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Design and Development of Intelligent Controller for EV BMS Application

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Abstract: - The necessity for a cutting-edge Battery Management System (BMS) driven by Artificial Intelligence (AI) to guarantee the best possible battery safety, efficiency, and longevity has increased due to the quick uptake of electric vehicles (EVs). Traditional BMS systems use preset algorithms to estimate the State of Health (SOH) and State of Charge (SOC), but these techniques are not flexible enough to adjust to changing battery conditions. By employing predictive modeling and intelligent data analysis to increase the accuracy of SOC/SOH estimates, AI-driven BMS gets beyond these restrictions. Furthermore, AI-based fault detection systems may identify early indicators of battery deterioration, lowering failure risk and enhancing safety. Predictive maintenance techniques and anomaly detection driven by AI guarantee pre-emptive diagnostics, averting unplanned battery failures. Higher efficiency and longer battery life result from the inclusion of AI-enhanced SOC estimation, which optimizes charge cycles and reduces energy losses. Additionally, cloud-based AI analytics greatly enhance performance management by offering remote battery diagnostics, adaptive control, and real-time monitoring. Additionally, self-learning algorithms that continually improve energy distribution and cell balance based on real-world data are implemented by the suggested AI-driven BMS. Preventive maintenance and economical battery use are made possible by AI-based failure prediction models, which enable early identification of possible problems. The solution guarantees data-driven optimization, remote updates, and dynamic charge control by fusing AI with cloud computing and IoT connection. The scalable, AI-powered BMS controller shown in this study improves battery longevity, performance, and dependability, making it a crucial part of next-generation EV technology.

Keywords: Arduino nano, raspberry pi, voltage sensor, dc motor, battery 12v, current sensor.

1. INTRODUCTION

The need for high-performance, intelligent Battery Management Systems (BMS) that guarantee the best possible battery longevity, safety, and economy has grown dramatically as a result of the quick uptake of electric vehicles (EVs). The main part of an EV is a BMS, which is in charge of keeping an eye on and controlling the temperature conditions, charge levels, and battery health. Conventional BMS systems are built on pre-established mathematical models and rule-based algorithms, which frequently don't adjust to changing driving circumstances, temperature swings, and the impacts of battery aging in the real world [1]. Artificial Intelligence (AI)-powered BMS systems have surfaced to address these issues, transforming energy optimization, predictive maintenance, fault detection, and battery monitoring [2]. A BMS is in charge of increasing battery life, reducing overheating, detecting defects, and guaranteeing optimal energy use. Conventional BMS systems are built on static mathematical models and predetermined rule-based algorithms, which are frequently rigid and unable to adjust to real-world variables like aging effects, dynamic driving circumstances, and temperature swings. A next-generation AI-driven BMS controller with real-time learning, self-adaptive control, and predictive analytics is presented in this study, "Design and Development of Intelligent Controller for EV BMS Application." The

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suggested system uses AI algorithms to dynamically modify battery performance depending on current operating circumstances, in contrast to standard BMS, which depends on fixed lookup tables and Kalman filters for State of Charge (SOC) and State of Health (SOH) estimates. Because of this, these traditional systems usually have inaccurate estimations of the State of Charge (SOC) and State of Health (SOH), which results in ineffective battery operation and unanticipated breakdowns [3]. AI improves fault diagnoses, long-term battery endurance, and charge cycle efficiency by allowing the BMS to spot hidden patterns in battery activity. Artificial intelligence (AI)-powered BMS systems have become a game-changer in battery management as a means of overcoming these obstacles. AI-powered systems use sophisticated data analytics, self-learning algorithms, and predictive intelligence to enhance battery performance, in contrast to conventional approaches that depend on static equations and sensor-based thresholds [4]. Predictive maintenance and problem detection are two of the fundamental issues with EV battery technology. Conventional systems usually use rule-based triggers and voltage thresholds to identify anomalies, which might not be enough to stop unplanned failures [5]. In order to reduce battery deterioration and improve operational safety, AI-powered fault diagnostic models use both historical and real-time sensor data to anticipate possible faults before they happen [6]. While they perform well in controlled environments, traditional estimating methods like coulomb counting, Kalman filters, and extended Kalman filters (EKF) have trouble with nonlinear battery behavior, aging effects, and changing ambient circumstances. Additionally, advanced AI-driven charge distribution algorithms enable dynamic energy balancing, guaranteeing optimal battery cell performance, minimizing premature aging, and enhancing total energy consumption [7]. The SOC and SOH estimate methods used in this research are AI-powered and achieve noticeably greater accuracy by utilizing historical patterns, self-adaptive models, and real-time battery data. Even in uncertain situations, AI improves estimate accuracy by continually learning from battery behavior. The suggested AI-driven BMS has cloud connectivity in addition to onboard intelligence, enabling real-time remote monitoring and optimization [8]. Over-the-air (OTA) updates and fleet-wide battery health tracking are made possible by the integration of Internet of Things (IOT) technology, which permits constant data sharing. Early problem identification is a major difficulty in battery management. Conventional fault detection systems only sound an alarm when battery conditions above certain safety thresholds since they are threshold-based [9]. In addition to lowering maintenance costs, its cloud-based AI architecture guarantees that EV batteries are continuously optimized for performance, safety, and sustainability. By integrating with cloud-based battery management systems, the suggested AI-BMS solution enables centralized monitoring of many EVs and data-driven fleet operations optimization [10]. In order to provide next-generation electric cars with self-learning, predictive intelligence, and cloud connection, this article introduces a scalable, AI-powered intelligent BMS controller. This intelligent system is a critical invention for the future of sustainable transportation as it solves the drawbacks of traditional BMS and increases battery longevity, energy efficiency, and EV safety and dependability.

