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## International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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# Regenerative Braking System in Electrical Vehicles

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**ABSTRACT:** The regenerative braking system in electric vehicles is an energy-efficient technology designed to recover kinetic energy during braking and convert it into electrical energy for battery storage. In conventional braking systems, this kinetic energy is lost as heat due to friction, leading to energy wastage and reduced overall efficiency. The proposed system utilizes a DC motor that operates in dual mode, functioning as both a motor during driving and a generator during braking. The generated electrical energy is processed using power electronic components such as rectifiers, MOSFETs, and DC-DC converters to ensure proper conditioning before being stored in the battery. This system improves overall vehicle efficiency, extends driving range, reduces mechanical wear on braking components, and lowers maintenance costs. By optimizing energy recovery and utilization, the regenerative braking system contributes to the development of sustainable and environmentally friendly electric vehicle technology.

**KEYWORDS:** Regenerative Braking, Electric Vehicles, Energy Recovery, DC Motor, Power Electronics, Battery Charging, Energy Efficiency, Sustainable Transportation, MOSFET Control, Dual Mode Operation.

## I. INTRODUCTION

Electric vehicles (EVs) have emerged as a promising solution to address the growing concerns of environmental pollution, fossil fuel depletion, and energy efficiency in the transportation sector. Unlike conventional internal combustion engine vehicles, EVs operate using electrical energy stored in batteries, which powers an electric motor for vehicle movement. While EV technology offers several advantages such as zero tailpipe emissions and reduced operating costs, improving overall energy efficiency remains a key challenge. One of the major areas of energy loss in EVs occurs during braking, where kinetic energy is typically dissipated as heat in traditional friction-based braking systems.

In conventional braking systems, the vehicle's kinetic energy is converted into thermal energy through friction between brake pads and discs or drums. Although this method is reliable and widely used, it results in significant energy wastage and increased wear and tear of mechanical components. This not only reduces system efficiency but also increases maintenance costs and shortens the lifespan of braking parts. These limitations highlight the need for a more efficient braking approach that can conserve energy while maintaining vehicle safety and performance.

To overcome these challenges, regenerative braking systems have been introduced, especially in electric and hybrid vehicles. The regenerative braking system works on the principle of energy recovery, where the electric motor functions as a generator during braking. Instead of wasting kinetic energy, it is converted into electrical energy and stored back into the battery. This process improves overall energy utilization and extends the driving range of the vehicle, making EVs more efficient and practical for everyday use.

The system integrates mechanical, electrical, and electronic components to achieve controlled energy conversion and storage. Power electronic devices such as MOSFETs, rectifiers, and DC-DC converters are used to regulate and condition the recovered energy before it is fed back into the battery. Additionally, a control mechanism ensures smooth switching between driving and braking modes, allowing the system to operate efficiently under different driving conditions without affecting vehicle stability.



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Overall, the regenerative braking system plays a crucial role in enhancing the performance and sustainability of electric vehicles. By recovering energy that would otherwise be lost, it not only improves energy efficiency but also reduces mechanical wear and environmental impact. This technology represents an important step toward the development of smarter, greener, and more energy-efficient transportation systems for the future.

### II. AIM AND OBJECTIVES

#### Aim:

The main aim of the regenerative braking system in electric vehicles is to design and develop an efficient energy recovery mechanism that converts the kinetic energy of the vehicle during braking into electrical energy, which can be stored back in the battery system. This aims to improve overall energy efficiency, extend driving range, and reduce energy wastage in conventional braking systems.

#### Objectives:

- To design a system that effectively converts kinetic energy into electrical energy during braking instead of dissipating it as heat.
- To improve the overall energy efficiency of electric vehicles by recovering and reusing braking energy.
- To implement a dual-mode operation of the electric motor, enabling it to function as both a motor during driving and a generator during braking.
- To develop a control mechanism using electronic components such as MOSFETs and relays for smooth switching between driving and regenerative braking modes.
- To ensure proper power conditioning using rectifiers, capacitors, and DC-DC converters for safe and efficient battery charging.
- To reduce the wear and tear of mechanical braking components, thereby increasing their lifespan and reducing maintenance cost.
- To enhance the driving range and performance of electric vehicles by utilizing recovered energy effectively.

### III. LITERATURE SURVEY

Regenerative braking systems are widely recognized as an effective solution for improving the energy efficiency of electric and hybrid vehicles. Unlike conventional braking systems, which dissipate kinetic energy as heat through friction, regenerative braking recovers this energy and converts it into electrical energy for reuse.

