Battery Management System with On-Demand EV Battery Service Network

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Abstract:

The pervasive use of electric vehicles is redesigning the current transportation sector, but even with all those developments, some prominent obstacles like the battery range and charging infrastructure are still not up to the mark. ChargeAlert is one of the IoT-based ondemand charging service networks that integrates an EV battery monitoring system to eliminate some of these problems. Evelta INA219 Voltage/Current Sensor monitors the real-time batteries while the ESP32 Xiao C3 microcontroller addresses wireless communication and cloud-based analytics. The user can get status information of a battery's charge level and demand for local charging service providers through a mobile application. ChargeAlert also introduces the principle of a bi-directional converter, which enables an energy transfer between EVs. Vehicles can thus temporarily supply or share power with other vehicles. This paper identifies and details the technological components, system architecture, and data processing capabilities of real-time data of ChargeAlert that might revolutionize its way of using the energy from EV batteries in operating electric vehicles, in a more efficient way of unrelenting state-of-the-art comfort. The system cuts Charging anxiety and creating a more robust, reliable EV infrastructure.
Keywords: Electric Vehicle (EV), IoT-based Battery Monitoring, Bidirectional Converter, On-Demand Charging Network, State of Charge (SoC), Energy Sharing, ESP32 Xiao C3, Evelta INA219, Battery Management System (BMS), Mobile Application.

I. INTRODUCTION

The trend around the world toward electric vehicles (EVs) will be dominated by the demand for cleaner, more sustainable forms of transportation, although among the biggest challenges to further uptake persists-and that remains limited battery range. Worrying about how far consumers could drive before the battery runs out is becoming fearfully daunting considering the lack of charging infrastructure in many places, a phenomenon often referred to as range anxiety that huge stress for EV drivers, especially in underprivileged or underserved areas, where charging stations could be rare.

ChargeAlert was designed to solve these problems by providing an IoT-based real-time battery monitoring platform along with the network of on-demand charging services. ChargeAlert always keeps track of the State of Charge (SoC) of an EV'S battery and also sends out alerts to the user if the battery is running low, and at the same time provides a mobile application interface in which they can request charging services from providers in the immediate locale. In addition to its ability to monitor in real-time, ChargeAlert features a bi-directional converter that enables the transfer of energy between the vehicles, which also enhances the variety of charging alternatives available to the users.

This paper discusses the technological underpinning of the ChargeAlert system: Hardware components and subcomponents of the system, communication protocols, Data processing mechanisms, and the user interface. Real-time monitoring is at the core of the paper. ChargeAlert is likely to reduce range anxiety and make owning an EV far more convenient, while the efficiency of battery management is slated to be improved.

II. METHODOLOGY:

2.1 System Overview:

ChargeAlert is an all-in-one system for the EV battery, with monitoring, energy-sharing, and on-demand charging services in real-time. There are three main constituents in the ChargeAlert system:

1. **Battery Monitoring and Alert System**:

- This system core is built on the ability of continuously monitoring the State of Charge (SoC) of the EV's battery using Evelta INA219 Voltage/Current Sensor, as it data provides highly accurate results of the two parameters of voltage and current levels necessary for determining battery condition as well as remaining capacity.

- The sensor is integrated by means of ESP32 Xiao C3 microcontroller that processes the data and transmits it to the cloud. The ESP32 uses Wi-Fi to communicate with the cloud-based platform ThingSpeak, which stores and analyses the battery data.
- When the battery charge falls below a predefined threshold, the system sends a real-time alert to the user's mobile device via the ChargeAlert mobile application. This alert notifies the user of the need to charge their vehicle and provides options for requesting charging services.

2. **Bidirectional Converter**:

- One of the key features that ChargeAlert has is that it has a bidirectional converter. This means that this converter will allow for battery-to-battery energy transfer. It can work as a rectifier as well because it can convert the AC power from the utility line into DC power to charge the EV battery. Also, it works as an inverter because it can convert the DC power from the EV battery to AC to charge another EV or device.
- The two-way converter thus allows peer-to-peer energy sharing, which would be very useful in energy networks where such infrastructures are either non-existent or unreliable.
- Limited charging infrastructure. Two EVs can connect to share energy, making one vehicle able to top off its battery by power from another vehicle. This provides an added flexibility for the users of EVs since they are not as dependent on dedicated charging stations.

