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Optimized Power Distribution in Regenerative Braking with Smart Relay Control

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Abstract

This project presents an enhanced regenerative braking system for electric vehicles (EVs) utilizing a dual-battery energy storage mechanism with intelligent relay control to maximize energy recovery efficiency. The system captures kinetic energy during braking, converts it into electrical energy, and optimally distributes it between two batteries using an automated relay system that prioritizes the battery with lower charge levels. Key components include a PIC microcontroller for control, a boost converter for voltage regulation, sensors for system monitoring, and an LCD for real-time feedback. By improving battery balancing and energy management, the system enhances EV range and efficiency, contributing to sustainable and advanced green transportation technologies.

Keywords: *Regenerative braking, EVs, dual-battery, relay control, energy recovery, PIC microcontroller, boost converter, battery balancing, green transportation.*

1. Introduction

With the growing demand for energy-efficient and environmentally friendly transportation, regenerative braking systems have become a key technology in electric and hybrid vehicles. Traditional braking systems rely on friction to slow down the vehicle, converting kinetic energy into heat, which is then wasted. This not only enhances the overall energy efficiency of the vehicle but also extends its range by reusing energy that would otherwise be lost [1][2]. This project focuses on designing a regenerative braking system that captures energy during braking and stores it in the vehicle's battery. The stored energy is then used to power the vehicle, reducing the need for external charging and improving overall fuel efficiency. A key feature of this system is the use of a PIC microcontroller to monitor and control the process. The microcontroller continuously reads the battery voltage and automatically switches between charging the battery and powering the motor based on the battery's charge level. This intelligent control ensures the system operates efficiently, optimizing energy flow and enhancing vehicle performance. This project aims to contribute to the development of more sustainable transportation solutions by improving energy recovery, reducing emissions, and extending the life of vehicle components [3].

2. Hardware Components

Equipment Name

- Regulated Power Supply.
- PIC Microcontroller.
- 12v-2amp Li-Ion Battery.
- 2 Voltage Sensors.
- DC Motor
- Wheel.
- Uni-Directional Current Flow.
- Boost Converter.
- LCD display.
- Relays.
- Crystal Oscillator.

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- Reset.
- LED Indicators.
- Stepdown transformer

2.1 Regulated Power Supply

Power supply is a supply of electrical power. A device or system that supplies electrical or other types of energy to an output load or group of loads is called a power supply unit or PSU. The term is most generally applied to electrical energy supplies, less frequently to mechanical ones, and infrequently to others. A power force may include a power distribution system as well as primary or secondary sources of energy similar as Conversion of one form of electrical power to another asked form and voltage, generally involving converting AC line voltage to a well- regulated lower- voltage DC for electronic bias. Low voltage, low power DC power force units are generally integrated with the bias they supply, similar as computers and ménage electronics. Figure 1 shows Regulated Power Supply [4].

- Batteries.
- Solar power.

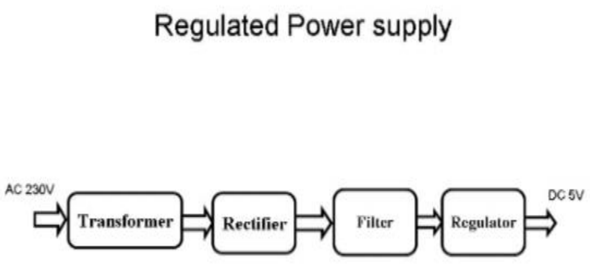

Figure 1 Regulated Power Supply

2.2 Pic Microcontroller

With a CPU, memory, and peripherals, a microcontroller can be regarded as an embedded system that operates independently. PIC16F72 is an 8-bit microcontroller based on CMOS FLASH that is compatible with PIC16C72/72A and PIC16F872 devices. Self-programming, an ICD, two comparators, five channels of 8-bit Analog-to-Digital (A/D) conversion, two capture/compare/PWM functions, a synchronous serial port that may be set up as a 2-wire I2C bus or a 3-wire SPI bus, a USART, and a parallel slave port are among its features. It also has 200 ns instruction execution.