Electric motors enable this process by operating in both motoring and generating modes, forming the core principle of energy recovery. Power electronic components such as rectifiers, DC-DC converters, and MOSFETs are essential for regulating the generated energy to ensure efficient and safe battery charging. Control strategies play a crucial role in managing the transition between regenerative and mechanical braking, as regenerative braking alone is insufficient at low speeds or during emergencies.

Additionally, proper battery management is required to prevent overvoltage, thermal stress, and degradation, thereby improving battery lifespan. The system also reduces wear on mechanical braking components, lowering maintenance costs while retaining conventional brakes for safety. Overall, regenerative braking significantly enhances vehicle efficiency and sustainability, despite challenges such as energy losses, control complexity, and battery limitations.



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### IV. RESOURCES / COMPONENTS USED

Sr. No.	Component Name	Specification / Description	Function in System
1	Battery	48V / 12Ah Lithium-ion	Supplies power to DC motor during driving and stores regenerated energy during braking.
2	DC Motor	500W, 24–48V	Converts electrical energy to mechanical energy (driving mode) and vice versa (generator mode).
3	Controller Circuit	MOSFET-based PWM Control	Manages motor operation, throttle input, and switching between drive and regenerative modes.
4	Rectifier	Bridge Diode Configuration	Converts AC output from generator mode to DC for battery charging.
5	Filter Capacitors	470µF / 100V	Smoothens DC voltage by reducing ripple after rectification.
6	DC-DC Converter	Step-down type, 48V → 12V	Regulates voltage for safe battery charging and auxiliary circuits.
7	Throttle Sensor	Hall-effect type	Controls motor speed during driving mode.
8	Brake Switch	Mechanical / Hall Sensor	Detects braking action and triggers regenerative mode.
9	Monitoring Unit	LCD / IoT-based	Displays system parameters such as voltage, current, and battery status.
10	Wheels & Shaft Assembly	Coupled with Motor	Provides mechanical motion and kinetic energy recovery during braking.

### V. METHODOLOGY

The proposed regenerative braking system is developed through a structured, multi-phase approach emphasizing energy flow design, control logic implementation, and conversion efficiency. The methodology ensures seamless transition between driving and braking modes while maintaining system stability and energy recovery efficiency.

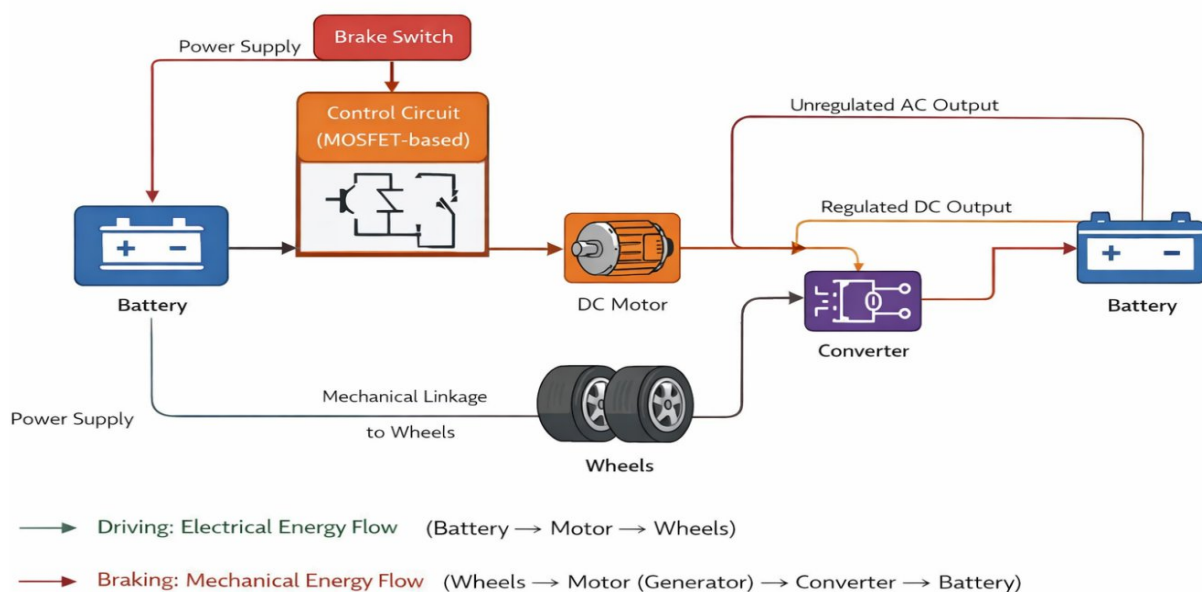
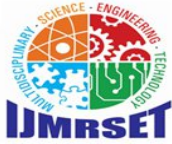


Fig.5.1 System Architecture of Regenerative Braking System.