One of the most important steps in improving the lifetime, safety, and efficiency of EV batteries is the design and development of an intelligent controller for the BMS. Because improved BMS systems are essential for monitoring and maintaining battery health, demand for them is rising as EV adoption grows globally. In order to maximize battery performance, this article focuses on developing an intelligent controller that combines adaptive control algorithms, predictive analytics, and real-time data monitoring. Key factors including temperature, cell balance, state-of-charge (SOC), and state-of-health (SOH) will all be precisely measured and controlled by the controller.

1.2 Literature Survey:

Research into AI-powered battery monitoring, predictive maintenance, and real-time problem diagnosis has increased due to the growing need for intelligent and efficient Battery Management Systems (BMS) in electric vehicles (EVs). Conventional BMS systems depend on preset estimating models and rule-based algorithms, both of which frequently malfunction in practical operational environments. Energy optimization, anomaly detection, and State of Charge (SOC) and State of Health (SOH) assessment are all made more precise and adaptable by the incorporation of Artificial Intelligence (AI) into BMS technology. The difficulties, approaches, and technical developments pertinent to this work are highlighted in this literature review, which examines significant scientific contributions in AI-based BMS development.

Battery Management Systems:

An essential part of electric vehicles (EVs) is a battery management system (BMS), which keeps an eye on, regulates, and maximizes battery performance to guarantee efficiency, safety, and dependability. In lithium-ion battery packs, the BMS is essential for controlling the State of Charge (SOC), State of Health (SOH), fault detection, temperature regulation, and energy distribution [1]. Conventional BMS systems, which rely on set rule-based algorithms and classical estimating methodologies, are no longer sufficient to handle the complex and dynamic nature of battery behavior as EV technology develops [2].

In order to enhance battery performance, this study, "Design and Development of Intelligent Controller for EV BMS Application," presents an AI-powered BMS that combines cloud-based monitoring, predictive fault diagnosis, and real-time adaptive control. This intelligent BMS analyzes historical and real-time battery data using Artificial Intelligence (AI) algorithms, as opposed to traditional BMS systems that rely on Kalman filters, equivalent circuit models, and predefined lookup tables. This ensures proactive battery maintenance and increased accuracy in SOC and SOH estimation.

For accurate range estimation and effective energy use, the battery's State of Charge (SOC), which indicates its remaining energy level, is essential. Due to the impacts of battery aging, traditional SOC estimate methods like Kalman filters and Coulomb counting frequently suffer from measurement drift and mistakes. By employing self-learning algorithms that constantly improve charge forecasts based on historical and real-time data, the suggested AI-driven BMS improves SOC estimates.

