Development of IoT-Based Dual-Channel Battery Charger with Real-Time Monitoring

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Abstract— **The development of efficient and controlled battery charging systems has become increasingly important with the growing use of electronic devices and energy storage systems. This research aims to develop an Internet of Things (IoT)-based charger monitoring and control system for optimizing the 12 V battery charging process. The developed system employs a dual-channel architecture capable of serving two batteries with automatic and manual operation capabilities. The main system components include a voltage divider-based voltage sensor, ACS712-5A current sensor, ESP32 microcontroller, dual-channel relay, and a Nextion 2.7-inch LCD touchscreen as the user interface. The IoT platform utilizes the Blynk application, enabling remote monitoring and control via smartphone. Test results demonstrate that the system is capable of monitoring charging parameters with high accuracy and providing responsive control both locally and remotely. The system successfully implements adaptive automatic charging logic based on battery conditions and provides safety features to prevent overcharging. This research contributes to the development of smart charger technology that can improve charging efficiency and extend battery lifespan.**

Keywords— ***IoT, battery monitoring, automatic charger, power charging, ESP32***

I. INTRODUCTION

In the modern era, the use of batteries as a power source has been increasing, particularly in portable electronic devices, Electric Vehicles (EV) [1], [2], [3], Uninterruptible Power Supply (UPS) systems, and renewable energy systems such as Photovoltaic Energy Storage Systems [4], [5]. However, non-optimal battery charging remains a major challenge in these various applications. Inefficiency in power charging can cause several primary problems, such as battery capacity degradation [6], [7], [8], increased risk of overcharging and undercharging [9], and uncontrolled high energy consumption [10].

One common problem in conventional battery charging systems is the dependence on manual control methods or simple timer-based systems that do not consider the real-time condition of the battery. These systems are unable to automatically adjust current and voltage according to battery requirements, resulting in faster degradation and reduced battery lifespan [6], [11], [12]. Furthermore, the lack of monitoring of key parameters such as voltage, current, temperature, and state of charge in conventional systems potentially increases the risk of system failure and even fire due to excessive heat [3], [13].

With the development of Internet of Things (IoT) technology, remote monitoring and control of the charging process can be performed more effectively [3], [14], [15]. IoT enables the integration of sensors to read key battery parameters in real-time and transmit data to web-based platforms or mobile applications for further analysis. This system also enables more adaptive and automatic power regulation based on actual battery conditions, thereby improving energy efficiency and extending battery lifespan [6], [7], [9].

Several IoT-based battery charger systems have been reported in the literature. Husin and Hisham [12] proposed a single-channel smart charger using a microcontroller and CC–CV algorithm. Inti et al. [3] developed an IoT-based hi-tech charger for electric vehicles with a single-channel output and Wi-Fi connectivity. Kirdpipat et al. [4] demonstrated solar battery charging monitored via a smartphone application, but without automatic multi-channel management. Compared to these systems, the proposed work introduces (1) a dual-channel architecture enabling simultaneous and independent charging of two batteries, (2) adaptive cut-off logic per channel, and (3) channel isolation verified under concurrent operation.

Based on these conditions, the development of a battery charging system capable of monitoring critical parameters in real-time and implementing adaptive automatic control is necessary. An ideal system should be able to monitor voltage, current, and battery temperature with high accuracy, automatically adjust charging parameters based on battery conditions, and provide an interface that enables remote monitoring and control. The main challenges in developing such a system include the integration of accurate monitoring sensors, the implementation of responsive and safe control algorithms, and the development of a reliable IoT platform for remote operation.

II. METHODS

A. System Architecture

The developed system employs a modular architecture that integrates three main components: a monitoring system, a control system, and an IoT platform. This architecture is designed to provide flexibility in development and ease of system maintenance. The monitoring system functions to perform real-time acquisition of charging parameter data, the control system is responsible for regulating the charging process based on detected battery conditions, while the IoT platform facilitates communication and remote control through a smartphone application. Fig. 1 shows the designed circuit schematic.