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### A. Energy Flow Design

The initial stage involves designing the basic energy flow structure of the system. The electric vehicle operates in two distinct modes — **Driving Mode** and **Braking Mode**. In **Driving Mode**, electrical energy stored in the battery is supplied to the DC motor through a MOSFET-based control circuit. The motor converts electrical energy into mechanical energy, driving the wheels. Speed and torque are regulated using a potentiometer-based throttle input, ensuring smooth acceleration and optimal power usage.

### B. Control Mechanism Implementation

The second stage focuses on the control logic that governs the transition between driving and regenerative braking modes. The control circuit uses **MOSFETs, relays, and brake switch signals** to manage switching operations. When the brake is applied, the circuit disconnects the motor from the battery and reconfigures the connections to enable reverse energy flow. This ensures the motor safely operates as a generator without disturbing system stability or causing electrical transients.

### C. Energy Conversion Process

The third stage deals with the conversion and conditioning of the recovered energy. During braking, the kinetic energy of the rotating wheels is transmitted back to the DC motor, which functions as a generator. According to electromagnetic induction principles, this mechanical motion is converted into electrical energy. However, the generated output is unregulated and may contain AC components or voltage fluctuations, requiring further processing before it can be stored.

### D. Power Conditioning and Storage

In this stage, the generated electrical energy is processed for safe storage. The unregulated AC output from the generator is first converted into DC using a **bridge rectifier**. A **filter capacitor** smoothens the DC voltage by reducing ripple. The regulated DC output is then passed through a **DC-DC converter**, which ensures proper voltage levels for battery charging. This step is crucial for maintaining battery health and maximizing energy recovery efficiency.

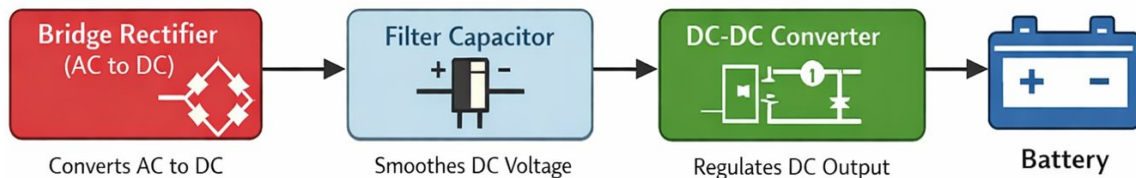


Fig.5.1(a) System Architecture of Regenerative Braking System.

### E. System Testing and Validation

The final stage involves testing and validating the system performance under various operating conditions. Parameters such as **voltage, current, braking efficiency, and energy recovery rate** are monitored using sensors and a display unit. The system is evaluated for smooth transition between modes, minimal energy loss, and stable operation. Experimental results confirm that the regenerative braking system effectively recovers a significant portion of kinetic energy, thereby improving overall vehicle efficiency.

## VI. FLOWCHART

The system initiates by performing the initialization of all integrated modules. Subsequently, it executes continuous monitoring of the vibration sensor to detect abnormal events. Upon identification of an accident, the system acquires the corresponding GPS coordinates, which are simultaneously rendered on the LCD display for real-time visualization. Furthermore, an emergency alert containing the precise location details is transmitted via the GSM communication module to designated recipients, thereby ensuring timely assistance.



