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Review of Regenerative Braking System for Electric Vehicle

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Abstract: ***Electric vehicles (EVs) are becoming increasingly popular due to their zero emission environmental friendliness and lower cost of operation compared to conventional vehicles running on fossil fuels like Petrol & Diesel. Fossil fuels are the depleting fuel resources, detrimental to the environment due to greenhouse gases they produce. Many countries have set the target to reduce use of fossil fuels run vehicles by 50% by 2050* and increase the use environment friendly vehicles such as Electric Vehicles, hybrid Vehicles and Hydrogen Fuel Cell operated Vehicles which would constitute a major part of vehicles on road.***
India has set the target of increasing the use of Electric Vehicles from existing 15% to 30% by 2050. However, one of the stumbling blocks in case of EVs is the range of the battery, which can be a limiting factor for long-distance travel. Apart from that, EV comparatively a new & emerging technology lacks the sufficient number of charging stations. On this background, the Regenerative Braking System (RBS) is an innovative promising technology that can help increase the range of electric vehicles by recovering the kinetic energy that would otherwise be lost during braking and deceleration.
This research paper explores the fundamentals of Regenerative Braking System (RBS) in electric vehicles (EVs), including types of RBS, primary components, working principle, advantages, limitations, challenges and future scope.
Keywords: Regenerative Braking System, RBS, Electric Vehicles, EVs, Fuel Efficiency, Green Vehicles.

I. INTRODUCTION

It's an era of carbon neutral vehicles. With increase in global warming due to greenhouse gases produced by conventional fossil fuel based vehicles and depleting conventional fuel resources there is an urgent need for the design, development & use of innovative carbon neutral, fuel efficient vehicles.
'Electric vehicles', also known as 'EV's, famously called the "green" vehicles are powered by one or more electric motors, use electricity stored in batteries instead of petrol or diesel as primary source of fuel. They are becoming increasingly popular due to their low environmental impact, zero carbon emissions, energy efficiency, and negligible operating costs.
Reducing the carbon footprint is the compelling task we face today as global warming is increasing at alarming rate and researchers and scientists are of an opinion of reducing the greenhouse gases will help reduce global warming.
Many countries have taken steps in reducing their dependence on depleting and costly fossil fuel resources and find new and innovative transporting technologies to address the global warming issue.
India has also taken steps in this regard by increasing the use of alternate means of transportation like Electric Vehicles or EVs. India has set the target of increasing use of EVs up to 30% from its current 15% share by 2030.
EVs come in various forms, including all-electric vehicles (AEVs), which rely entirely on battery power, Hybrid Electric Vehicles (HEV) and plug-in hybrid electric vehicles (PHEVs), which use both electric and petrol/diesel power. They can also vary in size, from two wheelers to small city compact cars to large SUVs, commercial transport buses used for public transport and trucks.
One of the primary advantages of EVs is that, they produce zero emissions while driving thus reducing air pollution and greenhouse gas emissions. They are also generally more efficient than traditional petrol/diesel -powered vehicles, as electric motors convert more than 75%-90% of the energy stored in the battery into motion, compared to about 20%-35% for petrol/diesel engines.
The use of Electric Vehicles (EVs) has increased significantly in the last decade and more specially so in the past few years since major automobile manufacturers are launching various electric car models and EV market is booming like never before.
One of the significant features of Electric Vehicles is called Regenerative Braking System or RBS.

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Regenerative Braking System is just like conventional hydraulic or pneumatic braking system primarily used for stopping / slowing down the vehicle in motion, however, the kinetic energy (K.E.) wasted in the form of heat while braking in case of conventional braking is instead utilized in RBS to recharge the batteries by means of a motor generator which uses friction principle to generate power which in turn recharges the batteries.
The RBS system is specially designed to recover the kinetic energy (KE) during deceleration and braking, which can be used to recharge the vehicle's battery.
EV being a comparatively a new & emerging technology, lacks the sufficient number of charging stations. On this background, the Regenerative Braking System (RBS) is an innovative promising technology that can help increase the range of electric vehicles by recovering the kinetic energy that would otherwise be lost during braking and deceleration. [1]

Various types of regenerative braking Systems currently in use:

A. Flywheel RBS

Flywheel RBS is a type of braking system used in hybrid and electric cars. The system works by capturing the energy that is generated when a vehicle decelerates or brakes, and then storing it in a flywheel for later use.
When brakes are applied, the kinetic energy (K.E.) of the vehicle is converted into electrical energy by a generator, which is then used to charge a flywheel. The flywheel, which is typically made of carbon fiber or steel, stores the energy in the form of rotational motion. When the vehicle is accelerated, the energy stored in the flywheel is used to supplement the power from the engine, giving the vehicle much needed power boost that reduces fuel consumption and emissions.
Flywheel RBS is an efficient and environmentally friendly technology that can significantly improve the fuel economy and performance of hybrid and electric vehicles. It is also relatively lightweight and compact, making it a good option for vehicles with limited space for additional components. [2] [3] [4] [5]

B. Electromagnetic-flywheel RBS

An electromagnetic-flywheel RBS combines the features of both the electromagnetic effect and flywheel RBS.
In this RBS system, the kinetic energy (K.E.) generated during braking is converted into electrical energy through the use of an electric motor acting as a generator. The generator produces electrical current by creating a magnetic field that interacts with the conductive material in the brake rotors. The electrical energy is then used to charge a flywheel instead of charging the batteries, which stores the energy in the form of rotational motion.
The advantage of an electromagnetic-flywheel RBS is that it provides the precise and efficient braking control of an electromagnetic system, while also harnessing the energy storage capabilities of a flywheel. Compared to short life span of Lithium ion batteries electric flywheel RBS is the more cost effective RBS system.
This system is particularly useful in HEVs and EVs, where energy efficiency is of a key importance.
However, electromagnetic-flywheel RBS is generally more complex and expensive than other types of regenerative braking systems, and requires careful engineering to optimize performance and minimize weight and space requirements. [2] [3] [4] [5]

C. Spring loaded RBS

The spring-loaded RBS is generally used in heavy-duty vehicles such as buses and trucks and also in bicycles and wheelchairs.
In this system, when the brakes are applied, the kinetic energy (K.E.) generated during braking is used to compress a set of springs. The compressed springs store the energy as potential energy (P.E.), which is used to supplement the power from the engine.
When the vehicle accelerates, the compressed springs are released, and the potential energy (P.E.) is converted into kinetic energy (K.E.) to help propel the vehicle. The energy released from the springs is captured by an electric generator, which converts it into electrical energy to charge the vehicle's battery and/or power other electrical components.
The spring-loaded RBS is a relatively simple and cost-effective and technology which improves the fuel economy and performance of heavy-duty vehicles.
However, it is not as efficient as other types of RBS, and the capacity of the springs limits the stored energy.
In case of bicycles, a spring is wound around a cone during braking effort to store the energy. This energy can then be utilized while going uphill or over rough terrain. [2] [3] [4] [5]

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D. Hydraulic RBS

The Hydraulic RBS is particularly used in HEVs and EVs use hydraulic pressure to convert kinetic energy (K.E.) into electrical energy.

In this system, when the brakes are applied, the hydraulic pressure generated by the braking action is used to power a hydraulic pump. The pump then converts the kinetic energy (K.E.) into hydraulic pressure, which is used to turn a hydraulic motor which acts as a generator. The generator produces electrical current, which is then used to charge the vehicle's battery or power other electrical components.

The advantage of hydraulic RBS is that it can generate a high level of braking force with minimal mechanical wear, and can also recover a significant amount of energy during braking. This can help to improve the fuel economy and reduce the emissions of hybrid and electric vehicles.

Hydraulic RBS has the longest energy storage capability compared to other RBS systems, as compressed fluid does not dissipate energy over time. However, compressing gas with a pump is a comparatively slow process and severely limits the power of the hydraulic RBS.

Also, it is more complex and expensive than other types of RBS, and may require additional components such as hydraulic fluid reservoirs and pumps. [2] [3] [4] [5]

E. Electromagnetic RBS:

Electromagnetic RBS which is our area of interest for this research paper, is primarily used in HEVs and EV cars that works by converting kinetic energy (K.E.) into electrical energy through the use of electromagnetic force.

When brakes are applied, the kinetic energy (K.E.) of the vehicle is converted into electrical energy by an electric motor acting as a generator. The generator creates a magnetic field, which interacts with the conductive material in the brake rotors, producing electrical current. This electrical current is then used to charge the vehicle's battery or to power other electrical components.

The advantage of electromagnetic RBS is that it allows for a high level of control and precision over the braking force applied, enabling the vehicle to be brought to a smooth stop.