3. **Mobile Application**:

- ChargeAlert is the user application-the set that has a graphical interface to the battery status updates, notifications, and access to nearby charging providers. The application features a user-friendly interface that simulates that of an Ola or Uber ride hailing service; thus, the users can easily request charging assistance with just a few taps.
- Peer-to-peer energy sharing is also enabled within the app among EV owners, where they can supply energy and request energy from around the corner. This will establish a collaborative charging network that utilizes the potential which will enable individual EV owners to charge one another areas in which charging stations are not numerous.

2.2 Block Diagram:

The following block diagram illustrates the flow of data and energy within the **ChargeAlert** system, highlighting the key components and their interactions:

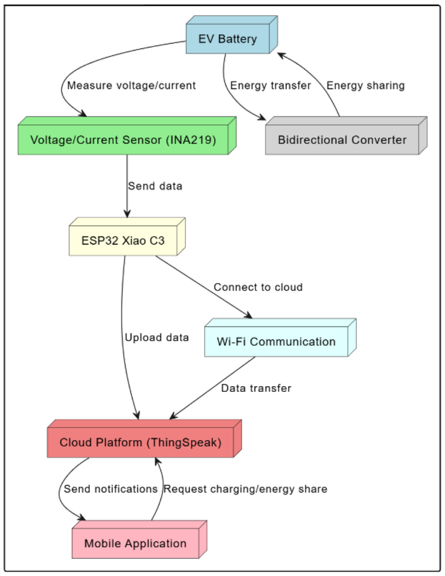

Fig 2.2.1 Block Diagram

- **Input**: EV Battery (48V-72V)
- **Voltage/Current Sensor (INA219)**: Monitors real-time battery voltage and current
- **ESP32 Xiao C3**: Microcontroller that processes and transmits data to the cloud
- **Cloud Storage and Analytics (ThingSpeak)**: Stores, processes, and analyses battery data, triggering alerts based on SoC thresholds
- **Mobile Application**: Receives alerts and provides access to charging services and energy-sharing options
- **Bidirectional Converter**: Enables bidirectional energy transfer for charging and energy-sharing between EVs

This architecture ensures seamless communication between the EV battery, the cloud platform, and the user's mobile device, providing notifications.

III. DESIGN ARCHITECTURE/HARDWARE CONFIGURATION:

3.1 Voltage Sensing Unit:

The INA219 Voltage/Current Sensor is highly imperative for the ChargeAlert system as it allows to acquire accurate measurement of voltage and current reading values of the EV battery. These values are very important because they can be utilized to calculate SoC to design an intelligent algorithm that will allow the system to determine and evaluate the health status of the battery in relation to its performance. The INA219 sensor has a resolution of 16 bits so measurements will be quite high accuracy for the real-time monitoring of batteries, such as electric vehicles. To protect the sensor and to make sure it stays within its safe voltage range to 26V, a voltage divider circuit is used. The battery voltage varies from 48 to 72, and the INA219 cannot withstand such voltage level, thus reducing it from that using R1 = 10kΩ and R2 = 8.36kΩ resistors, which were selected based on the reduction. Another 1N4749A Zener Diode is also provided in the circuit to act as a voltage surge protector that does not allow unforeseen instances of high voltage spiking to cause damage to the sensor.

3.2 ESP32 Xiao C3 Microcontroller:

The brain of the ChargeAlert system shall be the ESP32 Xiao C3 microcontroller, from which data will be processed from the INA219. The ESP32 shall have Wi-Fi connectivity by which it shall send the microcontroller is programmed in C++ and links the ThingSpeak API, which provides analytics and cloud-based data visualization capabilities. Using the ThingSpeak API, the system can monitor, process, and analyse battery data with the insights obtained in determining when to communicate the alert of the low battery to the user. Since the ESP32 has very low power consumption, The system does not consume a considerable amount of the battery of the EV during monitoring and therefore is an efficient solution for continuous operation.

