" BATTERY MANAGEMENT SYSTEM USING PREDECTIVE MODEL BASED CONTOL. "

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Abstract- This paper presents the design and analysis of a Battery Management System (BMS) integrated with a Pulse Width Modulation (PWM) control technique to enhance the performance and efficiency of DC motors. The system utilizes an Arduino- UNO micro-controller, L293D motor driver IC and multiple sensors to regulate voltage and current effectively. The experimental results, represented by the graph, demonstrate the system capability to maintain stable voltage levels despite input fluctuations. The PWM technique successfully minimized energy losses by adjusting the duty cycle based on real-time feedback and thereby optimizing energy usage and extending the lifespan of the motors. The proposed BMS proves to be a cost-effective and efficient solution for managing power in DC motor applications, highlighting its potential for broader applications in energy-sensitive systems.

Keywords- Battery Management System, Pulse Width Modulation, State of Charge, State of Health.

I. INTRODUCTION

In this paper, we design a motor control system using an Arduino UNO micro-controller, an L293D motor driver IC and various peripheral components. The primary goal is to regulate the speed of a DC motor with an encoder and two additional gear DC motors to generate voltage drops for dynamic load simulation. The circuit includes potentiometer for speed and voltage control, switches for power and PWM activation and measurement devices like voltmeters and ammeters for monitoring performance. It allows for precise control and analysis of motor behavior under different operating conditions, making it suitable for applications in robotics, automation and automobiles.

Pulse Width Modulation(PWM):

PWM is used to control the speed of the DC motors by adjusting the delivered power. The Arduino UNO generates PWM signals through its digital PWM pins, which are connected to the L293D motor driver IC. The motor driver then regulates the voltage supplied to the motors based on these signals. The potentiometer allow manual adjustment of the desired speed, affecting the duty cycle of the PWM signals. Switch is used to activate or deactivate the PWM compensation logic, enabling precise control over motor speed. It helps in achieving smooth acceleration and efficient power usage. By adjusting the duty cycle of the PWM signals, the system can effectively control the speed of the main motor and the gear motors, ensuring stable performance under varying load conditions.

II. LITERATURE REVIEW

The development of BMS using PWM techniques has been extensively studied to improve the efficiency, lifespan and safety of batteries, particularly in electric vehicles (EV). PWM is a modulation technique that regulates power delivery by adjusting the width of voltage pulses, making it effective for controlling charging and discharging rates. The integration of PWM in BMS allows for precise control over power distribution, preventing overcharging, overheating and deep discharging of batteries. Research indicates that PWM based BMS enhances energy efficiency by reducing losses during power conversion and ensuring balanced power distribution across battery cells. Several studies focus on the application of PWM in sensorless control techniques for Brushless DC (BLDC) motors used in EV. For instance, the use of digital PWM with back-EMF detection has been proven effective in eliminating the need for physical sensors, thus reducing system costs while maintaining high performance. This method also simplifies the control architecture, making it suitable for in-wheel motor integration. Additionally, low-cost sensorless control schemes leveraging PWM are proposed to expand the operational speed range of BLDC motors without compromising efficiency or increasing component count. These advancements highlight the potential of PWM based control strategies to enhance the reliability and cost-effectiveness of EV power-trains.

Furthermore, advanced algorithms for State of Charge (SoC) and State of Health (SoH) estimation are often integrated into PWM based BMS. Techniques such as Coulomb counting and Kalman filtering are utilized to provide accurate real-time data on battery status, which is essential for making informed decisions about power management. Studies also emphasize the role of PWM in cell balancing, where it helps maintain uniform charge distribution among battery cells, thereby preventing over-voltage and under-voltage conditions. The effectiveness of PWM in thermal management is another critical aspect, as it ensures that the battery operates within optimal temperature ranges, reducing the risk of thermal runaway. Overall, PWM based BMS is seen as a promising solution for extending battery life, enhancing safety and improving the overall performance of EV.

III. AIM AND OBJECTIVES:

Aim:

The aim is to design and implement a BMS using PWM techniques to efficiently control and monitor the performance of DC motors and simulate real-world load conditions for batteries in EV. This system seeks to optimize battery performance, extend lifespan, and ensure safe and reliable power management.

Objectives:

1. **To Control Motor Speed and Power:** Use of PWM signals generated by the Arduino UNO to regulate the speed and power of DC motors through the L293D motor driver, ensuring efficient energy utilization.
2. **To Simulate Load Conditions:** Implement gear DC motors to create voltage drops, simulating various load conditions that batteries might experience in EV applications.
3. **To Monitor Battery Parameters:** Integrate voltmeters and ammeters to continuously monitor voltage drops and current consumption, providing real-time data for assessing battery performance.
4. **To Implement Adjustable Control:** Utilize potentiometer for fine-tuning speed and voltage levels,

enabling precise control of the motor's operation based on different load scenarios.