It is also an efficient and environmentally friendly technology that can significantly improve the fuel economy and performance of HEVs and EVs. It is complex and expensive compared to other regenerative braking systems. [2] [3] [4] [5]

Currently, the most commonly used type of RBS is the electromagnetic RBS which is our area of interest for this Research Paper.

II. LITERATURE REVIEW

1) *According to Mr. S. K. Patil (Vol-4 Issue-4 2018 IJARIIE-ISSN(O)-2395-4396 8997 www.ijariie.com 1007); emphasizes the need of specific technology that can recover the energy produced during the braking effort, which usually gets wasted.* Therefore, in case of automobile vehicles one of the useful technology is the RBS. When driver applies the brakes vehicle comes to a halt and the K.E. gets wasted due to resultant friction and dissipation of heat. Using RBS in automobiles enables to recover the K.E. of the vehicle up to certain extent which is generally lost during the braking effort. In this paper the author discusses two methods to utilize the K.E. which is usually wasted by converting it into either electrical energy or into mechanical energy. RBS system can convert the K.E. into electrical energy with help of electric motor generator. And it can also convert the K.E. into mechanical energy, which is supplied to the vehicle whenever it is needed, with the help of a flywheel energy storing mechanism.
2) Authors Liang Li Xianyao Ping, Jialei Shi Xiangyu Wang, Xiuheng Wu in their Research paper named “Energy recovery strategy for regenerative braking system of intelligent four-wheel independent drive electric vehicles” (DOI: 10.1049/itr2.12009) discuss the series of Regenerative Braking Systems with innovative control architecture which can effectively improve the energy recovery. Although this Research paper explore the RBS beyond our area of interest it provides insights about the latest developments happening in the RBS segment which helps us to understand the future scope of RBS system in different vehicles like four wheel independent EV drives.
3) Author Jarrad Cody’s Research Paper focuseson the RBS in an EV. Here, the RBS system employs the Independent Switching strategy is considered to control the current flow during different stages of the cruising profile of EV. The proposed experimental work is in progress to fit with the commercially available Bladeless DC motor and power supply together with the controller developed in-house.

4) Authors Mr. Shivam Sharma, Ashish Narayan Singh, Rahul Yadav, Abhinav Jha, Kumar Vanshaj, Md. Fahim in their Research paper named "Regenerative Braking System" published in "Volume: 3 | Issue: 4 | May-Jun 2019 www.ijtsrd.com e-ISSN: 2456 – 6470" explore the fundamentals of Regenerative Braking System about the RBS model they have developed for their Project Work which gave us insights about the overview of RBS.

III. NEED OF REGENERATIVE BRAKING SYSTEM

The need for regenerative braking systems arises from the fact that conventional braking systems in vehicles convert kinetic energy into heat, which is then dissipated into the atmosphere. This results in a significant amount of energy being wasted during braking, which can reduce the overall efficiency of the vehicle.

Regenerative braking systems address this issue by capturing the kinetic energy that is lost during braking and converting it into electrical energy that can be stored in the vehicle's battery or used to power other vehicle systems. This captured energy can then be used to power the vehicle during acceleration, reducing the amount of energy required from the battery or other energy storage device.

Another point is that EV a comparatively new and emerging technology, lacks the sufficient number of charging stations so it's an imperative to find ways to prolong the use of batteries of EV, where Regenerative Braking System comes in. [1] [6] [7]

IV. COMPONENTS OF REGENERATIVE BRAKING SYSTEM

The Regenerative Braking System in an electric vehicle includes several components that work together to recover and store energy.

These components include:

1) *Electric Motor:* The electric motor function as a generator, converting kinetic energy into electrical energy during braking effort.
2) *Power Electronics:* The power electronics in an EV control the flow of electrical energy between the battery, electric motor, and regenerative braking system.
3) *Battery:* The recovered energy during braking is stored in the battery for later use.
4) *Brake System:* The brake system in an EV is designed to work with the regenerative braking system, allowing for efficient energy recovery.

V. WORKING PRINCIPLE

The Regenerative Braking Systems work on the principles of energy conservation and electromagnetic induction, as governed by the laws of thermodynamics and electromagnetism.

The Law of Conservation of Energy, also known as the First Law of Thermodynamics, which states that, "energy can neither be created nor destroyed, but it can only be transformed from one form to another".

During regenerative braking, the kinetic energy of the moving vehicle is converted into electrical energy by means of a motor generator, which is stored for later use. This conversion process ensures that the total amount of energy in the system remains constant.