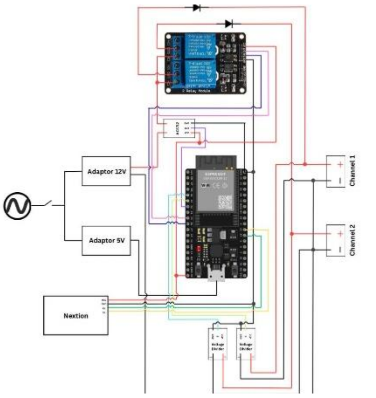


Fig. 1. Circuit schematic.

The main hardware components of the system consist of an ESP32 DevKit V1 microcontroller that functions as the central processing unit with built-in WiFi connectivity capability to support IoT communication. The monitoring system uses a voltage divider-based voltage sensor conFig.d for each battery channel, enabling independent monitoring of two 12 V batteries. The ACS712-5A current sensor is integrated for monitoring charging current with a measurement range of 0-5 A, suitable for battery charging applications.

The control system implements a dual-channel relay to perform charging switching control on each battery channel. The relays can be controlled independently, providing flexibility in managing multiple battery charging according to the conditions and requirements of each battery. The user interface uses a Nextion 2.7-inch LCD touchscreen that provides a local interface for system monitoring and control, equipped with LED indicators to display system operation status.

The software components consist of ESP32 firmware developed using Arduino IDE with integration of WiFi, Blynk, and specific libraries for the sensors used. The IoT platform uses Blynk as a cloud service that provides connectivity with mobile applications for remote monitoring and control.

B. Monitoring System Design

The main parameters monitored in this system include battery voltage from both channels and the charging current flowing during the charging process. Voltage monitoring on both channels uses a voltage divider sensor, and the ACS712-5A current sensor is used to monitor the charging current flowing to the battery. The voltage and current sensors have been validated, enabling battery voltage readings with accuracy consistent with readings on measuring instruments.

Sensor calibration was performed using a calibrated reference multimeter (Fluke 87V, accuracy ±0.05%) at five operating points spanning the full measurement range (10 V–15 V for voltage; 0 A–5 A for current). The resulting mean absolute errors were ±0.04 V (SD = 0.02 V) for voltage and ±0.05 A (SD = 0.02 A) for current, corresponding to deviations of approximately 0.3% and 1.0% of full scale, respectively.

C. Control System Design

The developed control system provides full flexibility to users to control the battery charging process according to operational needs and preferences. The main control system can be accessed through the Nextion LCD touchscreen, which functions as a Human Machine Interface (HMI) for direct interaction with the charger system. On the LCD display, various buttons and control menus are provided that enable users to control all aspects of system operation. The control interface is designed with a user-friendly approach, selecting the operation mode (Monitoring or Control), providing buttons to start and stop the charging process, and performing real-time monitoring of system status.

The control system integrates a 2-channel relay as the main actuator to perform the charging switching process on both battery channels. The relays can be controlled individually for each channel, providing flexibility in managing multiple battery charging. Relay control can be performed either manually through the LCD interface or automatically based on control algorithms programmed in the ESP32 microcontroller.

The manual control feature allows users to directly control the charging process, including enabling or disabling charging on specific channels. Meanwhile, the control algorithm programmed into the microcontroller allows the device to operate automatically according to predetermined parameters. The control algorithms are described in pseudocode below:

```
BEGIN
INITIALIZE sensors, relay_CH1 = OFF, relay_CH2 = OFF
CONNECT to Wi-Fi and Blynk server
LOOP every 2 s:
    READ V_CH1, I_CH1, V_CH2, I_CH2// from sensors
    DISPLAY V_CH1, I_CH1, V_CH2, I_CH2 on Nextion LCD
    TRANSMIT data to Blynk cloud
    FOR each channel CHx in {CH1, CH2}:
      IF mode_CHx == AUTO THEN:
        IF V_CHx < V_cutoff (14.5 V) THEN
          relay_CHx = ON   // connect adapter, charging allowed
        ELSE IF V_CHx >= V_cutoff (14.5 V) OR I_CHx <= I_cutoff (0.1 A) THEN
          relay_CHx = OFF  // disconnect adapter, charging complete
      ELSE IF mode_CHx == MANUAL THEN:
        relay_CHx = user_command  // ON or OFF from LCD / Blynk button
    END FOR
END LOOP
END
```