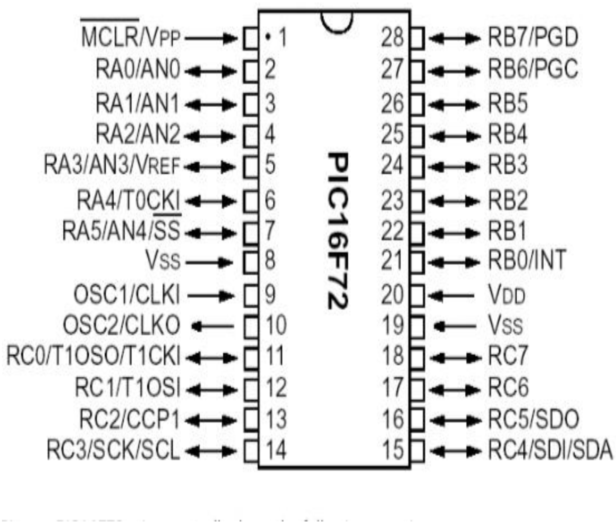

Figure 2 Pic Microcontroller

2.3 12V-2AlMP LI-ION Battery

A 12V-2A Li-ion battery refers to a lithium-ion (Li-ion) rechargeable battery that operates at a nominal voltage of 12 volts and can provide a maximum current of 2 amperes. 12V 2A Li-ion battery stores energy through a reversible electrochemical reaction and releases it when needed, with the ability to supply up to 2 amps of current to connected device.

2.4 Voltage Sensor

A voltage detector is a device that detects and measures the electrical voltage in a circuit or across a load. It plays a critical role in monitoring the voltage levels of electrical systems and ensuring that they operate within safe or optimal ranges. Figure 3 shows Voltage Sensor [5].

Figure 3 Voltage Sensor

2.5 DC Motor

A DC motor as a generator works based on the principle of electromagnetic induction, where mechanical energy (such as the movement of a vehicle) is converted into electrical energy.

When a DC motor is used as a generator, the

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following process happens: **Motor Conversion To Generator Mode:** Normally, a DC motor uses electrical energy to produce mechanical motion, but when it is turned or rotated by an external force (like the vehicles wheels or during braking), it works in reverse. The mechanical energy from the movement of the vehicle's wheels is used to turn the motor. **Generation of Electrical Energy:** As the motor's rotor spins, the magnetic field inside the motor causes the motion of the armature (rotating part of the motor). This motion induces a flow of electric current in the armature windings, converting the mechanical energy into electrical energy. **Current Flow:** The induced electrical current flows out of the motor and can be directed to a battery or capacitor to be stored for later use. The voltage generated depends on the speed at which the motor is turning. Higher speeds generally produce higher voltages. **Braking and Energy Recovery:** In the context of regenerative braking, when the vehicle decelerates, the wheels of the vehicle turn the motor, converting the vehicles kinetic energy into electrical energy. This energy is then stored in the battery, which can later be used to power the vehicle again. In summary, when a DC motor operates as a generator, it converts the vehicles kinetic energy (from braking or coasting) into electrical energy, reducing energy wastage and improving the vehicle's overall energy efficiency. This makes it an essential component of regenerative braking systems in electric and hybrid vehicles. Figure 4 shows DC Motor.

Figure 4 DC Motor

2.6 Wheel

A wheel is a circular component that is designed to rotate around an axis, typically used to facilitate motion, reduce friction, and carry loads in various mechanical systems. The invention of the wheel is one of the most significant achievements in human history, revolutionizing transportation, machinery, and countless other aspects of daily life. The wheel is an essential and versatile component in mechanical engineering and transportation [6]. By reducing friction and enabling smoother movement, it has played a central role in the development of human society. Whether in vehicles, machinery, or recreational devices, wheels continue to be indispensable in both everyday life and specialized industries. Figure 5 shows Wheel.

Figure 5 Wheel

2.7 UNI Directional Current Flow

Unidirectional current flow refers to the flow of electric charge (current) in only one direction through a conductor or circuit. This is in contrast to bidirectional current flow, where the current can flow in both directions, typically seen in alternating current (AC) systems. In a unidirectional current flow setup, the current always flows in a consistent direction from the power source (like a battery or a DC power supply) through the circuit and back.

