's transmission.

The empty weight of the 1994 Toyota Kijang Super is around 1200 kg. The car that was converted from gasoline to electricity was stripped of its engine, fuel lines, radiator, and exhaust lines during the retrofit process and then outfitted with 16 units of lead-acid batteries, electric motors, motor controllers, and chargers, resulting in an empty vehicle weight of roughly 1600 kg of the converted car. [5]

Fig.2 1994 Toyota Kijang Super gasoline-to-electric

By comparing the amount of electrical energy used with and without the regenerative braking technology, the modified car was put to the test. When the accelerator pedal is not being depressed, this regenerative braking feature is designed to engage automatically. As a result, the vehicle's inertia can be transformed into electrical energy and then fed back into the battery. Undoubtedly, the energy conversion causes the car to slow down. The braking effect on the car is comparable to an engine brake on a conventional car because the value of the regenerative braking current is lower than the current needed for propulsion.

In Bandung City, a 12.4 km route was approved as a vehicle test route. To avoid a breakdown during the testing time, the battery was completely charged before the test. To determine how much energy an EV used throughout each test, all the data were processed.

2.1.2 Results and Context

It can be seen that both sets of measured energy consumption statistics form a fairly symmetrical, normal distribution with and without regenerative braking. The vertical line in the middle represents the population value on average. The range of energy consumption for testing with regenerative braking is 143.94–146.58 Wh/km, and it is 95% likely that the actual average energy consumption falls within this range.

In a similar manner, the outcomes of vehicle testing without regenerative braking reveal a range of 153.30-156.27 Wh/km. This leads to the conclusion that the average energy consumption value for each test could be considered as the population's value.

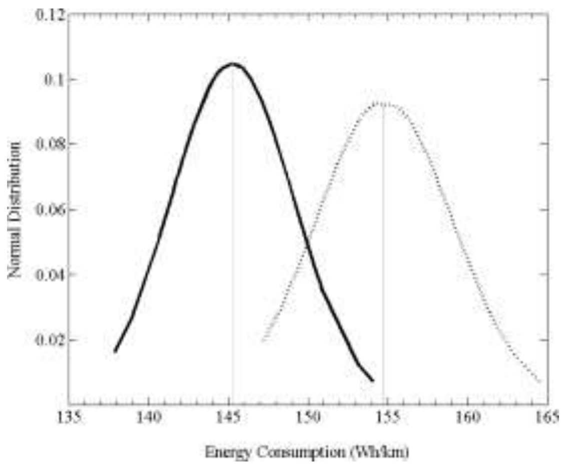

Fig 3: Measurements Results [5]

Average energy consumption without regenerative braking and average energy consumption with regenerative braking varies by 9.53 Wh/km. Based on these findings, it is possible to infer that the regenerative braking system on the modified car employed in this study might lower the power usage by 6.16 percent, or 9.53 Wh/km. This figure indicates a rise in vehicle efficiency. Increasing vehicle efficiency could enable it to travel further on the same amount of energy.

2.1.3 Limitations of the Regenerative Braking System

The motor capacity of the electric regenerative braking is limited at high speeds, and even at low speeds it is restricted by the battery's input current limit. Because less than half of the braking energy is absorbed by the regenerative brake, the amount of power needed to stop the vehicle exceeds the RBS's capacity, which lowers the amount of energy that can be recovered by the friction braking system. As a result, when constructing an RBS, a relationship between the system's structure, development time, cost, and brake dependability must be created. It is also observed that not only the motor capacity but also the battery input current affect to the electrical brake limit. Additionally, it has been found that the electrical brake limit is influenced by both the battery input current and the motor capacity.

III. A PROPOSED METHOD TO INCREASE THE AMOUNT OF REGENERATIVE ENERGY

Due to the motor capacity and battery current limit mentioned above, the regenerative brake of EVs and HEVs is restricted. As a result, both the mechanical brake and the regenerative electric brake must be engaged. Large motor and battery capacities are required to increase regenerative energy, but this becomes challenging due to cost and the limit of the inverter capacity.

In this paper, to improve the distribution of braking forces, fuzzy logic control is used to boost the regeneration energy.[6] Currently, common electric motors that are used in EVs are Switched Reluctance Machine (SRM), induction motor (IM) and brushless Direct Current (BLDC).

The reason BLDC motors are the most common is due to their high efficiency, optimum torque speed characteristics, dependability, stability, minimal noise, and simple structure to control. [7] The primary flaw in BLDC motors, however, is the torque ripple, which leads to cogging torque.

Reusing brake energy can significantly help, which is a key difference between conventional cars and electric vehicles in terms of energy efficiency.

3.1 Simulation Result and Experiment

The accompanying simulation and experimental findings demonstrate that the suggested strategy may recover energy while ensuring safe braking in various circumstances. Controlling the inverter's switching sequence is recommended as a practical energy regeneration technique for electric vehicles (EVs) with BLDC motors, without the need for any additional hardware like an ultracapacitor, converter, or intricate winding changeover. This study came to the conclusion that by adopting this technique, an EV's driving range may be enhanced by roughly 16.2%.