The pseudocode above describes the complete control logic executed by the ESP32 firmware. Upon startup, the system initializes all sensors and sets both relay channels to the OFF (open) state, ensuring no current flows to the batteries. The ESP32 then establishes a Wi-Fi connection and registers with the Blynk cloud server. Once connected, the main control loop executes continuously at a 5-second interval, which matches the data transmission interval used in the IoT communication stability test.

Within each loop iteration, the ESP32 reads the battery voltage from each channel via the voltage-divider sensor and the charging current via the ACS712-5A sensor. The measured values are simultaneously displayed on the Nextion LCD and transmitted to the Blynk cloud for remote monitoring via smartphone. Voltage and current regulation is handled entirely by the external fixed-output charger adapter, which inherently produces a CC–CV-like charging profile.

For each channel independently, the firmware evaluates the active operating mode. In automatic (AUTO) mode, the relay is closed (ON) as long as the measured battery voltage remains below the cut-off threshold of 14.5 V, allowing the adapter to charge the battery. When the voltage reaches or exceeds 14.5 V, or the charging current drops to or below 0.1 A, indicating that the battery is fully charged and the relay is opened (OFF), disconnect the adapter from the battery and prevent overcharging. In manual (MANUAL) mode, the relay state is controlled directly by the user through either the Nextion LCD touchscreen or the Blynk smartphone application, with no automatic cut-off logic applied.

D. *IoT Platform Implementation*

The IoT platform selected for implementation is Blynk, which provides a stable and user-friendly cloud-based infrastructure for remote monitoring and control applications. Blynk IoT platform integration enables the charger system to be accessed and controlled remotely through a smartphone application. In the customized Blynk application, users can set the charger operation mode to work automatically or manually according to usage requirements. Automatic mode enables the system to perform charging with optimized control algorithms, while manual mode provides full control to users to set charging parameters.

The smartphone application interface is designed with a comprehensive and intuitive display, providing real-time monitoring features that display voltage status and charging current for both battery channels. Monitoring data is displayed in the form of bars and numerical values that are easy to read and understand. Additionally, the application is also equipped with control buttons that enable users to activate or deactivate charging on each battery channel independently.

III. RESULTS AND DISCUSSION

A. *System Implementation*

The system has been successfully implemented with dual-channel charger specifications capable of serving two 12V battery chargers. The prototype is integrated in a compact enclosure with dimensions of 25cm × 20cm × 10cm. The system has been integrated in a modular configuration that facilitates ease of operation. The implementation enables monitoring of parameters such as voltage and charging current, as well as control of the charging process through a local interface or the Blynk IoT platform accessible through a smartphone application. Fig. 2 shows the prototype that has been created.

Fig. 2. Charger prototype.

Monitoring result data from all sensors is integrated and displayed in real-time on the Nextion 2.7-inch LCD touchscreen mounted on the charger unit. The monitoring interface on the LCD is designed with an intuitive and easy-to-understand display, showing the voltage values of both battery channels and charging current. Several available display menus can be seen in Fig. 3.

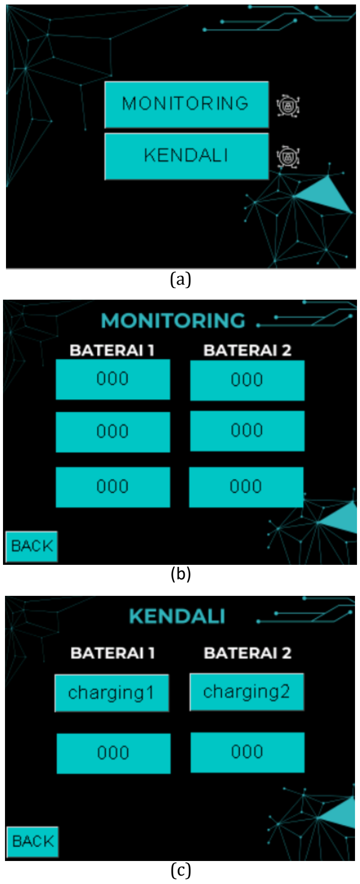


Fig. 3. Display of (a) main menu; (b) monitoring menu; (c) control menu.