2.8 Boost Converter

A DC-DC converter that steps up (increases) the input voltage to a higher output voltage is called a boost converter. It is a type of switching regulator that uses an inductor, a switch (typically a transistor), a diode, and a capacitor to efficiently convert a lower input voltage to a higher output voltage. Boost converters are widely used in various electronic devices where a higher voltage is required from a lower-voltage source, such as in battery-powered devices, renewable energy systems, and power management circuits. Figure 6 shows Boost Converter.

Figure 6 Boost Converter

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2.1 LCD

An LCD display is among the most often connected devices to a micro controller. 16x2 and 20x2 LCDs are among the most widely used LCDs that are linked to the numerous microcontrollers. This means 16 characters per line by 2 lines and 20 characters per line by 2 lines, respectively. Figure 7 shows LCD.

Figure 7 **LCD**

2.2 Relays

A relay is an electrically operated switch. multiple relays use an electromagnet to operate a switching operation, but other operating principles are also used. Relays find operations where it's necessary to control a circuit by a low- power signal, or where several circuits must be controlled by one signal. A type of relay that can handle the high power needed to directly drive an electric motor is called a contactor. Solid- state relays control power circuits with no moving parts, rather using a semiconductor device triggered by light to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to cover electrical circuits from overload or faults; in current electric power systems these functions are performed by digital instruments still called" protect. Figure 8 Shows Electrically Operated Switch [7].

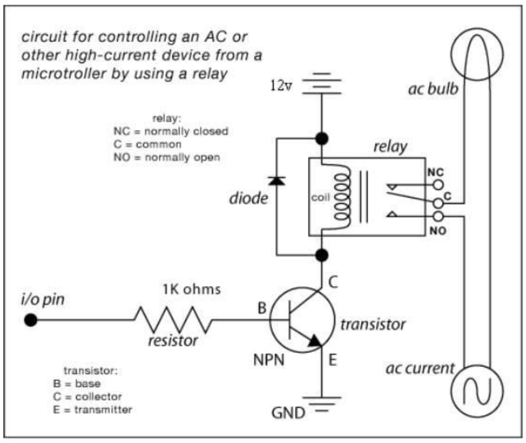

Figure 8 **Electrically Operated Switch**

2.3 Reset Button

Figure 9 **Rest Button**

A reset button is a physical or virtual control used to restore a device, system, or software to its original or default state. The purpose is to allow users to troubleshoot issues, recover from malfunctions, or start fresh without needing a complete power cycle or reinstallation. Figure 9 shows Rest Button.

2.4 LED Indicator

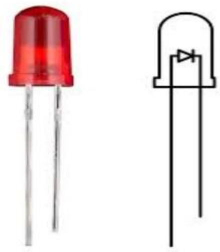

Figure 10 **LED Indicator**

An LED indicator is a small light-emitting diode (LED) used to convey information or status to users, typically by displaying different colors or patterns of light. These indicators are commonly found on a wide range of electronic devices, appliances, and systems to signal various conditions such as power status, error states, activity, or mode of operation. Figure 10 shows LED Indicator.

2.5 Stepdown Transformer

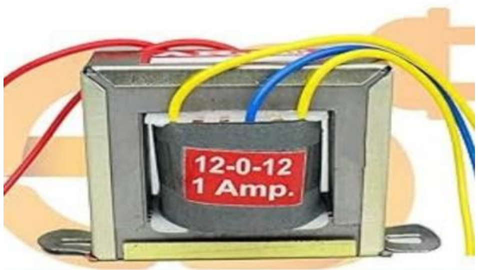

Figure 11 **Stepdown Transformer**

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A transformer is a device that uses inductively connected conductors to transfers electrical energy between circuits without altering its frequency. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding. This fluctuating magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding. This effect is called mutual induction. Figure 11 shows Stepdown Transformer [8].