3.3 Bidirectional Converter:

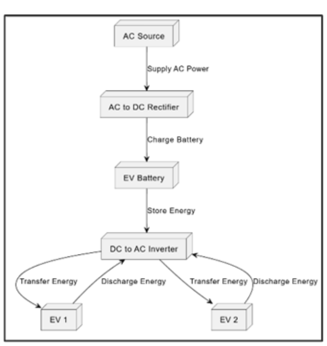

Fig 3.3.1 Bidirectional Converter Working

This converter is an integral component of the ChargeAlert system, thus enabling energy reversal from and to the device, making it possible to not only charge an EV's battery but to share energy with other vehicles as well. This component critically allows for the potential energy-sharing functionality of the system, as it enables two EVs to connect with each other to transfer energy from one vehicle to another. When an external source of power is being used to charge the EV, the converter converts AC power to DC to charge the battery. The converter acts as an inverter while the EV is giving up energy to some other vehicle, converting the DC power it draws from its battery into AC power to fill up the other vehicle's battery. This dual functionality enables the system to work satisfactorily even in places with shallow charging infrastructures.

3.4 Protection Circuits:

There are several protection mechanisms included in the ChargeAlert system design for safe and reliable operation of the system. The Zener diode included in the voltage divider circuit protects the INA219 sensor against damaging overvoltage spikes. In addition, circuit fuses and their equivalents are implemented in the system breakers to prevent overcurrent conditions; ensure current going through the battery and other associated components does not exceed dangerous levels.

IV. COMMUNICATION PROTOCOLS:

4.1 I2C Protocol:

The INA219 sensor sends voltage and current data to the ESP32 Xiao C3 microcontroller using the I2C communication protocol. The application suits the I2C protocol. The implementation of this protocol is straightforward and efficient in transferring information. This allows the sensor to present correct data to the microcontroller in a real-time fashion. With this protocol, the system can proceed with its intended task-monitoring the status of the battery-without undue delay or loss of information.

4.2 Wi-Fi Connectivity:

The ESP32 Xiao C3 is using Wi-Fi for internet connectivity and passing of data to the cloud server in ThingSpeak. The above connectivity will allow real-time streaming of battery data to be stored for analysis and give forth-time alerts on users' battery condition. This is one advantage of using Wi-Fi since there is no complicated wiring and infrastructure involved, thus easy to adopt in the integration of any EV.

4.3 Data Transfer to ThingSpeak:

Once the ESP32 has relayed the battery data to ThingSpeak, the cloud server processes and saves the data, and notifies of alarm conditions if any. The system is configured to throw alarms on the user smartphone application whenever the SoC of the battery falls below a dangerous level to ensure that the user receives timely information to act on appropriately. The ThingSpeak API further this will make the system do predictive analytics to enable a user in informing them on how healthy and when their battery should be charged.

V. DATA FLOW AND PROCESSING:

5.1 Data Capture:

The INA219 sensor is always capturing real-time data about the voltage and current of the battery. This data is necessary to calculate the State of Charge (SoC) so that the system may accurately report the health and performance of the battery.

5.2 Data Transmission:

After the INA219 sensor captures its data, it sends it to the ESP32 Xiao C3 microcontroller through the I2C protocol. The ESP32 then processes the data and uploads it to a cloud platform using Wi-Fi.

5.3 Data Storage and Analytics:

ThingSpeak also saves and analyses the data related to the battery; it logs and processes the data to establish an alert at what point, resulting in sending. ThingSpeak has real-time data visualization capabilities; thus, it is easily accessible to users a way of monitoring the SoC trend with time. Predictive analytics also can be used to monitor potential forecasted failures based on a trend that has emerged.

5.4 Alert System:

When reaching at a certain level below the SoC, an alert from ThingSpeak is sent to the mobile device of the user through ChargeAlert App. The alert message is shown to the user that his or her battery is low and offers charging services options for close-by providers.

The entire flow and processing are shown in the following flowchart:

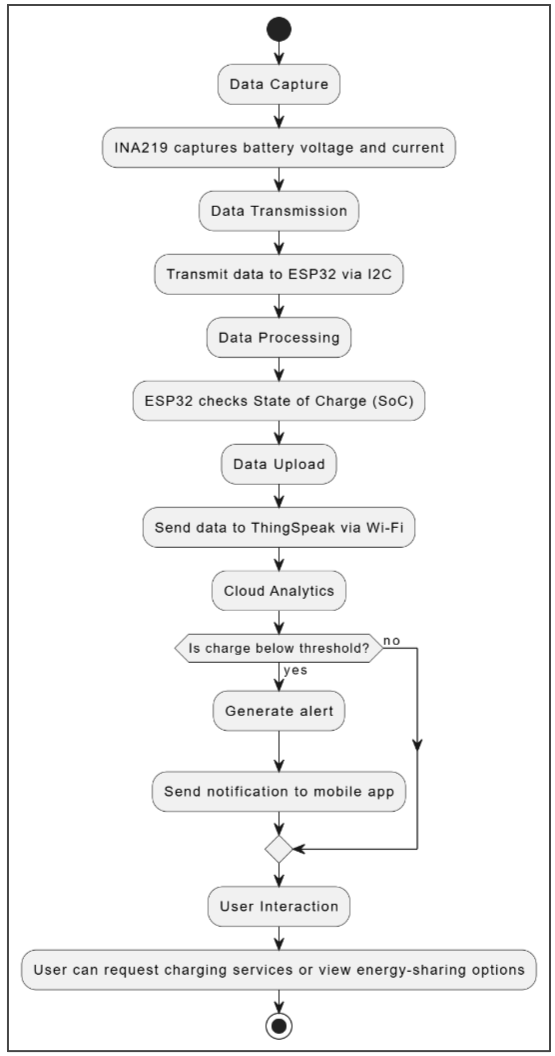

Fig 5.4.1 Data Flow and Processing

VI. SECURITY CONSIDERATIONS:

6.1 Data Encryption:

Data encryption is made through the application of encryption protocols during data transmission from ESP32, cloud, and mobile app to ensure data security. It cannot be intercepted by unauthorized parties or even accessed while in transit due to its encrypted format.

6.2 User Authentication:

Before accessing ChargeAlert mobile app, users are authenticated using the secure login procedure. Only the authorized users will have access and view information regarding the battery of the EV. Additionally, it can request charging services. This ensures that no one gains unauthorized access into the system; it also ensures confidentiality of user's data.

6.3 Network Security:

Since the system uses Wi-Fi connectivity, the security of the network has to be realized. WPA2, among other security measures, is used by the system to make the network secured from any unauthorized access as well as ensure that data transfer within the network should be secure.

VII. USER INTERFACE AND USER EXPERIENCE(UI/UX):

7.1 User Dashboard:

The ChargeAlert mobile application will provide the users with a real time dashboard of the current state of charge and voltage, current levels of their EV's battery. The dashboard shows predictive analytics which estimates how much longer the battery will last be based on the pattern of usage.

7.2 Notifications and Alerts:

The application will send push notifications to alert the user when the battery is running low or when an energy-sharing opportunity is available nearby. These notifications are quick-time and actionable so users can now respond to their battery-related issues immediately.

7.3 Energy Sharing Feature:

The energy sharing feature allows users to view nearby EVs which are available for the exchange of energy from one battery to another. Directly from the app, the users will be able to request or offer any services related to energy sharing, thus creating a peer-to-peer charging network that enhances EV users' flexibility in charging options.

7.4 Integration with Charging Providers:

The app interface features a map view where it gives the charging providers nearest to the person, and a person can request on-demand charging services as easily as requesting a ride through Ola or Uber. It connects users to local charging providers for easier identification of charging solutions in urban and rural settings.