The Regenerative Braking System also utilizes the principles of Electromagnetic Induction, governed by Faraday's Laws.

Faraday's First law states that whenever there is a change in the magnetic field through a closed loop of wire, an electromotive force (EMF) is induced in the wire. The magnitude of the induced EMF is proportional to the rate of change of the magnetic flux through the loop, and the direction of the induced EMF is such that it opposes the change in magnetic flux that produced it.

Faraday's second law, also known as the law of electromagnetic induction, states that the magnitude of the EMF induced in a circuit is equal to the rate of change of the magnetic flux through the circuit. In other words, the induced EMF is directly proportional to the rate at which the magnetic field changes and the number of turns in the circuit.

Mathematically,

$$EMF = -d\Phi/dt$$

where EMF is the induced electromotive force, Φ is the magnetic flux through the circuit, and $d\Phi/dt$ is the rate of change of the magnetic flux over time. The negative sign indicates that the induced EMF opposes the change in magnetic flux that produced it.

when a conductor is moved through a magnetic field, a voltage is induced in the conductor.
In the case of regenerative braking, the rotating wheels of the vehicle act as the conductor, and the magnetic field is generated by the electric motor. When the brakes are applied, the electric motor is reversed, and the energy generated by the rotating wheels is converted into electrical energy that is stored in the battery or capacitor. [1]

VI. ADVANTAGES OF RBS

The regenerative braking system in electric vehicles offers several advantages, including:

1) *Increased range*: The recovered energy during braking can be used to recharge the battery, increasing the range of the vehicle which is an important feature when there is a scarcity of charging stations.
2) *Reduced brake wear:* The regenerative braking system can reduce brake wear, as the electric motor is used to slow down the vehicle, reducing the need for traditional brakes. Thus improving the life of brakes.
3) Improved fuel efficiency: By recovering energy that would otherwise be lost during braking, the regenerative braking system can improve the overall fuel efficiency of the vehicle.

VII. LIMITATIONS & CHALLENGES

Despite the many advantages of the regenerative braking system, there are also some challenges that need to be addressed, including:

1) *Limited energy recovery:* The regenerative braking system can only recover a certain amount of energy during braking, and the amount of energy that can be recovered depends on several factors, including the speed of the vehicle and the state of charge of the battery.
2) *Cost:* The regenerative braking system can add to the overall cost of the vehicle, as it requires additional components, such as power electronics and a larger battery.
3) *Weight:* RBS in its current form increases the weight of the vehicle. This is detrimental in case of small, compact and light weight vehicles.

VIII. FUTURE SCOPE

Although, Regenerative Braking System is at its primitive stage and we still need the conventional braking system along with RBS, the future scope for RBS is quite promising.
There are many avenues to explore in the modification in RBS. As the demand for EVs is increasing, Automakers are investing heavily in the development of new and more efficient Regenerative Braking Systems.

Some of the areas of focus for future development include:

1) Improving the efficiency of Regenerative Braking Systems: Engineers are working on developing more efficient systems that can capture a greater percentage of the energy lost during braking by eliminating the technological constraints.
2) Integrating regenerative braking with other energy recovery technologies: Some researchers are exploring the potential for integrating regenerative braking with other energy recovery technologies, such as solar panels and kinetic energy recovery systems, to further reduce energy consumption.
3) Miniaturizing the regenerative braking system: Since RBS in its current form increases the weight of vehicle, efforts are being made to miniaturize the regenerative braking system to make it more compact and lightweight, which would make it more suitable for use in smaller vehicles and other applications.
4) Developing new materials for regenerative braking systems: Researchers are also exploring the use of new materials, such as carbon fiber, to create regenerative braking systems that are lighter, more durable, and more efficient.
5) Continuous Power generation: Continuous Power generation by means of a flywheel mechanism associated with Regenerative Braking System is one of the promising ways to generate the power while the vehicle is running at high speed. When a vehicle is running at high speed and RBS is applied a very high amount of torque is transferred. While theoretically most of the energy should be utilized to regenerate power, technological constraints limit the utilization of braking energy. Along with the regenerative braking effect, this high amount of torque can be utilized to run a flywheel which can recharge the battery by means of a dynamo.

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IX. CONCLUSIONS

The regenerative braking system (RBS) is an emerging innovative technology that can help increase the range of electric vehicles by recovering kinetic energy K.E. during braking effort and deceleration.

