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Design and Development of Battery Management System with Regenerative Braking Monitoring Using Arduino

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ABSTRACT

With the rapid increase in the use of electric vehicles and renewable energy systems, efficient battery management has become very important. Batteries are the main energy storage devices, and their performance and safety depend on proper monitoring of parameters such as voltage, current, temperature, and state of charge.

In this project, a Battery Management System (BMS) is designed and developed using Arduino Uno. The system continuously monitors battery parameters and displays real-time values on an LCD. It also calculates battery percentage and estimates discharge time based on load conditions.

A key feature of this project is regenerative energy monitoring. When current flows in reverse direction, the system detects it as regenerative condition and calculates the energy recovered. This helps in improving system efficiency.

The system also includes safety features such as low battery indication, over-temperature protection, and automatic cutoff using a relay module. The overall system is simple, cost-effective, and suitable for small-scale electric vehicle and battery applications.

Keywords: Battery Management System, Regenerative Braking, Arduino Uno, Energy Recovery, State Of Charge, Electric Vehicles.

1. INTRODUCTION

In today's world, the demand for clean and sustainable energy has increased significantly. Electric vehicles (EVs) and battery-based energy storage systems are becoming more popular because they reduce pollution and improve energy efficiency. Batteries play a major role in these systems, but their performance and safety depend on proper usage and monitoring.

A Battery Management System (BMS) is used to monitor battery parameters such as voltage, current, and temperature. It ensures safe operation by preventing overcharging, deep discharge, and overheating [18]. Without proper monitoring, batteries can degrade quickly and may become unsafe.

Another important concept in modern electric systems is regenerative braking. Normally, energy is lost during braking as heat, but regenerative braking converts this energy into electrical energy and stores it back into the battery [1]. This improves the overall efficiency of the system.

Several studies have been conducted on regenerative braking systems and energy recovery techniques [2][3]. These studies show that proper control strategies can significantly improve energy efficiency. However, most systems are complex and costly.

In this project, we aim to develop a simple and cost-effective system that combines battery

ISSN: 2945-4565 VOL 05, ISSUE 01, 2026

monitoring with regenerative energy tracking using Arduino. The system provides real-time data, safety features, and energy recovery analysis.

2. LITERATURE SURVEY

Many researchers have worked on battery management systems and regenerative braking technologies.
Szumska [1] provided a detailed review of regenerative braking systems and discussed various control strategies and challenges. Teasdale [2] studied energy recovery using battery and supercapacitor combinations and showed improved efficiency.
Li et al. [3] focused on regenerative braking control strategies and proposed methods to improve energy recovery. Purwanto et al. [4] implemented a regenerative braking controller using Arduino, proving that low-cost systems can be effective.
Joshi et al. [5] developed a regenerative braking system using BLDC motors and demonstrated improved performance. Yang et al. [6] analyzed energy efficiency and system performance in braking systems.
Hannan et al. [7] discussed advanced braking systems and their applications in EVs. Prakash et al. [8] introduced AI-based optimization techniques for regenerative braking systems. Suanpang [9] applied machine learning techniques to improve braking efficiency.
Other studies [10][11][12][13] emphasize the importance of energy recovery systems in improving efficiency and reducing energy loss. On the BMS side, IEEE research [18] highlights the importance of battery monitoring and safety. Thermal management systems are also essential to prevent overheating [19]. SOC estimation techniques are widely used to determine battery condition [22].
However, most of these studies focus on either battery monitoring or regenerative braking separately. There is a lack of simple systems that integrate both features effectively.

3. PROPOSED METHODOLOGY

The proposed system is designed to monitor battery parameters and track regenerative energy using an Arduino-based control system. The methodology includes several stages, from initialization to safety control and display.

System Initialization
When the system is powered ON, the Arduino Uno initializes all connected components to ensure proper functioning. During this stage:
All sensors (Voltage, Current, Temperature) are activated and calibrated
LCD display shows system startup messages such as:
- *"System Checking"*
- *"Initializing…"*

Relay module remains OFF to avoid sudden power flow
This step ensures that the system starts in a safe and stable condition before actual operation begins.