5. **To Enhance Safety and Efficiency:** Include switches for activating PWM control and managing power flow to prevent overloading and ensure safe operation of the system.
6. **To Optimize Energy Distribution:** Achieve balanced energy distribution and prevent degradation of battery cells through effective PWM based control and monitoring techniques.

IV. PROPOSED METHODOLOGY

The methodology involves designing of a BMS using an Arduino UNO and an L293D motor driver to control DC motors with PWM signals. Potentiometer are used for adjusting speed and voltage, while sensors like voltmeters and ammeters monitor real-time parameters. PWM signals generated by the Arduino regulate the charging and discharging processes to optimize energy distribution. Gear motors simulate load conditions by creating voltage drops, and switches manage power flow and PWM activation. The system ensures safety by incorporating over-current and over-voltage protection mechanisms. The design is tested using simulations and real-time experiments to validate efficiency and reliability. Data collected from sensors helps in fine-tuning PWM control, ensuring balanced power management and extended battery life.

Key Features of BMS:

1. **PWM Based Control:**
   Utilizes PWM to regulate charging and discharging rates, ensuring efficient power management and minimizing energy losses.
2. **Real-Time Monitoring:**
   Integrates voltage and current sensors for continuous monitoring of voltage drops, current flow and power consumption.
3. **Load Simulation:**
   Uses gear DC motors to create controlled voltage drops, simulating real-world load conditions for batteries.
4. **Adjustable Control:**
   Incorporates potentiometer for fine-tuning speed and voltage levels, enabling precise control of power distribution.
5. **Protection Mechanisms:**
   Features over-current and over-voltage protection to prevent damage to the battery and circuitry.
6. **Efficient Power Management:**
   Ensures balanced energy distribution and prevents battery degradation through effective PWM based control.
7. **Safety Switches:**
   Includes switches for managing power flow and enabling/disabling PWM control for added safety.
8. **Temperature Management:**
   Potential integration of temperature sensors to manage thermal conditions using PWM, preventing overheating.
9. **Micro-controller Integration:**
   Used Arduino UNO as the main controller for executing PWM signals, data acquisition, and decision-making.
10. **Enhanced Battery Life:**
    Promotes longer battery lifespan through balanced charging, cell protection, and efficient power usage.

V. OPERATIONAL ALGORITHM

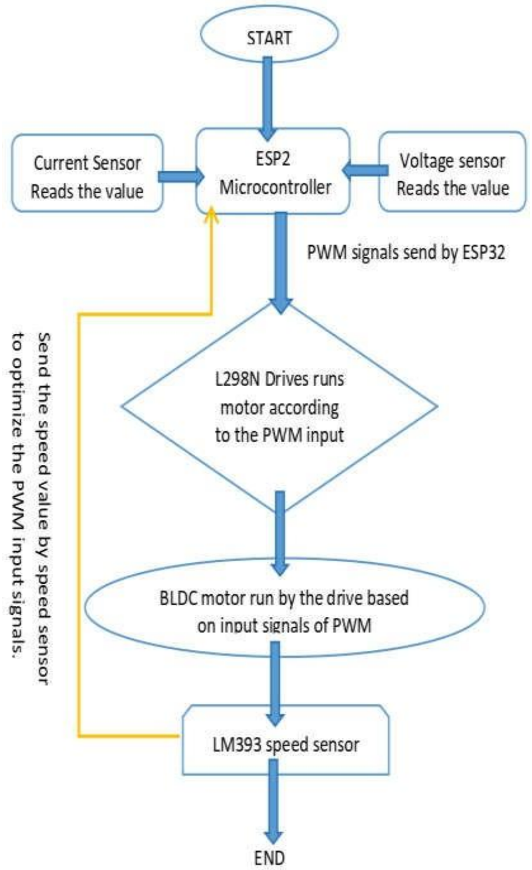

Fig.1. Algorithm of Power Flow in BMS.