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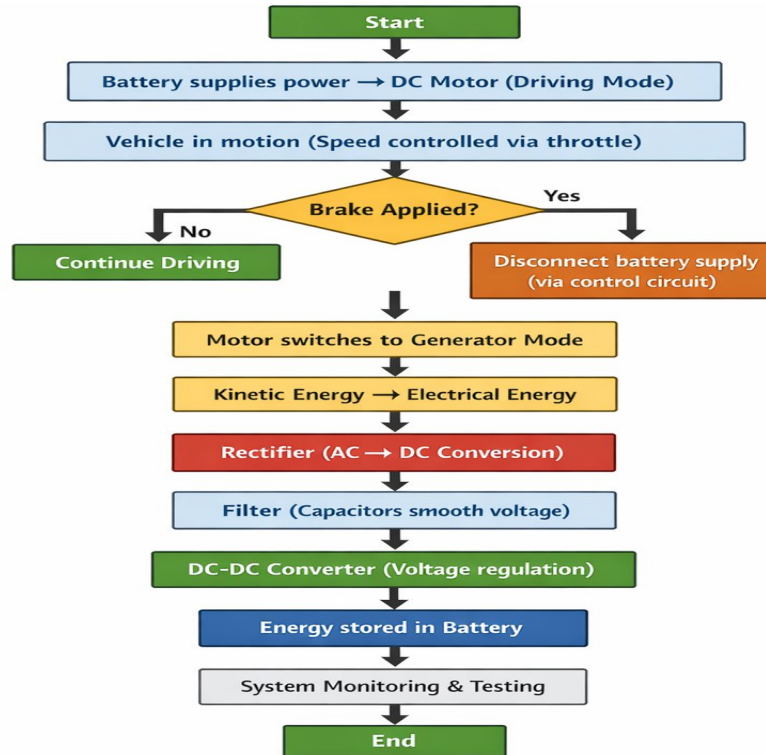


Fig.6.1. Flowchart of the Regenerative Braking proposed System.

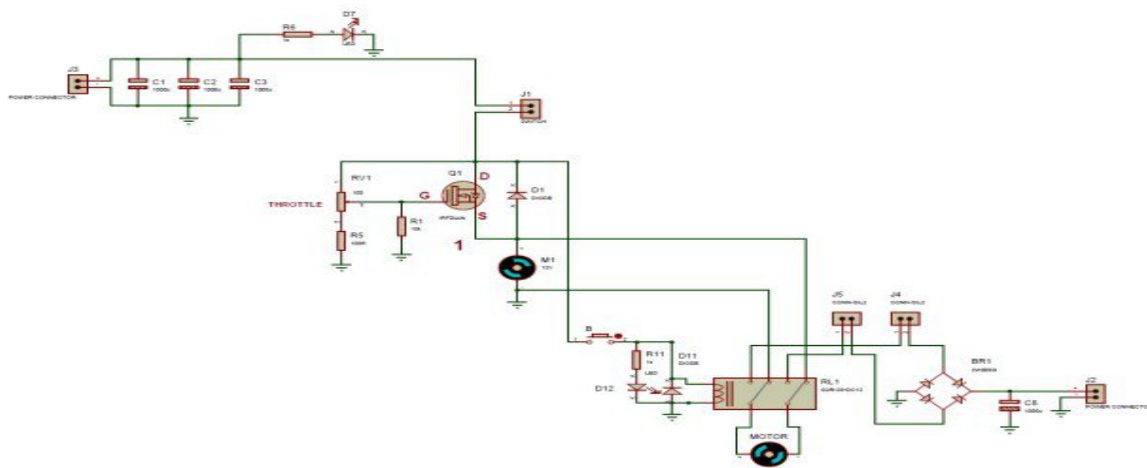
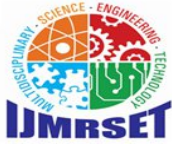


Fig.6.1. Circuit diagram of the Regenerative Braking proposed System.

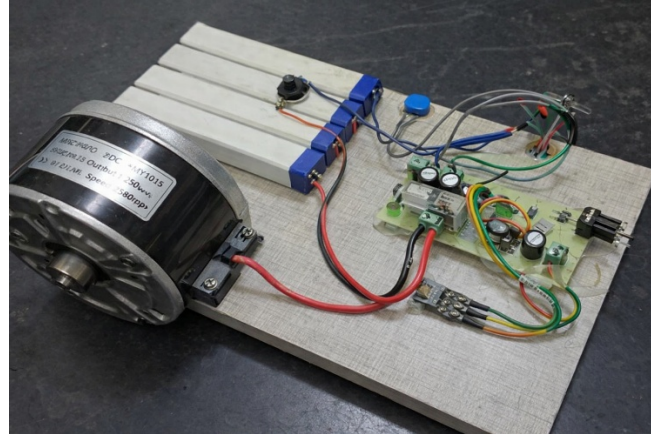
### VII. RESULT AND DISCUSSION

The implementation of the regenerative braking system in electric vehicles demonstrated successful energy recovery during braking conditions. It was observed that when the brake was applied, the DC motor effectively switched from motoring mode to generating mode, confirming proper dual-mode operation. In this state, the kinetic energy of the rotating wheels was successfully converted into electrical energy, validating the working principle of regenerative braking.