The battery's total health and aging state are defined by the State of Health (SOH), which also establishes how well the battery can store and distribute energy. The voltage, current, and temperature thresholds used in conventional SOH estimate techniques have a limited capacity for prediction. Predictive SOH models are integrated by the AI-powered BMS, which uses machine intelligence to identify deterioration patterns early and facilitate proactive battery management.
Battery management systems are essential for keeping an eye on and managing important battery pack characteristics. By controlling voltage, current, and temperature, traditional BMS systems prioritize performance and safety. Nevertheless, these systems sometimes don't have the capacity to anticipate battery health or adjust dynamically to shifting circumstances.
Early problem identification is a major difficulty in battery management. Conventional fault detection systems only sound an alarm when battery conditions above certain safety thresholds since they are threshold-based. This method, however, is unable to foresee slow deterioration or obscure irregularities that might result in disastrous failures like thermal runaway and short circuits. Predictive maintenance is made possible by AI-powered fault detection, which uses pattern recognition and anomaly detection algorithms to find possible issues before they happen. This feature prolongs battery life, improves safety, and drastically cuts downtime.
One of the biggest problems with battery packs is heat buildup, particularly during high-power cycles of charging and discharging. Reduced battery efficiency, increased aging, and safety hazards including thermal runaway might result from a poorly maintained thermal system. Dynamic temperature monitoring and adaptive cooling techniques are features of the suggested AI-powered BMS that guarantee thermal conditions stay within ideal bounds to prolong battery life [3].

2. BLOCK DIAGRAM:

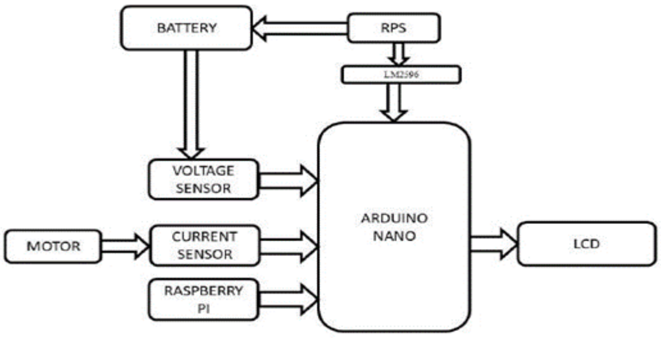

Fig1. block diagram

3. COMPONENTS:

- ➢ Buck Converter
- ➢ Arduino Nano
- ➢ Raspberry Pi
- ➢ Voltage Sensor
- ➢ Current Sensor
- ➢ Battery
- ➢ Dc Motor
- ➢ Transformer
- ➢ Rectifier
- ➢ Lcd Display

ARDUINO NANO:

The central microcontroller for managing the BMS's real-time data collection and control functions is the Arduino Nano. It is in charge of gathering voltage and current sensor data and sending it to the Raspberry Pi for additional processing. Because of its compact size, low power consumption, and simplicity of integration with other hardware components, the Arduino Nano was chosen.

For real-time monitoring and fault detection in BMS, where low latency and quick processing are essential for battery safety and performance, Hu et al. (2019) emphasized the need of utilizing a lightweight microcontroller. In this work, the Arduino Nano continually measures the voltage, current, and temperature of the battery and sends the data to the Raspberry Pi for AI-based predictive analysis over a serial communication link. In the event of serious problems like overcurrent, overvoltage, or overheating, the Arduino is configured to initiate precautionary shutdowns [1].

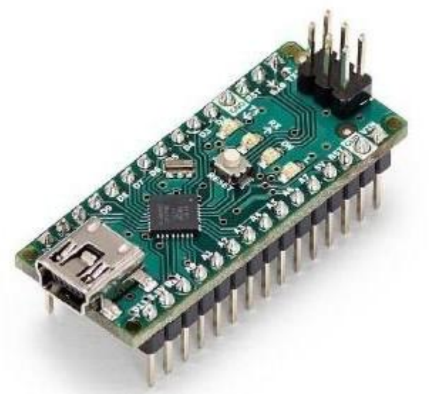

Fig2. Arduino nano

RASPBERRY PI:

Of order to conduct State of Charge (SOC) and State of Health (SOH) estimates, predictive maintenance, and problem diagnostics, Artificial Intelligence (AI) algorithms are implemented on the Raspberry Pi, which serves as the primary computer unit of the BMS. Because of its greater processing power and memory capacity, the Raspberry Pi enables high-level AI models, in contrast to Arduino, which manages low-level sensor control.

In order to manage massive amounts of real-time sensor data, Xiong et al. (2017) showed that AI models like neural networks and fuzzy logic-based systems need enough processing power [2]. In this study, the Raspberry Pi uses AI-based learning algorithms to analyze charging patterns, forecast battery degeneration, and optimize energy use after receiving sensor data from the Arduino Nano. Additionally, the Raspberry Pi manages cloud communication for OTA updates and remote monitoring.