2.6 Block Diagram & Explanation

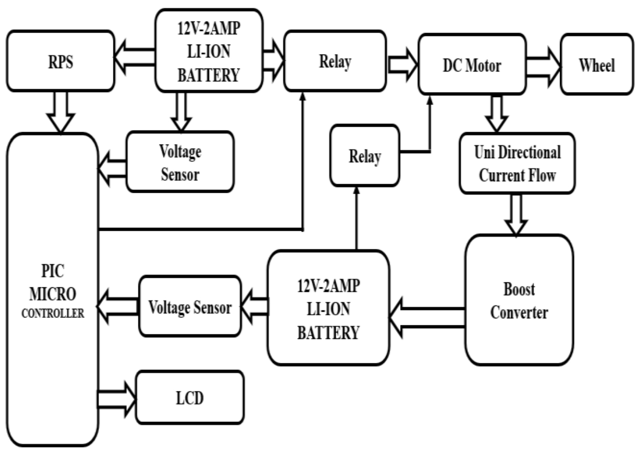

Figure 12 Regenerative Braking System

The main aim of the project is to design a regenerative braking system along with automatic switch over to the battery When the driver applies the brakes, instead of using traditional brake pads to create friction and slow the vehicle down, the electric motor of the vehicle acts as a generator. Figure 15 shows Before Giving Supply to The Motor. The vehicle's kinetic energy is used to turn the motor, which then slows the vehicle. As the motor slows the vehicle, it converts the kinetic energy of the moving vehicle into electrical energy. This electrical energy is stored into the rechargeable battery through charging circuit the main controlling device of the project is PIC Microcontroller. Microcontroller will continuously read the voltage values of two battery packs through voltage sensors. Whenever battery voltage is low, then the microcontroller will turn OFF the Relay to charge the battery and also turn ON another relay to powerup the motor. Figure 12 shows Regenerative Braking System.

2.7 Circuit Diagram and Explanation

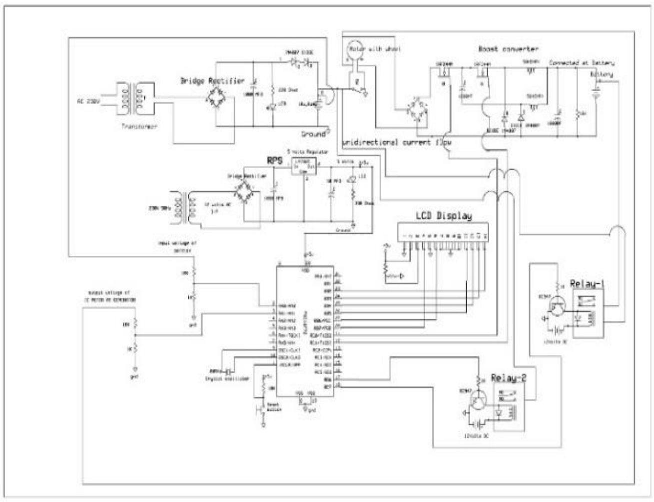

Figure 13 Schematic Diagram

Each component's interface area with the microcontroller is explained in the schematic diagram. A controlled power source is linked to the microcontroller's VDD pin, and the crystal oscillator is attached to the ninth and tenth pins [9]. Moreover, resistors are used to link LEDs to the microcontroller. The microcontroller's B2 and B7 pins are where the LCD is linked. Figure 14 shows Hardware Kit. The microcontroller's A0 pin receives the battery voltage sensor, whereas the A1 pin receives the voltage sensor from the DC motor (generator) output. The microcontroller is attached to the C0 and C1 pins and relay1 and relay2 is connected to RC6, RC7. Figure 13 shows Schematic Diagram.