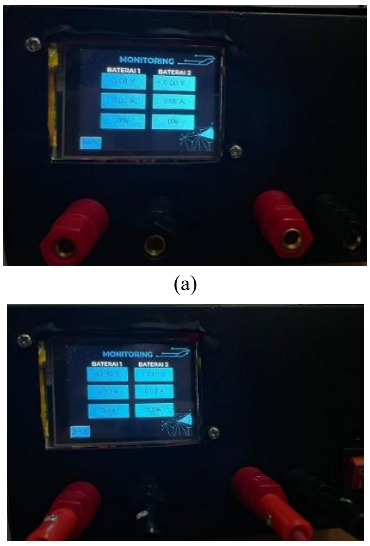
The main menu welcomes users with two options: "Monitoring" to view real-time data of battery status when the device is used in automatic mode, and "Control" to access manual charging control functions. When users select the Monitoring Menu, the screen will display real-time charging status for Battery 1 and Battery 2. The displayed data includes battery voltage, charging current, and charging percentage. Additionally, a "BACK" button is available for navigation back to the previous menu. Meanwhile, the Control Menu allows users to perform manual power charging. In this menu, there are buttons that can be used to activate or deactivate the charging process for each battery (Battery 1 and Battery 2).

Blynk IoT platform integration enables the charger system to be accessed and controlled remotely through a smartphone application. In the customized Blynk application, users can set the charger operation mode to work automatically or manually according to usage requirements. Automatic mode enables the system to perform charging with optimized control algorithms, while manual mode provides full control to users to set charging parameters. Fig. 4 shows the display available in the Blynk application.

Fig. 4. Display on the Blynk application.

B. Testing

The conducted testing validates that the prototype is capable of operating according to technical and functional requirements. The testing performed includes functional testing, battery charging characteristics, and IoT communication stability. System functionality evaluation includes verification of monitoring and control capabilities through both operation modes, namely local interface using LCD touchscreen and remote interface using the Blynk application on a smartphone. Fig. 5 shows that the monitoring system functions where there is a difference in sensor readings when the battery is before and after being installed on the charger.



(a)

(b)

Fig. 5. Monitoring display (a) before and (b) after battery installation

Test results demonstrate that the monitoring system is capable of performing real-time data acquisition and visualization of voltage and current, while the control system shows good responsiveness to instructions given through both operation interfaces. Additionally, Fig. 6 shows the monitoring data display sent in real-time through a smartphone application via an IoT system.

Fig. 6. Real-time monitoring data display.

Subsequently, battery charging characteristics testing was conducted on a 12 V – 20 Ah SLA battery, with a constant charging current of 3 A. Voltage and current parameters were recorded every 30 minutes during the charging process. The test results can be seen in Table 1.

TABLE 1. BATTERY CHARGING CHARACTERISTICS TESTING

Time (minutes)	Voltage (V)	Current (A)
0	11.80	3.00
30	12.10	2.98
60	12.50	2.95
90	12.85	2.90
120	13.15	2.80
150	13.40	2.65
180	13.65	2.40
210	13.90	2.10
240	14.10	1.60
270	14.28	0.95
300	14.50 (cut-off)	0.00

During charging. The battery voltage will continue to increase and will be read by the sensor until it reaches the cut-off value, and charging will be stopped automatically. Finally. Communication stability testing was conducted to assess the reliability of the IoT system in transmitting sensor data in real-time from the ESP32 microcontroller to the Blynk Cloud platform. The test data is presented in Table 2.

