Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN: 2581 - 611X)

VOLUME:8, ISSUE:2, AUGUST, PAPER NUMBER:47

IoT - BASED MONITORING AND MANAGEMENT OF ELECTRIC VEHICLE CHARGING SYSTEMS

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Abstract: *The demand for efficient and reliable charging systems is on the rise as electric vehicles become more adopted and popular. Simultaneously with the rise in the adoption of electric vehicles, the infrastructure beneath them needs to change so that they can be operated safely and effectively and sustainably. It has designed a new IoT-based monitoring and management system, particularly for EV charging, that monitors the individual cells inside battery packs. The system was specifically designed to focus on every cell as a way of improving processes of charging, better management of power, and the performance and life of batteries in EVs. The proposed system will integrate with advanced sensors of IoT. At cell levels, all critical parameters like voltage, current, and temperature will continuously get sensed and transmitted through real-time data by the advanced sensors. By monitoring these variables closely, the system can provide in-depth details about the condition of the battery and what its charging status is: information that is crucial in maintaining safety, efficiency, and optimal power management on the charging process. Take, for example, monitoring for voltage imbalances between cells something that could otherwise spell reduced battery performance or even greater safety hazards. Like temperature monitoring, overheating is another common problem that may degrade the life of the battery or even cause damage. Among its innovations, the system has a centralized dashboard that can visualize real-time data and trends needed for the optimizing charging of the battery. This system may be used to provide complete data on battery health, power consumption, and charging processes so that predictive maintenance can be conducted and failure during operation reduced. This system may also automatically shut off the charging at any time not considered peak hours or under conditions that minimize wear and tear while optimizing the usage of power. This monitors and manages the whole system by adopting the IoT technology, which has really jumped the bounds in EV charging technology. It ensures safety and durability with regard to batteries and contributes toward optimizing power management in developing a smarter, more sustainable transportation infrastructure by focusing on monitoring cell levels and real-time data analysis. This approach opens ways to more reliable and efficient use of EVs in supporting the global transition toward cleaner energy and reduces the environmental impacts of transportation.*

Keywords: *Electric vehicle, battery, monitoring, cell, IoT, Voltage.*

1. INTRODUCTION:

The rapid growth of electric vehicles (EVs) marks a revolutionary shift in global transportation, offering an environmentally friendly option to combat climate change and reduce greenhouse gas emissions. However, the widespread adoption of EVs poses challenges, particularly in relation to battery packs, which are critical components affecting the range, safety, efficiency, and longevity of an EV. A battery pack consists of thousands of cells arranged in series and parallel configurations. However, these cells degrade unevenly due to temperature changes, charging-discharging cycles, and manufacturing variations. Even a single faulty cell can decrease efficiency, increase the risk of thermal runaway, or cause system failure. The traditional battery management system monitors aggregate parameters such as voltage, current, and temperature. It lacks granularity for finding cell-level issues. The current gap is, however alleviated by monitoring system based on IoT; such a monitoring technique monitors cells' particular parameters like cell voltage and temperature in a real-time observation. The related sensors for IoT gather, relay information to the assessment center to ensure full examination of cell health, which enables an early detection fault (imbalances, charging, and overheating faults), along with the extents of degradations and further enhanced safety, effectiveness, and life time utilization. Granular, real-time monitoring through IoT improves decision-making with intuitive visualizations, ensuring the reliability of EVs while addressing adoption challenges. As the EV market expands, implementing IoT-based monitoring systems is essential for sustainability, enabling cleaner and greener transportation for a better environment.

1.1 INTRODUCTION TO ELECTRIC VEHICLE BATTERY SYSTEMS:

Electric vehicles are an innovative new concept in clean transportation. These vehicles cut greenhouse gas emissions and decrease the use of fossil fuels. The core component of EVs is the battery system, which contains a large number of lithium-ion cells connected together to store a lot of energy. The condition of these individual cells determines how well an EV works and how long it lasts. The internal components can be damaged also by even minor problems related to overcharging, over-discharging, temperature variance, or manufacturing defects of the battery. Traditional battery management systems will monitor the entire battery pack but often miss problems arising in individual cells. This can lead to inefficiencies, safety risks, and a shorter life. Adding IoT technologies to the EV battery system enables one to monitor each cell in real time to solve such issues. IoT sensors collect data on voltage, temperature, and other critical parameters, which enables granular health evaluations, predictive maintenance, and optimized charging processes. Actionable insights displayed through intuitive dashboards ensure proactive battery management, improving safety, efficiency, and overall EV reliability.