While there are some challenges associated with the system, the advantages are significant, including increased range of the vehicle battery, reduced brake wear, and improved overall fuel efficiency. As electric vehicles becoming more popular, and major automakers are bringing in new and compact EVs, the regenerative braking system will continue to play an important role in improving their overall performance and efficiency.

This paper presented an overview on fundamentals of Regenerative Braking System (RBS) in electric vehicles (EVs), including types of RBS, primary components, working principle, advantages, limitations, challenges and future scope. [8] [9]

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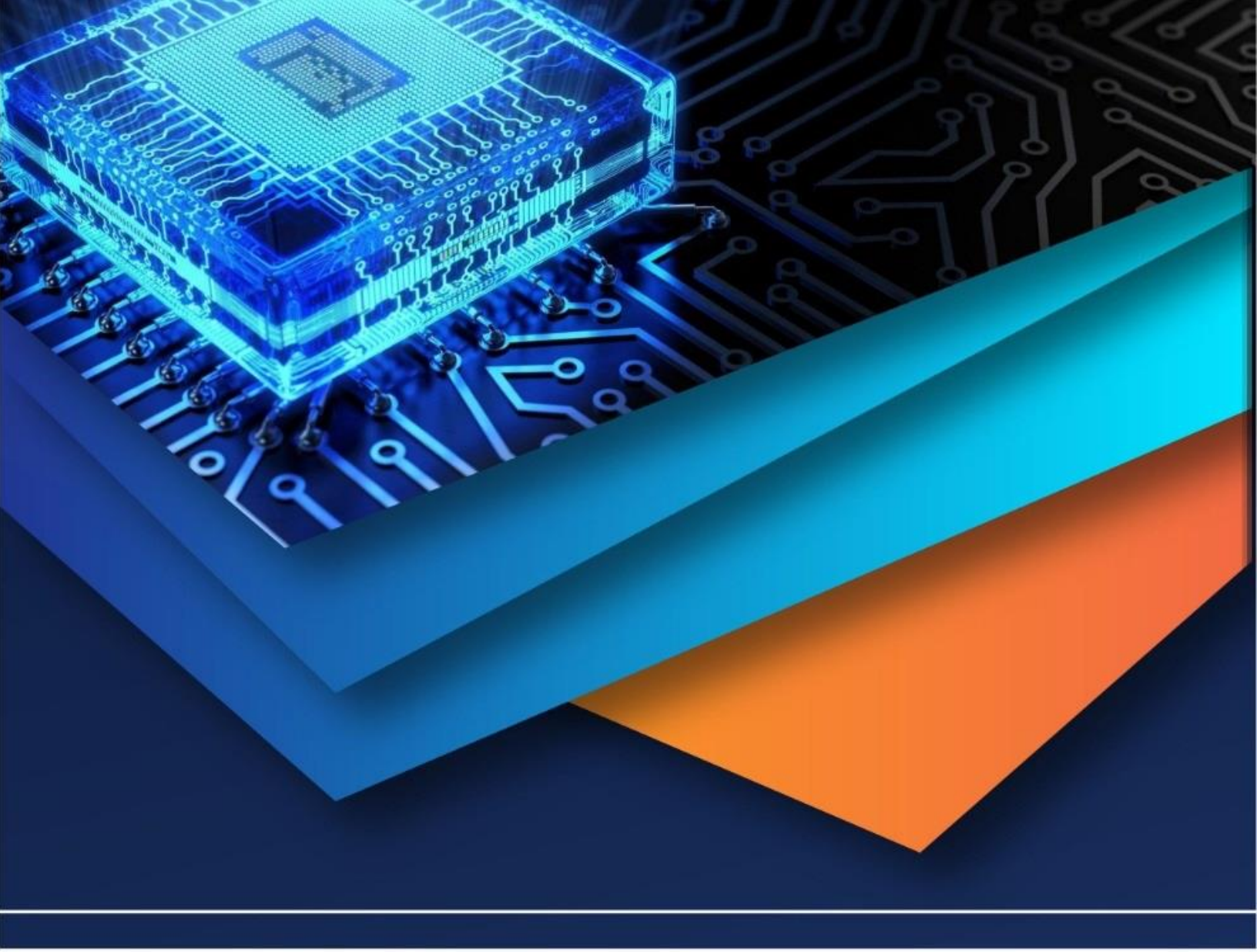
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