TABLE 2. IOT COMMUNICATION STABILITY TESTING RESULTS

Parameter	Average Value
Data packets sent	2160 packets
Packets successfully received	2120 packets
Data success rate	98,2 %
Average latency	1,9 seconds

Testing was conducted during 3 hours of continuous operation with data transmission intervals every 5 seconds. With this interval. The total data packets sent during 3 hours were 2160 data packets. From the test results. 2120 packets were successfully received by the server. while 40 packets (1.8%) experienced data loss (packet loss). generally caused by Wi-Fi signal interference and network latency. The value of 1.9 seconds is the average time delay between data sent by the ESP32 and received on the Blynk application on the smartphone. Measurement was performed using the timestamp comparison method. where each data packet includes the transmission time. then compared with the reception time recorded on the Blynk application.

C. Discussion

The IoT-based charger system developed in this research successfully integrates monitoring. automatic control. and remote communication functions effectively. The combination of the ESP32 microcontroller. ACS712-5A sensor. The Blynk Cloud platform enables data acquisition and real-time transmission with high accuracy and low latency.

Test results show that the system is capable of performing the charging process with stable constant current–constant voltage (CC–CV) characteristics. similar to commercial smart charger systems. In the initial phase (constant current). The current is maintained constant at 3 A until the voltage reaches approximately 13.6 V. Then the system transitions to the constant voltage phase with current decreasing exponentially to zero at 14.4 V.

This behavior is consistent with the research results of Husin and Hisham [12]. which states that microcontroller-based CC–CV algorithms can extend battery life up to 20% compared to manual charging without adaptive voltage control.

The communication system based on Blynk Cloud shows a data success rate of 98.2% with an average latency of 1.9 seconds. which is classified as very good for non-critical real-time applications. This value is consistent with the research results of Sangari et al. [10] and Gonzalez et al. [9]. which state that IoT-based monitoring systems with Wi-Fi protocol generally have a transmission success rate of 97–99% under standard network conditions.

With latency below 2 seconds. This system meets the needs of real-time data logging and remote control, as also proven by Inti et al. [3] on a hi-tech battery charger for electric vehicles.

The automatic system with a cut-off voltage of 14.5 V is proven to prevent overcharging that can cause electrochemical degradation in battery cells. According to Thomas et al. [11]. Overvoltage charging of 0.2V above the nominal limit can reduce effective battery capacity by up to 10% within 100 charging cycles.

With high-precision voltage control (deviation ±0.04 V). this system is estimated to extend the lifespan of SLA batteries by 15–25% compared to charging without intelligent control systems. Compared with recent IoT-based single-channel charger systems in the literature, this system offers dual-channel independent operation with comparable communication reliability. For instance, Kale and Chaudhari [6] reported a data success rate of 97.5% for a single-channel IoT battery monitor over Wi-Fi, while Sangari et al. [10] reported 97–99% under standard conditions; the 98.2% rate achieved here falls within this range and extends it to a dual-channel configuration. In terms of response latency, the measured 1.9 s average is consistent with values reported by Inti et al. [3] (approximately 2 s) for a single-channel EV charger. The primary system limitations are: (1) no dedicated NTC temperature sensor is embedded in this prototype, limiting thermal monitoring to fuse-level protection; and (2) scalability to more than two channels would require additional relay drivers and multiplexed sensing hardware. Integration with renewable energy sources such as solar PV is identified as a meaningful future direction, in which the CC–CV setpoints could be made adaptive based on available panel power.

IV. CONCLUSION

This research has successfully designed and implemented an Internet of Things (IoT)-based monitoring and control system to optimize the charging process for 12 V – 20 Ah SLA batteries. This system utilizes the ESP32 microcontroller as the control center. voltage and current sensors for monitoring main parameters. and the Blynk Cloud platform as the remote monitoring and control interface.

Test results show that the system is capable of monitoring voltage and current in real-time with high accuracy. The system is capable of performing battery charging processes manually or automatically and is equipped with an IoT-based monitoring system capable of maintaining IoT communication stability.

From these results. It can be concluded that the developed IoT-based charger system is capable of optimizing the battery charging process efficiently. safely. and adaptively. and provides ease of supervision through the integration of remote monitoring and control systems.

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