1.2 IMPORTANCE OF MONITORING INDIVIDUAL CELLS IN EV BATTERIES:

Electric vehicles rely on the operation of battery packs composed of many individual cells that cumulatively determine performance and energy capacity. However, variability in manufacturing, aging, or operational conditions at the individual cell level can lead to deviations, further affecting the overall efficiency, safety, and lifetime of a battery pack. Traditional systems can only monitor at the battery pack level thus missing subtle, cell level issues that tend to precipitate hidden degradation, lowered range, slower charging, worst of all, safety hazards such as thermal runaway-the catastrophic chain reaction caused by overheating.

Cell-level monitoring addresses these problems by providing real-time data on how each cell is working and in what condition. This detailed method is helpful in predicting when maintenance is required, ensuring safe working of cells, improving efficiency, and increasing battery life by a lot, thus reducing expensive replacements. Furthermore, visual dashboards can be used for monitoring and managing the system, enabling users and maintenance teams to quickly identify and address problems. Thus, cell-level monitoring is very important to ensure reliability, safety, and efficiency in electric vehicle battery management systems.

2. LITERATURE SURVEY:

Hernandez et al. (2021) consider optimizing the charging of electric vehicles using advanced analytics on the Internet of Things. This paper emphasizes the significance of utilizing real-time data to optimize the charging process, which can lead to substantial benefits in energy management and operational efficiency. By leveraging IoT technologies, the authors explore how data-driven strategies can effectively schedule charging times based on energy demand patterns and pricing signals from utilities. This optimization not only leads to savings in energy costs for users but also increases the overall efficiency of the charging system.

Kumar et al. (2021) highlight monitoring systems based on IoT applied to EV battery management systems. The paper introduces advanced monitoring techniques that contribute to the safety, efficiency, and longevity of EV batteries. The integration of IoT sensors into real-time monitoring frameworks allows for the continuous assessment of battery health, charging status, and environmental conditions. By employing predictive maintenance strategies, the authors suggest that potential issues can be identified and addressed before they lead to significant failures, thereby enhancing the reliability of EV battery systems. The use of IoT in battery management also enables better energy management strategies, optimizing charging cycles and prolonging battery life. This proactive approach is crucial in maintaining the performance of EV batteries, which are often considered one of the most critical components of electric vehicles.

Zhao et al. (2021) analyze the application of IoT and machine learning algorithms in the smart management of charging EVs. The authors provide evidence that machine learning can significantly enhance the performance of IoT-based charging systems through better anticipation of energy demand, optimized charging time scheduling, and improved decision making processes. By applying machine learning techniques to historical charging data, the system can learn patterns and predict future charging needs, allowing for a more adaptive charging infrastructure. This predictive capability is particularly valuable in urban environments where charging demand fluctuates widely throughout the day.

3.PROPOSED METHODOLOGY:

The proposed system is an IoT-based monitoring and management solution for electric vehicle battery packs, which provides the required safety, efficiency, and longevity through cell-level monitoring. The design was done around the ESP32 microcontroller using voltage, current, and temperature sensors to collect, process, and transmit real-time data concerning battery performance. The voltage sensors monitor individual cell voltages and detect imbalances that would indicate potential failures or degradation. The charge and discharge currents are measured using current sensors for the analysis of battery efficiency and load behaviour. LM35 temperature sensors are used for sensing overheating, so there is no thermal runaway. The sensor data is calculated by ESP32 after specific time intervals, and two most critical parameters SoC and SoH are calculated. SoC is obtained through integration algorithms of voltage and current. SoH evaluates the degradation of the battery based on capacity fade and internal resistance. The processed data is transferred through the ESP32-based Wi-Fi to a cloud-hosted remote dashboard. It acts as an interface for fetching real-time metrics such as voltage, current, temperature, SoC, and SoH with trend analytics for anomaly detection, trending, and long-term battery trends. It sends alerts once the critical conditions like overvoltage, overcurrent, or overheating are reached, thus making advance fault detection possible. The system reduces operational costs and optimizes the charging efficiency, thus elongating the lifespan of the battery. It ensures that batteries operate within safe parameters, thus improving the reliability and safety of EVs. Users can address issues quickly by utilizing real-time insights and data-driven alerts, which helps improve overall battery management and supports the sustainable adoption of EVs.

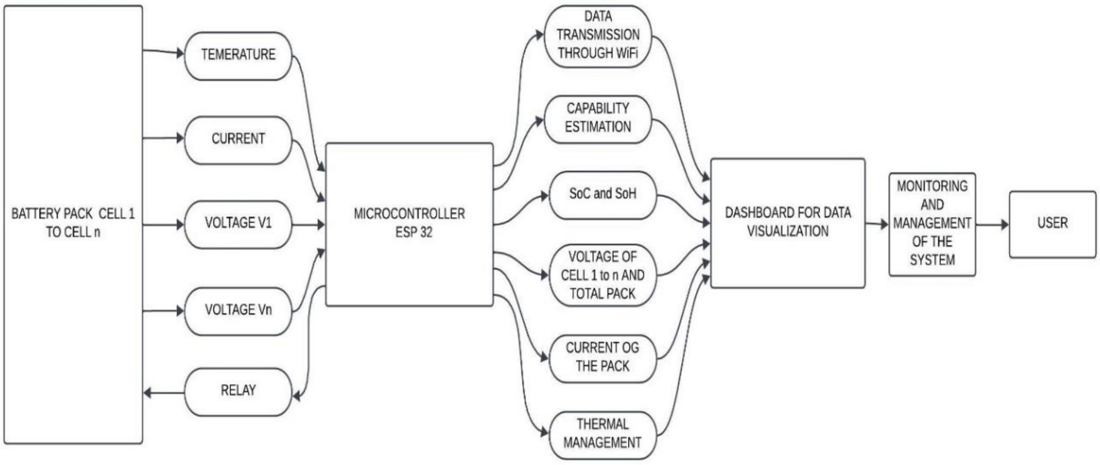

Figure 1: Block Diagram of the Overall System

3.1 HARDWARE:

The hardware part includes the deployment of the sensors and data acquisition of data from sensors through microcontroller and transfer of data to dashboard for visualization. The hardware includes the below described,