2.8 Hardware Kit

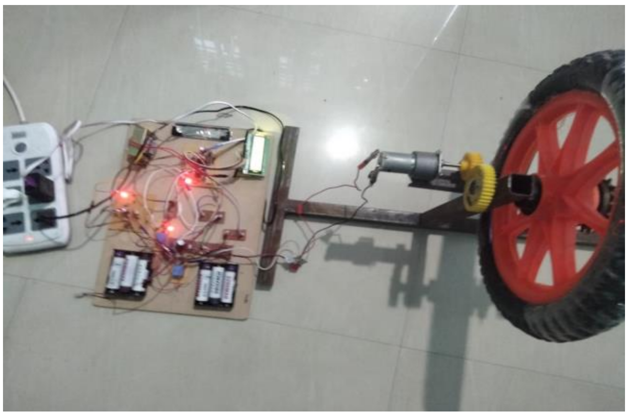

Figure 14 Hardware Kit

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2.9 Before Giving Supply to The Motor

Figure 15 Before Giving Supply to The Motor

The value of v1(Battery voltage) :12.90
The value of v2(Battery voltage) :12.3
The value of vg (generated votlage) :0.00

2.10 After Giving Supply to The Motor

Figure 16 After Giving Supply to The Motor

The value of v1(Battery voltage) :12.66
The value of v2(Battery voltage) :8.27
The value of vg (generated votlage) :0.00
Figure 16 shows After Giving Supply to The Motor.

2.11 After Regenerative Braking (Vg)

Figure 17 After Regenerative Braking (Vg)

Figure 17 After regenerative braking
The value of v1(battery voltage):12.66
The value of v1(battery voltage):12.00
The value of vg (generated voltage):6.50

That means the generated votlage 6.50 volts added to the battery (v2)

3. Result

Braking Force Application: When the driver applies the brakes, instead of using traditional brake pads to create friction and slow the vehicle down, the electric motor of the vehicle acts as a generator. The vehicle's kinetic energy is used to turn the motor, which then slows the vehicle. Conversion of Kinetic Energy to Electrical Energy: As the motor slows the vehicle, it converts the kinetic energy of the moving vehicle into electrical energy [10]. This is achieved by reversing the motor's role it's usually driving the wheels to move the car, but during braking, it acts as a generator. Energy Storage: The electrical energy generated is sent back to the battery for storage, where it can later be used to power the vehicle. This helps to extend the vehicle's range by recapturing energy that would otherwise be wasted. Slower Deceleration: Since regenerative braking doesn't use friction, it generally results in a smoother and less abrupt deceleration compared to traditional braking. The vehicle may still use conventional brakes when more stopping force is required, especially at lower speeds. The main aim of the project is to design a regenerative braking system along with automatic switch over to the battery. When the driver applies the brakes, instead of using traditional brake pads to create friction and slow the vehicle down, the electric motor of the vehicle acts as a generator. The vehicle's kinetic energy is used to turn the motor, which then slows the vehicle. As the motor slows the vehicle, it converts the kinetic energy of the moving vehicle into electrical energy. This electrical energy is stored into the rechargeable battery through charging circuit. The main controlling device of the project is PIC Microcontroller. Microcontroller will continuously read the voltage values of two battery packs through voltage sensors. Whenever battery voltage is low, then the microcontroller will turn OFF the Relay to charge the battery and also turn ON another relay to power up the motor.

Conclusion

In conclusion, the regenerative braking system designed in this project effectively showcases the potential of harnessing kinetic energy to improve the

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efficiency of electric vehicles. By integrating a PIC microcontroller, a 12V Li-ion battery, and supporting components, the system not only recycles energy during braking but also enhances battery life and driving range. The successful implementation of real-time monitoring and energy management reinforces the viability of regenerative braking as a crucial feature in modern EV design [11]. This project paves the way for future advancements in sustainable transportation technologies, emphasizing the importance of innovation in reducing environmental impact and enhancing energy efficiency.

Future Scope

The future scope of this regenerative braking system includes several enhancements and applications that can further improve its efficiency and integration. Future developments may focus on optimizing the control algorithms within the PIC microcontroller to maximize energy recovery in various driving conditions. Additionally, exploring the use of advanced energy storage systems, such as supercapacitors, could allow for quicker energy discharge and capture. The system could also be adapted for integration into larger transportation networks, such as public transit systems and freight vehicles, to amplify its impact on energy savings. Furthermore, incorporating machine learning techniques for predictive analytics could enhance system responsiveness and adaptability, ensuring even greater efficiency in energy management. Overall, these advancements could significantly bolster the role of regenerative braking in the broader landscape of sustainable transportation solutions.

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