Fig3. Raspberry PI

VOLTAGE SENSORS:

High-quality voltage and current sensor modules with a 5A to 60A measurement range are available here. An apparatus that senses electric current flowing through a wire and produces a signal proportionate to that current is called a current sensor. The 12V battery's charging and discharging conditions are tracked by the voltage sensor. Determining the SOC and identifying abnormalities like overvoltage or undervoltage need precise voltage measurement.

Since mistakes in voltage sensing might result in inaccurate state predictions and battery mismanagement, Zhang & Lee (2011) underlined the need of precise voltage measurement in SOC calculation. In this work, the Arduino Nano continually checks the battery voltage levels using data from the voltage sensor. To protect the battery, the Arduino initiates an automated shutdown if the voltage rises beyond the specified safety thresholds. The Raspberry Pi uses AI-based prediction models to interpret this data and dynamically update the SOC settings. The signal that is produced may be a digital output, analog voltage, or current. Both the AC and DC voltage levels can be detected using voltage sensors. This sensor's output can be switches, analog voltage signals, current signals, audio signals, etc., while its input can be voltage [3].

Fig4. voltage sensor

DC MOTOR:

The resistors As the name suggests, DC motors run on "direct," or essentially continuous, terminal voltage and current. Although it is feasible to create a "true DC" machine with geometry in what is commonly referred to as a "acyclic" form, these machines have extremely low terminal voltages and, as a result, significant terminal currents in relation to their power ratings. Therefore, a mechanical switch or commutator has been used in every DC motor application to convert the machine's armature's constant or DC terminal current into alternating current.

Any rotary electrical motor that transforms direct current (DC) electrical energy into mechanical energy is referred to as a DC motor. The most prevalent kinds depend on the forces 32 generated by induced magnetic fields as a result of the coil's current flow. Almost every kind of DC motor has an internal mechanism, either electronic or electromechanical, that allows it to periodically alter the direction of the current flowing through a portion of the motor.

Fig5. dc motor

16*2 LCD:

LCD is an abbreviation for liquid crystal display. This type of electronic display module is utilized in many different circuits and devices, including TV sets, computers, calculators, and cell phones. These displays are mostly favored for seven segments and multi-segment light emitting diodes. This module's primary advantages include being affordable, easily configurable, having animations, and having no restrictions on the display of unique characters, special effects, animations, etc.

Fig6: 16*2 LCD

An AI-driven BMS has a strong basis thanks to the Arduino Nano, Raspberry Pi, voltage and current sensors, DC motor, and 12V battery. The Raspberry Pi processes this data using AI models for SOC/SOH estimates and predictive fault detection, while the Arduino manages low-level sensor data collecting and preventative measures. The AI model can modify energy distribution and avoid operational problems thanks to the voltage and current sensors, which offer real-time insights into battery performance. The battery is the primary energy source, while the DC motor acts as a dynamic load, assisting the system in adjusting to actual driving circumstances. Higher economy, longer battery life, and increased safety are all guaranteed by this integrated system, which makes it adaptable for use in future EV applications.

4. WORKING:

The creation of an AI-powered Battery Management System (BMS) for electric vehicles (EVs) is the main goal of the article "Design and Development of Intelligent Controller for EV BMS Application." The system's primary functions include fault detection, dynamic load handling, cloud-based monitoring, AI-based condition estimate, and real-time data collecting. By using self-learning algorithms and predictive maintenance techniques, the intelligent BMS is intended to improve battery performance, safety, and longevity while overcoming the drawbacks of traditional battery management systems [1]. Data collection from the linked parts, such as the voltage sensor, current sensor, DC motor, and 12V battery, starts the process. As the main microcontroller, the Arduino Nano is in charge of gathering sensor data and managing the DC motor. During cycles of charging and discharging, the Arduino keeps an eye on the voltage and current levels and sends this information to the

Raspberry Pi for additional processing [2]. The State of Charge (SOC) and State of Health (SOH) of the battery are estimated in real time by the AI model installed on the Raspberry Pi [3].

Accurate SOC estimate depends on the voltage sensor, which detects the battery's charging and discharging voltage. The AI model can estimate how much power is available and comprehend the battery's charge condition with the aid of voltage monitoring. Calculating the battery's energy consumption and forecasting the pace of capacity loss depend on the current sensor, which tracks the current flow during charging and draining [5]. This sensor data is continually gathered by the Arduino Nano and transmitted to the Raspberry Pi, where the AI model processes it to improve SOC and SOH forecasts.