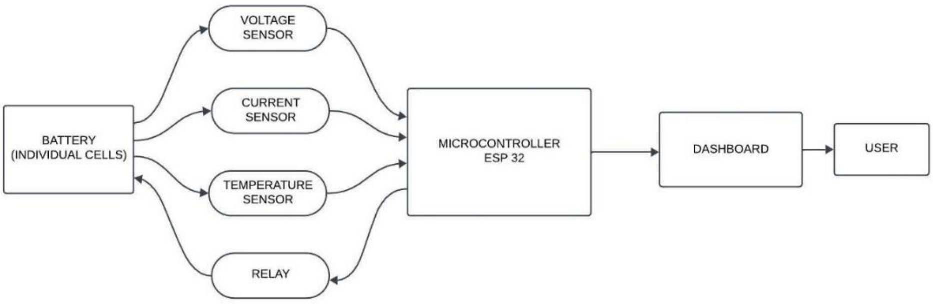

Figure 2: Block Diagram of the Hardware Setup

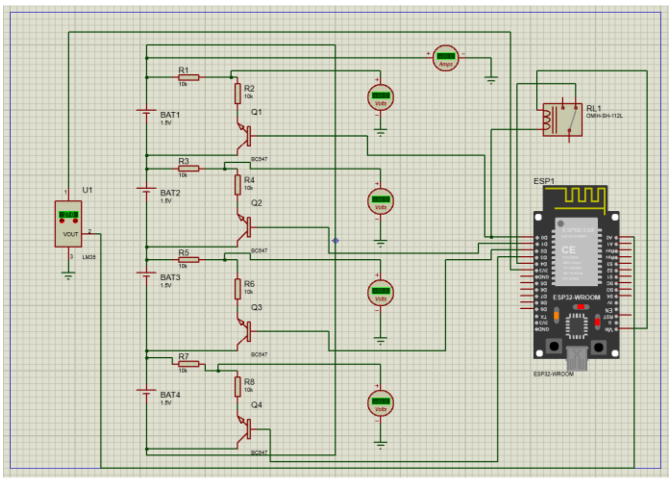

Figure 3: Circuit Design of the Hardware Setup

3.2 TARGET BOARD:

A device in which a microcontroller, Analog to digital converter (ADC), Digital to analog converter (DAC), crystal oscillator and other electronic components are fabricated on a printed circuit board is known as the target board. Here in this system the target board is ESP32.

3.3 VOLTAGE DETECTION MODULE:

The voltage sensors monitor each cell of the battery pack. The voltage measures the voltage of each cell, and it transmits the analog signals to the ADC of the ESP32 microcontroller. Since the ESP32 will work at 0 to 3.3 volts, a voltage divider takes the higher cell voltages, for example, 3.7 V, to a readable range. This is the formula for voltage divider:

$$Vout = Vin \times R2 / (R1 + R2)$$

The ESP32 reads Vout, computes the actual cell voltage, Vin, and sends it to a cloud server or dashboard. Real-time monitoring identifies faulty cells, prevents overcharging/undercharging, improves safety, and maximizes battery life through optimized charging.

3.4 CURRENT DETECTION MODULE:

The system uses a sensitive Hall-effect current sensor, such as the ACS712, to monitor the current flowing through each battery cell. This keeps things safe and efficient and makes the battery last longer. The sensor gives a voltage that matches the current, expressed as:

$$I = (Vout - Voffset) / Sensitivity$$

Where I is the current, Vout is the sensor output voltage, Voffset is the zero-current voltage (e.g., 2.5V), and Sensitivity is the sensor's gain (e.g., 185 mV/A). The ESP32 reads and processes the sensor output using its ADC, converting it into digital data. Real-time monitoring enables fault detection, overcharge/undercharge alerts, and predictive maintenance, ensuring optimal performance.

3.5 TEMPERATURE SENSOR:

The LM35 temperature sensor is very important in checking the temperature of the EV batteries. This keeps it safe and from thermal runaway which can make it have shortened life as well as set fires. The LM35 provides accurate temperature readings: ±0.5°C from -55°C up to 150°C; its output voltage increases as the temperature rises:

$$T(°C) = Vout(mV) / 10$$

ESP32 is taken in by ADC as it takes in an analog output from the LM35, processes it, and then sends real-time temperature readings to the IoT dashboard wirelessly. This way, actual real-time monitoring may kick in cooling systems or charge-stopping when overheated, keeping the battery protected, lasting longer, and working well.

3.6 SOFTWARE:

The software part includes the collection of data from the microcontroller and processing of the data and visualizing it in a dashboard for further analysis. the software includes the below described,