In order to effectively distribute the braking force between the front and rear axle motors and improve braking economy, a regenerative braking management technique based on fuzzy logic and series regenerative braking is proposed.

Brushless motors are frequently utilised in automotive technology because of its improved torque-speed characteristics, high efficiency, [8]-[12] extended operational life, larger speed ranges, and low maintenance requirements. In this paper, a two-boost method, a unique regenerative braking strategy, is suggested for electric vehicles (EVs) powered by BLDC motors. Based on this technique, a BLDC motor driver's power switch switching sequence is altered, resulting in the motor driver becoming two simultaneous boost converters. In order to demonstrate the effectiveness of the suggested strategy, simulations and experimental testing are provided, along with a comparison of this method to a single-boost method.

Based on simulation and experimental findings, the two-boost method increases energy regeneration and, consequently, efficiency when compared to the single boost method.

3.2 Result:

For the energy regeneration in EVs powered by a BLDC motor, a new technique known as the two-boost method is suggested. The foundation of this approach is the split-up of the BLDC motor driver circuit into two boost converters. The single-boost method, which transforms the BLDC motor driver into a single boost converter, is the basis for the approach on which this method is built. Every 60 electrical degrees in the single-boost approach, two phases are employed; in the two-boost method, all three phases are used simultaneously. Both techniques include opening high-side switches, which cause the body diodes to function as boost converter diodes. [8]

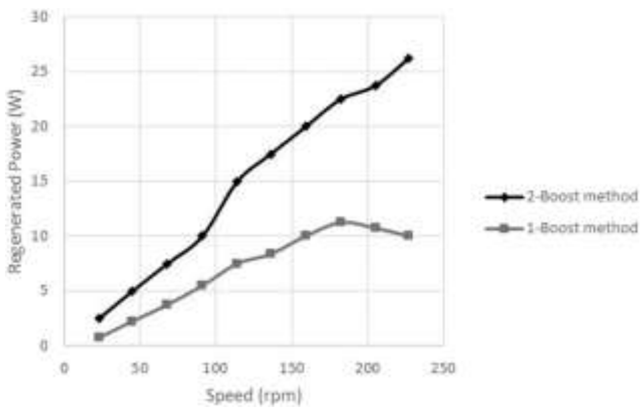

Fig.4: Simulation Result for the regenerated power in a single boost and two boost method.

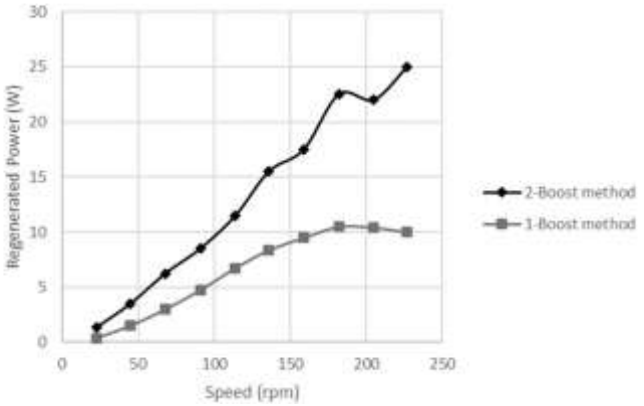

Fig.5: Experimental results for the regenerated power in the single-boost and two-boost methods

Both systems use the motor speed and input battery voltage to determine the duty cycles of the motor driver's low-side switches. The phase position indices must be determined by an additional timer when using the two-boost method. Based on the simulation and experimental findings, the two-boost approach provides the battery with more regenerated energy than the single-boost method does, by a factor of more than two. Additionally, the simulation findings demonstrate that, in the two-boost method, if the load torque is fixed, the speed varies linearly with no regard for the electrical torque. [10] According to simulation and experiment data, adopting the two-boost method for regenerative braking will enhance the amount of energy that is recovered and the effectiveness of the system.

IV. CONCLUSION:

This paper provides details on the workings and characteristics of regenerative braking systems. RBS, which is now only employed in a few number of EVs, can also be applied to traditional brakes and other motion control systems. Economic input can be obtained through the reduction of mechanical losses, and energy savings can be attained as a result of electrical energy that is recovered, when they are widely employed. These systems have a strong emphasis on energy recovery, energy consumption reduction, cost reduction, and clean air provision.

Later, testing in a real-world setting was done to observe the electrical energy consumption of a gasoline-fueled vehicle that had been converted to an electric vehicle. The average energy consumption of a car with regenerative braking is most likely between 143.94 and 146.58 Wh/km, according to testing. The range for a car without regenerative braking, however, would be between 153.30 and 156.07 Wh/km. Using regenerative braking technology on the modified car under consideration reduces electricity usage by 9.53 Wh/km or 6.16 percent, according to the statistics. This decrease in electricity consumption equates to an increase in vehicle efficiency. With the same amount of energy, increasing a vehicle's efficiency can increase its mileage. Additionally, the simulation findings demonstrate that, in the case of the two boost approach, while the load torque is constant, the speed varies linearly with no regard for the electrical torque. Using the two boost method for regenerative braking will increase the regenerative energy and system efficiency, according to simulation and testing data.

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