From fig.1. with an initialization phase where the system powers up and prepares the sensors, ESP32 micro-controller and L298N motor driver for operation. In the first step, current and voltage sensors read the electrical parameters directly from the battery. The current sensor measures the flow of electric charge, while the voltage sensor captures the potential difference across the battery terminals. Both of these measurements are crucial for assessing the battery SoC and detecting any anomalies in power delivery. The gathered data is then transmitted to the ESP32 micro-controller for processing. Once the ESP32 has received the sensor data, it evaluates the voltage and current levels to determine the appropriate control actions. Simultaneously, it also receives information about the motor speed if a speed sensor is available. Based on this collected information, the ESP32 generates a PWM signal tailored to the current power status and motor requirements. PWM is an effective technique for controlling motor speed by varying the duty cycle of the signal, which directly impacts the amount of power delivered to the motor. The ESP32 sends this PWM signal to the L298N motor driver, which serves as an interface between the micro-controller and the DC motor. The motor driver adjusts the power supply to the motor according to the received PWM signal, enabling smooth and precise speed control. As the DC motor operates, an LM393 speed sensor monitors its actual speed and sends this data back to the ESP32, establishing a feedback loop. This feedback mechanism is essential for maintaining accurate control over the motor speed. If the sensor data indicates a discrepancy between the desired and actual speeds, the ESP32 recalculates and modifies the PWM duty cycle to correct any deviations. This continuous adjustment process ensures that the motor runs at the optimal speed, preventing power wastage and ensuring efficiency. Moreover, by constantly monitoring the voltage and current values, the system can preemptively identify and mitigate risks such as over-current or under-voltage scenarios, thereby enhancing both safety and the lifespan of the battery.This proposed algorithm presents a robust and dynamic control strategy for battery management, combining real-time monitoring, PWM based control, and a feedback loop to optimize power usage and extend the battery life. By leveraging the capabilities of the ESP32 micro-controller and the L298N motor driver, the system ensures efficient and stable motor operation under varying load conditions.

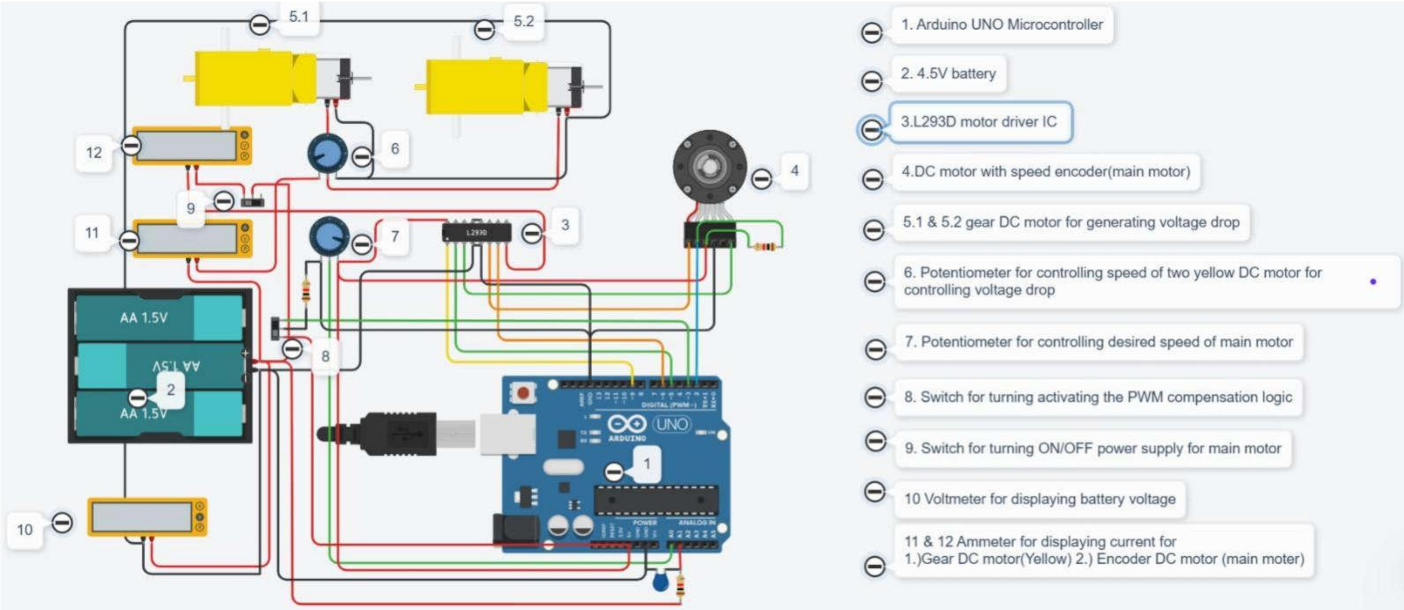

Fig.2. Simulation Model - TinkerCAD.

VI. MAIN COMPONENTS

From fig.2. the BMS that integrates multiple components to control and monitor a DC motor's speed efficiently. Each component plays a vital role in ensuring the system's stability, efficiency, and safety. Below is a detailed explanation of the main components:

1. ESP32 Microcontroller

The ESP32 is a powerful micro-controller unit (MCU) that serves as the brain of the system. It processes data from sensors, executes control algorithms and generates PWM signals to regulate the motor's speed. It features built-in Wi-Fi and Bluetooth capabilities, which could allow for remote monitoring and control if integrated into the system. In this arrangements, the ESP32 reads voltage, current, and speed sensor data to dynamically adjust the motor speed through PWM signals.