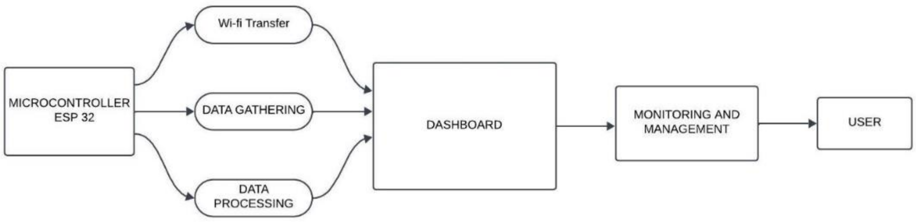

Figure 4: Block Diagram for the Software Setup

3.7 VISUALIZATION DASHBOARD:

This web-based system monitors and manages the EV charging systems using Firebase for data management, HTML/CSS in the front end, and JavaScript in the back-end logic. The system acquires data from a connected ESP32 microcontroller that has voltage, current, and LM35 temperature sensors. Through the transistor in this system, it captures accurate voltage at supported time intervals that aid cell balancing to ensure optimum performance in the battery. The ESP32 continuously sends sensor data to Firebase, which stores and manages the data. The backend logic is in JavaScript, and real-time visualizations are integrated with Chart.js. The user dashboard displays total voltage, current, temperature, and individual cell voltages with trends analyzed over weekly or monthly intervals. This complete visualization provides insights into system performance and battery health. Another most important concept of the system is predictive maintenance, which senses malfunctioned cells before harmful effects impact operational efficiency and potential failures. Health Indicators help users to diagnose their defective cells and prolong lifespan while under battery protection. In addition, features of cell-balancing ability ensure equalize charge transfer to all the cells. This platform, with real-time monitoring, remote access, and advanced IoT-based practices, upgrades the safety and efficiency of batteries as well as helps in decision-making. It also combines Firebase, JavaScript, and Chart.js to give reliable control, adaptive performance, and predictive maintenance to EV battery systems.

3.8 ALGORITHM OF THE SYSTEM:

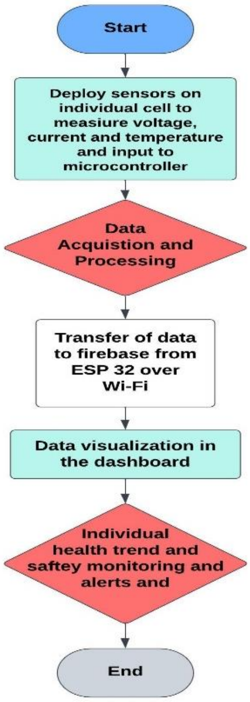

Figure 5: Algorithm of the system

5. RESULT AND DISCUSSION:

The IoT-based monitoring and management system for electric vehicle charging ensures that the battery is operated safely, efficiently, and reliably. Real-time data on voltage, temperature, and current from individual cells can be collected to address issues such as cell imbalance, overheating, and power inefficiency. It identifies imbalances through voltage monitoring that reduce performance, while temperature monitoring prevents overheating, which is the primary cause of battery degradation. The central dashboard will provide a view of the status of battery health and charging trends, thus allowing optimal charge schedules, such as those charged during off-peak hours to save on energy cost. Predictive maintenance avoids sudden failures, hence improving dependability and life span. This new system reduces waste energy, minimizes its environmental effects, and supports worldwide transition to sustainable transportation. It improves the performance of the battery but also helps consumers consume energy in smarter ways, thus increasing the reliability of EVs and supporting cleaner solutions for energy that meet ever-increasing demands for efficient technologies that are environmentally friendly.

5.1 OUTPUT OF HARDWARE:

The components making up this system include an ESP32 microcontroller, voltage sensors, relays, and an LM35 temperature sensor, which are all used for monitoring critical battery parameters. The relay is dedicated to every cell of the battery, so isolated voltage evaluation is performed and cross-interference minimized to improve measurement accuracy. The ESP32 reads in real-time values of single cell voltages, the total voltage, current, and temperature. This setup easily determines imbalanced cells or overheating, thereby ensuring battery safety and extending life. Testing confirmed the system's ability to provide accurate, reliable measurements over multiple charge cycles, making it suitable for EV applications and enhancing battery health management and charging safety.

Figure 6: Output of the hardware setup

5.2 SOFTWARE:

The software component collects the most critical battery data, like individual cell voltages, pack voltage, and temperature, and stores them. Through relays, the ESP32 microcontroller toggles to measure cell voltages and sends the data to the Firebase for storage and safe retrieval. With a cloud dashboard, the system provides smooth data visualization in terms of weekly and monthly trends in voltage, current, and temperature; this is helpful in monitoring health, predicting cell failures at an early stage, and identifying inefficiencies. The Firebase-integrated system enhances EV battery safety, efficiency, and longevity through consistent monitoring, proactive management, and timely maintenance alerts.