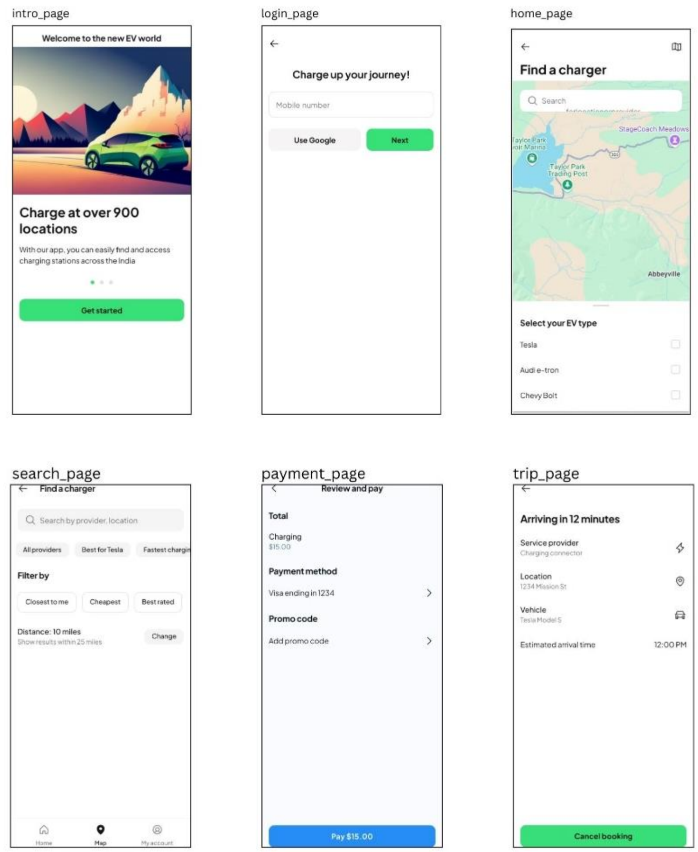

Fig 7.1 UI of the mobile application

VIII. PERFORMANCE METRICS:

8.1 Sensor Accuracy:

The INA219 sensor gives measurements that are extremely close to the actual ones, thus providing accurate data about the battery captured by the system. The system has an error margin of less than 1%, which makes it suitable for monitoring batteries in electric vehicles in real-time.

8.2 System Latency:

System latency refers to sending the alerts on time to the user. The ESP32, the microcontroller and communication protocols of Wi-Fi are optimized to decrease latency thus minimizing the time between data capture, processing, and notification. The general expectation of this system's latency is set to be less than 5 seconds, hence ensuring real time operation.

8.3 Energy Transfer Efficiency:

The bidirectional converter applied in the system can exchange with a 90-95% efficiency, thus reducing energy loss that will occur during the transfer from one battery to another. That's how energy sharing between vehicles is practical. This does not cause any considerable power losses.

IX. LIMITATIONS AND CHALLENGES:

9.1 Limited Charging Infrastructure:

The primary restriction ChargeAlert system faces from the charging provider is the availability, especially in rural areas. Although the system is designed to reduce dependence on fixed stations through peer-to-peer energy sharing, it remains bounded by the availability of nearby willing EVs to share their energy.

9.2 Long-Term Battery Health Predictions:

Although the system monitors and alerts in real-time, long-term battery health is not easy to predict. To accurately predict long-term efficiency, large datasets and intricate algorithms that factor in variables such as temperature, driving habit, and age will need to be developed. There is still much to be done before the system is adequately able to predict how fast the batteries are going to deteriorate.

9.3 Connectivity Issues:

Also dependent on Wi-Fi. So, it may not work well in poor internet areas. Access. There are also areas where either cellular networks or alternative means of communication will be necessary to ensure that the system is working reliably in rural or other remote areas.

X. FUTURE SCOPE:

10.1 Smart Grid Integration:

Future path of ChargeAlert lies within the mains, as it forms an interface to integrate with smart grids that can optimize energy distribution based on real-time demand and supply. The system shall relate to the smart grid, thus actively modifying energy flows to enable charging in off-peak times when electricity is relatively less expensive and readily available.

10.2 Predictive Maintenance Using Machine Learning:

Other areas for future work are the addition of machine learning algorithms to provide more sophisticated predictive maintenance. Historical data about battery health could be utilized to predict failures and further optimize charging cycles to enhance the life of batteries and lower the cost of maintenance.

10.3 Global Scalability:

As the market of electric vehicles grows, there is room for ChargeAlert to scale the number of possible charging by implementing international charging standards, providers may cover a wide area. In this way, a global network of energy-sharing-enabled vehicles can make ChargeAlert the central component of the EV ecosystem around the world.

XI. CONCLUSION:

The ChargeAlert system produces an innovative solution to the barriers of battery range anxiety and limited charging infrastructure that are currently hindering the rollout of electric vehicles. In fact, it can be seen as a source that provides real-time monitoring for batteries, on-demand charging services, and even shares energy among various vehicles to improve the user experience and overall efficiency of EV battery management. The integration of IoT technology, bidirectional converters, and mobile app interfaces with this system turn it into a comprehensive tool for modern users of EVs while its potential in smart grid integration and predictive maintenance gives further light to the system's evolvement in step with advancement in the EV market. Future research and development will enhance scalability, reliability, and long-term forecast ability of battery health.

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