The DC motor mimics the vehicle's load behavior. The AI model modifies the battery's output to ensure steady performance during dynamic load circumstances, such acceleration and deceleration [7]. By dynamically controlling the energy flow in response to the motor's power demand, the BMS system avoids problems like thermal overload and over-discharging. In order to preserve efficiency, the AI model modifies the charging and discharging rates based on its prediction of the battery's response to various load scenarios [8].

In predictive maintenance and defect detection, the AI model is essential. To spot early indicators of battery deterioration or abnormalities including overvoltage, overcurrent, short circuits, and overheating, the system continually analyzes sensor data. To stop more harm, the AI model modifies the charging or discharging rate and sounds a warning if an abnormal pattern is found [10].

As a precaution, the Arduino Nano performs emergency shutdowns in the event that the battery surpasses certain safety criteria. Dynamic cell balance is another important system feature. Cells in multi-cell battery packs frequently age at varying rates, which results in uneven charge levels and decreased total capacity. To guarantee consistent cell performance, the AI-powered BMS evaluates each cell's charge level and redistributes energy. This prolongs battery life and increases energy efficiency by preventing overcharging and undercharging [4].

Additionally, by connecting the BMS to a distant server, the Raspberry Pi makes cloud-based monitoring possible. Battery performance data is sent to the cloud via the AI model, where it is analyzed to find patterns and improve predictive maintenance models. In order to ensure that the AI model can continually develop based on fresh battery performance data, the system enables over-the-air (OTA) updates. The system can also monitor the whole fleet, which enables centralized performance control for several EVs.

The BMS may modify the charging and discharging rates in response to current operational conditions thanks to the AI model's adaptive energy management capacity [9]. In times of high demand, such sudden acceleration, the system produces more energy while keeping the temperature constant. The AI model lowers energy usage under low-load circumstances to lessen battery degradation and increase longevity. The AI-based control system's dynamic nature guarantees that the battery runs within ideal bounds in a variety of scenarios [1]. A number of safety precautions are included into the system to guard against damage to the battery. Protection against overvoltage and undervoltage makes ensuring the battery charges and discharges within safe working parameters. While thermal protection makes sure the battery doesn't overheat while under a lot of load, overcurrent prevention stops excessive current draw. Before serious malfunctions happen, the AI model anticipates possible safety hazards and modifies system behavior to reduce them [4].

In conclusion, to ensure optimal battery health, the AI-powered BMS continually gathers sensor data, interprets it using AI models, calculates SOC and SOH, dynamically balances cell performance, and modifies charging and discharging rates. Real-time remote monitoring and OTA updates are made possible by the system's cloud connectivity, which guarantees the BMS's continued adaptability and scalability. This clever controller is a crucial invention for next electric vehicles as it increases battery efficiency, prolongs lifespan, and boosts overall EV performance [5].

5. RESULTS:

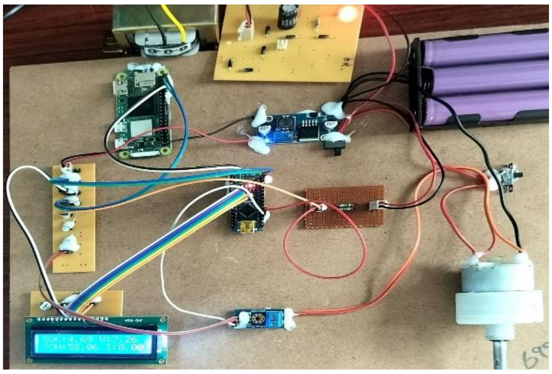

Fig7. final output results

6. CONCLUSION:

The study "Design and Development of Intelligent Controller for EV BMS Application" effectively creates a Battery Management System (BMS) driven by AI that improves the longevity, performance, and safety of EV batteries. Because they rely on rigid algorithms, traditional BMS systems frequently malfunction in dynamic working environments. By employing AI-based models for dynamic cell balancing, predictive fault detection, and State of Charge (SOC) and State of Health (SOH) estimates, this work gets beyond these restrictions. The system incorporates a Raspberry Pi for AI-based processing and control, and an Arduino Nano for real-time sensor data collection. By anticipating issues like overcharging, overheating, and capacity loss before they arise, the AI model enhances battery safety and permits preventative maintenance. By distributing energy evenly among cells, dynamic cell balancing increases battery capacity and prolongs its lifespan. According to this article, AI-driven BMS systems greatly improve battery safety and performance while increasing operating longevity. This system's successful deployment creates a dependable, scalable, and future-ready solution for electric vehicles of the next generation.

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