5.2.1 OUTPUT OF HOME PAGE:

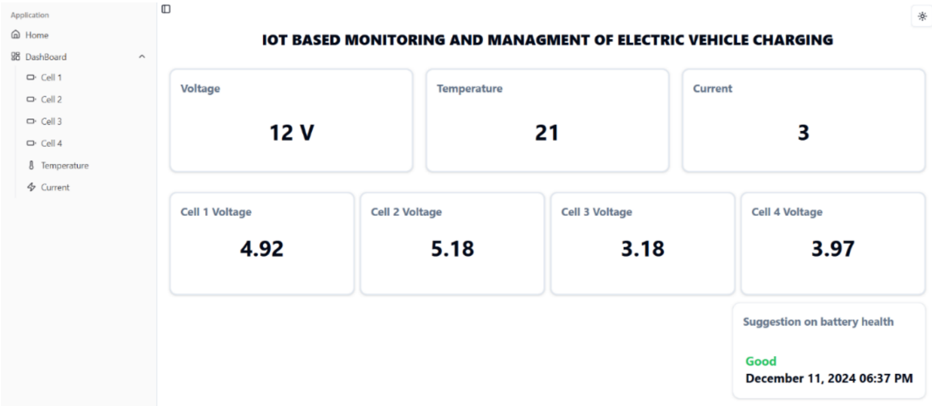

Figure 7: Home page of the dashboard

The dashboard displays the total voltage, individual voltage of cells, temperature of the battery pack and current collected from the battery pack. Also, the dashboard displays the weekly and monthly trends of voltage at cell level, current and temperature for the analysis of the battery health and efficiency.

5.2.2 OUTPUT OF INDIVIDUAL CELL VOLTAGE:

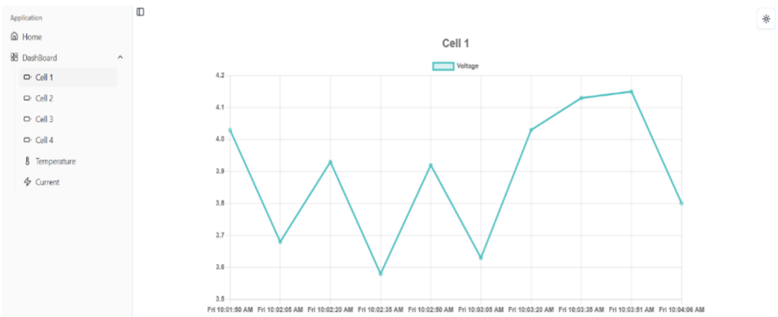

Figure 8: Cell 1 to n voltage analysis the dashboard

The above figure illustrate cell voltage analysis for cells 1-4 in the battery pack. Real-time and accurate voltage measurements are needed to monitor cell health and operational efficiency.

5.2.3 OUTPUT OF CURRENT FLOW IN THE CIRCUIT:

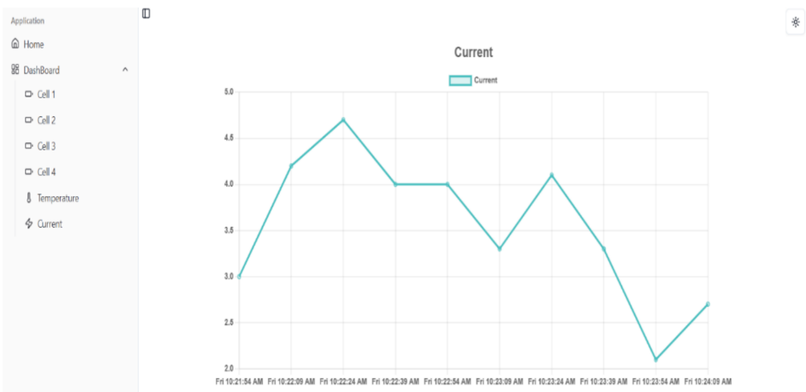

Figure 12: Current reading analysis in the dashboard

This figure represents the readings on the dashboard display that are critical to know regarding instantaneous current flow for safe and efficient charging.