2. L298N Motor Driver

The L298N is a dual H-bridge motor driver IC that controls the DC motor's direction and speed based on the PWM signals received from the ESP32. It acts as an intermediary between the micro-controller and the motor, handling the higher power requirements of the motor that the ESP32 cannot supply directly. This driver allows the motor to run forwards or backwards and provides adequate current to ensure stable operation.

3. DC Motor with Speed Encoder

The DC motor is the primary load in the system, responsible for performing mechanical tasks. It is coupled with a speed encoder that measures the motor rotational speed. The encoder generates pulses proportional to the motor speed, which are sent back to the ESP32 for real-time speed monitoring and feedback control. This feedback mechanism is crucial for maintaining precise speed control under varying load conditions.

4. LM393 Speed Sensor

The LM393 is a comparator based speed sensor that reads the motor's speed and sends pulse signals to the ESP32. It helps in forming a closed-loop control system by providing real-time speed data, enabling the ESP32 to adjust the PWM signals accordingly. This sensor ensures that the motor speed remains consistent with the desired set-point.

5. Voltage and Current Sensors

These sensors monitor the voltage and current drawn from the battery to assess the power consumption and health of the system. Voltage Sensor measures the battery output voltage and detects under-voltage or over-voltage conditions that could damage the system. And current Sensor measures the current flowing to the motor, helping to prevent over-current scenarios that might overheat or damage the motor or driver. Both sensors send their readings to the ESP32 for analysis and decision-making.

6. Battery Pack

The battery pack provides the necessary DC power for the entire system, including the motor driver and sensors.
Maintaining an optimal charge level is crucial for the longevity and efficiency of the system. The power from the battery is managed and regulated through the voltage and current sensors to ensure safe operation.

7. Feedback Control System

The integration of speed, voltage and current sensors with the ESP32 establishes a feedback loop. By continuously monitoring the motor’s speed and electrical parameters, the ESP32 can make real-time adjustments to the PWM signal to ensure optimal performance. This closed-loop control mechanism enhances the efficiency, accuracy and safety of the BMS.

VII. RESULTS

The results of the experiment demonstrate the effectiveness and limitations of the DC motor control system designed using the Arduino UNO micro-controller and L293D motor driver IC. The system successfully managed voltage regulation initially, maintaining levels close to 100 with minor fluctuations. However, as the operational load increased, significant voltage drops were observed, indicating limitations in the control ability to sustain higher power demands effectively. Additionally, the graph reveals that the system's ability to stabilize voltage at lower levels, around 70 and below, was partially effective but marred by continuous minor fluctuations. This suggests that while the control mechanism can adapt to varying load conditions, its response time and compensation accuracy require improvement. That control system demonstrates potential for effective voltage management under moderate loads but requires further optimization for handling larger variations efficiently. Enhancements in power regulation algorithms and improved feedback mechanisms could contribute to more stable and reliable performance in future implementations.

Fig.3. TinkerCAD Output Waveform.

From fig.3. indicate that while the system can initially sustain a voltage just below 100 with minor fluctuations, significant drops occur subsequently. These drops suggest that while the control mechanism is partially effective, it encounters challenges under certain conditions, possibly due to load variations or power supply limitations. The sharp declines in voltage observed in the graph imply that the system's response to increased load is not entirely smooth, leading to substantial reductions in output voltage. This finding highlights the need for enhancing the load-handling capabilities of the control system to prevent abrupt performance losses.

As seen in the graph, the voltage eventually stabilizes at a lower level, with minor fluctuations. Thus while the system can operate at reduced power levels, further refinement is necessary to minimize these fluctuations and ensure consistent performance across different operational ranges.

VIII. CONCLUSION

The implementation of a Battery Management System (BMS) using Pulse Width Modulation (PWM) techniques has proven to be an effective solution for optimizing power management, enhancing safety, and extending the lifespan of batteries, particularly in electric vehicle (EV) applications. The integration of the Arduino UNO microcontroller, L293D motor driver, and various sensors enabled precise control over motor speed and power distribution. The use of PWM facilitated efficient energy utilization by managing charging and discharging rates, while real-time monitoring through voltage and current sensors ensured accurate assessment of battery performance.

ABBRIVATIONS:

BMS: Battery Management System.
PWM: Pulse Width Modulation.
EV: Electric Vehicles.
BLDC: BrushLess DC Motor.
SoC: Stste of Charge.
SoH: State os Health.
MCU: Micro Controller Unit.

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