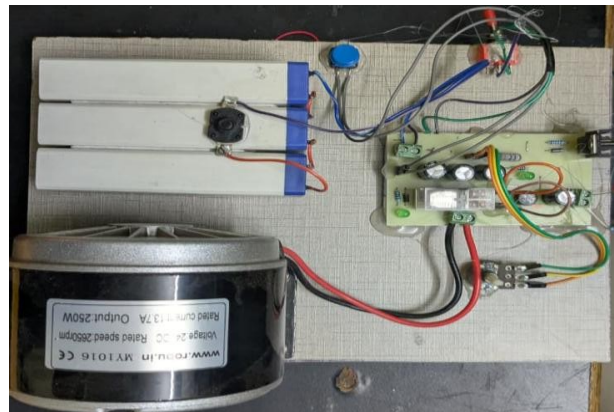
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*ig. 7.1(a) Model Setup*

The generated electrical energy was processed through the bridge rectifier, filter capacitors, and DC-DC converter, ensuring a stable and regulated output. This conditioned energy was successfully stored back into the battery, resulting in partial recharging during braking cycles. The system exhibited measurable improvement in battery voltage during repeated braking operations, indicating effective energy recovery.



*Fig. 7.1(b) Model Setup*

Experimental observations revealed a noticeable improvement in overall energy efficiency compared to conventional braking systems, where kinetic energy is completely dissipated as heat. In the proposed system, a portion of this energy was reused, leading to better energy utilization and reduced dependency on external charging sources. Additionally, the load on friction braking components was reduced, resulting in lower wear and improved mechanical durability.

The control system, comprising MOSFETs, relays, and brake switch circuitry, performed efficiently by ensuring smooth and accurate switching between driving and braking modes. No significant delay or instability was observed during operation, confirming the reliability of the switching mechanism. Overall, the system successfully achieved its objectives of energy recovery, efficiency improvement, and partial battery charging, validating the feasibility of regenerative braking in electric vehicle applications.

### VIII. CONCLUSION AND FUTURE SCOPE

The regenerative braking system for electric vehicles successfully demonstrates an effective method of recovering kinetic energy that is otherwise wasted in conventional braking systems. By converting this energy into electrical form and storing it in the battery, the system significantly improves the overall energy efficiency of electric vehicles. This



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makes the technology highly beneficial for extending driving range and optimizing energy usage. The integration of electrical, electronic, and control components such as DC motors, MOSFETs, relays, rectifiers, and converters ensure smooth and reliable operation. The dual functionality of the motor as both a drive unit and a generator forms the core of the system, enabling efficient energy conversion during braking conditions.

Although the system does not recover all the kinetic energy due to unavoidable losses in conversion and control stages, the recovered energy is still substantial enough to improve performance and reduce energy wastage. It also reduces dependency on mechanical braking systems, thereby lowering maintenance costs and increasing component lifespan.

In conclusion, the regenerative braking system is a highly effective and practical solution for modern electric vehicles. It enhances energy efficiency, supports sustainable transportation, and contributes to environmental conservation. With further advancements in power electronics, battery technology, and control systems, the performance and efficiency of regenerative braking systems are expected to improve even further in future applications.

### Future Scope

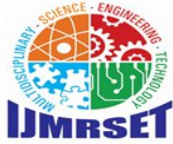
The regenerative braking system presents significant opportunities for further research and development. Future work can focus on the following areas:

- **Advanced Energy Storage:** Integration of supercapacitors and next-generation battery chemistries (such as solid-state or lithium-sulfur) to enhance energy recovery and storage efficiency.
- **Smart Control Systems:** Implementation of AI-based predictive algorithms for optimized switching between driving and braking modes, ensuring maximum energy utilization.
- **Enhanced Power Electronics:** Development of high-efficiency converters and low-loss semiconductor devices to minimize energy losses during conversion and conditioning.
- **Vehicle Integration:** Expansion of regenerative braking systems into hybrid and heavy-duty vehicles, improving sustainability across diverse transportation sectors.
- **IoT and Monitoring:** Incorporation of IoT-enabled monitoring units for real-time performance tracking, predictive maintenance, and adaptive control.

Overall, advancements in **power electronics, control strategies, and energy storage technologies** are expected to significantly improve the performance, efficiency, and reliability of regenerative braking systems in future electric vehicle applications.

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