5.2.4 OUTPUT OF TEMPERATURE OF THE BATTERY PACK:

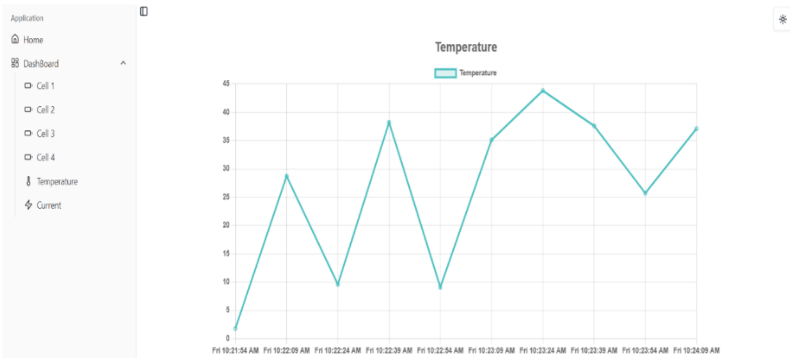

Figure 13: Temperature analysis in the dashboard

Displays temperature analysis display on dashboard could monitor the battery pack thermal conditions and avoid overheating conditions to enhance the safety aspect.

5.2.5 WEEKLY AND MONTHLY ANALYSIS OF THE PARAMETERS MEASURED:

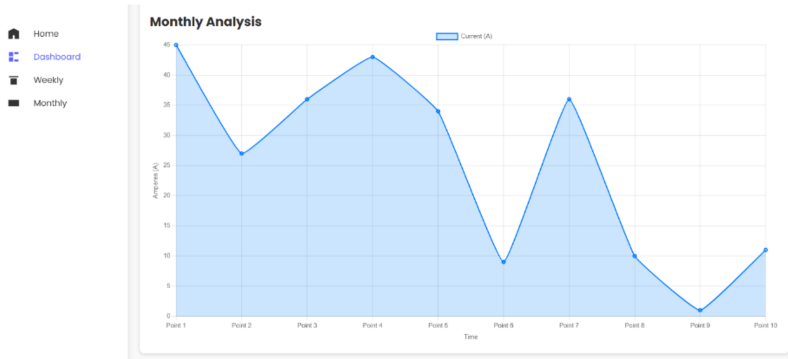

Figure 14: Weekly and monthly analysis in the dashboard

This display shows weekly and monthly data trends to analyze cell health, performance, and charging efficiency to allow for predictive maintenance and optimization.

6. CONCLUSION:

The IoT-based monitoring and management system for electric vehicle (EV) charging offers a significant advancement in EV technology. It overcomes key concerns associated with battery health, safety, and efficiency, it provides real-time monitoring of cells within the EV battery pack to optimize the charging process and ensure better power management while prolonging the life of the battery. Advanced sensors continuously feed data on critical parameters, such as voltage, temperature, and current, ensuring that the battery operates safely and reliably. This collection of real-time data prevents cell imbalances or overheating, providing predictive maintenance and making the chance of unexpected failure close to nil. A centralized dashboard can track real-time data and trends and provide a good view of how battery health and charging processes are performing. Such insights will inform the decisions of what to do for the maintenance schedule, such as optimizing the charge cycle; automatically cut off during off peak hours or power consumption reduction for lessened battery wear. Thus, overall better performance in the EV charging infrastructure is expected with safe and efficient use of the system. It is an IoT-based solution that will significantly contribute to more advanced EV charging infrastructure, ensuring smarter power management, increasing the safety and lifespan of batteries, and monitoring and managing charging processes at a cell level, thereby improving confidence of reliability in EVs, while contributing to the global push toward sustainable transportation. It aligns with the need for more efficient and environmentally friendly adoption of EVs, focusing on real time data acquisition and advanced analytics of the system.

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