Data Acquisition
The system continuously collects real-time data from sensors:

Voltage Measurement
- Voltage sensor is connected across battery terminals
- Measures battery voltage accurately

ISSN: 2945-4565 VOL 05, ISSUE 01, 2026

- Provides input to Arduino via analog pin

Current Measurement (ACS712)

- Connected in series with load
- Measures:
  - Charging current
  - Discharging current
- Detects **negative current during regenerative braking**

Temperature Measurement (DHT11)

- Placed near battery
- Monitors temperature continuously
- Prevents overheating

All sensor outputs are transmitted to Arduino for further processing.

Data Processing

Arduino processes the collected data and performs calculations:
Battery percentage (SOC) using voltage method
Power consumption calculation
Charging/discharging detection
Estimated discharge time
This processing enables intelligent monitoring of battery performance.

Regenerative Energy Calculation

During braking, the DC motor acts as a generator and produces electrical energy.
When current becomes negative → regenerative condition detected
Energy is calculated using:
$Energy = Voltage \times Current \times Time$
The system accumulates this energy and displays it
This improves system efficiency by utilizing otherwise wasted energy.

Safety Monitoring

The system continuously checks safety conditions:
High Temperature → Relay OFF (system shutdown)
Low Voltage → Battery cutoff
Overcurrent → Protection activated
This ensures battery safety and increases lifespan.

Display and Monitoring

The LCD display provides real-time information:
Voltage (V)
Current (A)
Temperature (°C)
Battery percentage (%)
Charging/Discharging status
Regenerative energy

System Design and Circuit

The system is designed to integrate sensors, controller, and load into a single working unit.

ISSN: 2945-4565 VOL 05, ISSUE 01, 2026

System Architecture

The system consists of:
Battery Pack
Sensors (Voltage, Current, Temperature)
Arduino Uno (Controller)
Relay Module (Protection)
LCD Display (Output)
DC Motor (Load)
Motor Controller

Arduino Pin Connections

Component	Arduino Pin	Component	Arduino Pin
Voltage Sensor	A0	LCD SDA	A4
Current Sensor (ACS712)	A1	LCD SCL	A5
DHT11	D2	Relay Module	D7

Fig4.2: Pin Connection

Circuit Working

1. Voltage Sensor
- Connected across battery
- Sends analog signal to A0

2. Current Sensor
- Connected in series with load
- Measures bidirectional current

3. Temperature Sensor
- Connected to digital pin D2
- Sends temperature data

4. Relay Module
- Controlled via D7
- Cuts off power during unsafe conditions

5. LCD Display
- Uses I2C communication
- Displays real-time system data

Power Flow

Battery (+) → Sensors → Relay → Motor Controller → Motor
Battery (−) → Common Ground
This ensures proper energy flow and monitoring.

Working Principle
1. Sensors collect real-time data
2. Arduino processes data
3. LCD displays values
4. Safety conditions checked
5. Relay activates if needed

4. RESULTS AND DISCUSSION

The system was tested under different conditions such as charging, discharging, and regenerative operation.

ISSN: 2945-4565 VOL 05, ISSUE 01, 2026

Experimental Observations

Sr. No.	Voltage (V)	Current (A)	Temperature (°C)	SOC (%)	Regen Energy (J)
1	23.8	2.5	28	90	0
2	23.5	3.2	30	85	0
3	23.0	4.8	32	78	0
4	22.6	5.5	34	70	0
5	22.2	6.8	36	65	120
6	21.9	-2.5	35	67	180
7	22.1	-3.8	34	69	215
8	22.4	-1.5	33	72	300

Fig5.2: Experimental Observations

5.3 RESULT ANALYSIS

1. Voltage Calculation (ADC = Analog to Digital Converter)

From observation table:

Voltage = 22.4 V Using formula:

Voltage = (ADC × 5 / 1023) × 5 Assume ADC = 920

Voltage = (920 × 5 / 1023) × 5 Voltage ≈ 22.4 V

Current Calculation (ACS712)

From observation table:

Current = 5.6 A Using formula:

Current = (ADC − 512) × 5 / (1023 × 0.066)

Assume ADC = 585

Current = (585 − 512) × 5 / (1023 × 0.066)

Current ≈ 5.6 ATemperature

From observation table: Temperature = 34 °C Measured directly from sensor

State of Charge (SOC)

From observation table:

Voltage = 22.4 V

SOC = (Voltage − 18) / (24 − 18) × 100

SOC = (22.4 − 18) / 6 × 100 SOC ≈ 73 %

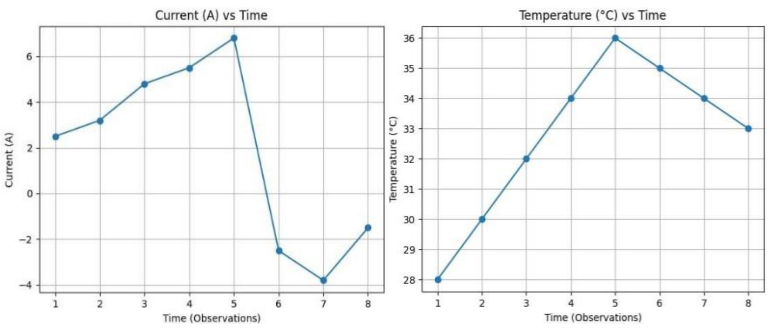
Regenerative Energy From observation table: Voltage = 22.4 V Current = 3.2 A

Time = 3 sec

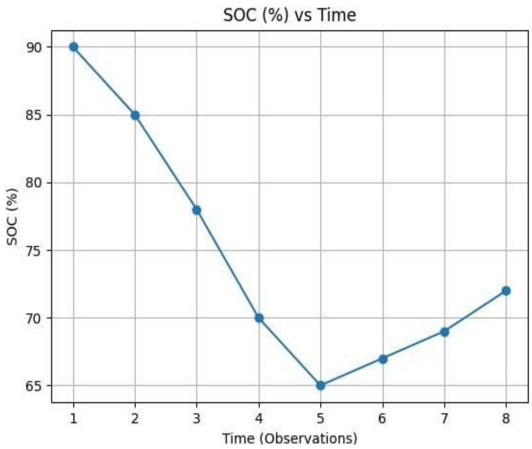
Energy = Voltage × Current × Time Energy = 22.4 × 3.2 × 3

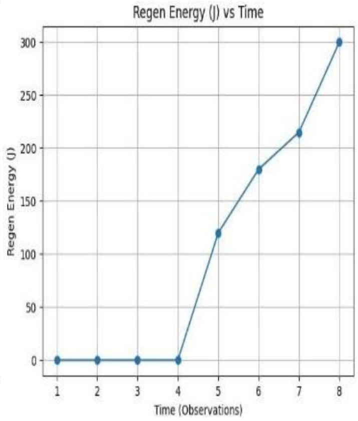
Energy ≈ 215 Joules

5.4 GARPHICAL REPERSENTATION



ISSN: 2945-4565 VOL 05, ISSUE 01, 2026





5. ADVANTAGES OF SYSTEM

- Low cost and simple design
- Real-time monitoring
- Energy recovery tracking
- Safety features included
- Easy to implement

FUTURE SCOPE

- Integration with IoT and mobile applications
- Use of advanced sensors for higher accuracy
- AI-based battery health prediction
- Application in large-scale EV systems

6. CONCLUSION

The project successfully demonstrates the design and development of a Battery Management System integrated with regenerative energy monitoring. The system monitors battery parameters, ensures safety, and improves efficiency through energy recovery.
It is a cost-effective and practical solution suitable for small-scale applications such as electric vehicles and battery systems.

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ISSN: 2945-4565 VOL 05, ISSUE 01, 2026

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Prototype Real Image