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Design and Construction of Remote Inverter Battery Management System

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Abstract – **The project aims to create a Smart Inverter Battery Management System (IBMS) with an Internet of Things (IoT) device. This device sends information to Blynk, a cloud-based platform, updating users about their home inverter on their smartphones in real-time. The IBMS is focused on improving solar power production and remote storage mechanisms, encouraging greener energy habits. The Blynk mobile application allows users to manage their power consumption based on battery voltage capacity. The central processor is an ESP32 Development Board comprising an ESP32 microchip for Wi-Fi/Bluetooth connectivity and a SIM800L module for Global System for Mobile Communications (GSM)/General Packet Radio Service (GPRS) communication. Smart grids could incorporate the IBMS, potentially transforming renewable energy management. Studies indicate that IoT with voltage and current sensors enhances inverters as eco-friendly power sources.**

Keywords- Remote monitoring, Inverter battery management, IoT integration, Energy management, Smart technologies, Renewable energy, Load management

I. INTRODUCTION

The global energy sector is facing tremendous challenges due to the need to mitigate climate change and achieve energy security. The solar power sector, as well as renewable energy in general, has seen an enormous surge as countries go green and embrace self-sustainability in terms of energy [1]. However, integrating renewable energy into existing infrastructure faces challenges, especially in terms of the effective functioning of storage systems like batteries. IoT has emerged as a key alternative for overcoming the limitations associated with conventional battery management techniques in renewable energy sources [2]. This refers to a network of physical devices such as sensors, software, and other technologies that enable those devices to connect and exchange data over the internet. These connected devices can be remotely monitored and controlled, thus leading to disruptions in various sectors [3]. In relation to renewable energy, it means that an IoT-based system can be created to facilitate real-time monitoring of battery health and performance from anywhere.

The proposed Integrated Battery Management System (IBMS) leverages the Internet of Things (IoT) to overcome the limitations of existing Battery Management Systems (BMS) in solar power. It uses IoT technology together with a relay system to provide remote monitoring and control that nullify limitations, thus making it a more sustainable and efficient battery management approach [4]. This study is centered on the design and development of an IBMS for solar power systems. The ESP32 development board is used for the project since it is cost-effective and efficient, as well as having Wi-Fi and Bluetooth functionality built-in. The technical scope includes both hardware and software components, where hardware consists of an ESP32 board plus additional sensors to measure real-time data about battery state [5]. The IBMS project determines the future of battery management and renewable energy. Real-time information about battery conditions enables it to provide predictive maintenance and optimum charging cycles for customers. This causes an extended lifetime of batteries that results in less waste of energy, leading to sustained growth, therefore integrating solar power or other renewable sources with higher efficiency and reliability [6].

It is important to note that the IBMS project can serve as a springboard for other innovations in this sector, which will be useful for future studies into intelligent power control systems. The results of the study conducted, in addition to present-day technology, are grounds upon which advanced adaptable solutions may be built to manage batteries and thus help combat rising concerns and promote sustainable energy use on a larger scale. The most vital aspects of an IBMS project signify enormous potential in battery management across many sectors [7]. It provides real-time information about key industrial equipment's battery health in order to enable predictive maintenance, eliminate costly downtime, and ensure critical machinery's dependability. Battery state remote monitoring also enhances home security systems by detecting any potential battery issues at an early stage and making sure that essential equipment remains powered all through [8]. Finally, IBMS sets up a basis for interacting smoothly with smart home technologies, incorporating battery health data into wider ecosystems, and thereby enabling automated operations that optimize power usage patterns across various devices.

II. LITERATURE REVIEW

The integration of smart technologies is transforming the energy industry. Notably, smart grids, renewable energy, and intelligent management systems are being integrated into these industries. Such technologies provide real-time tracking, automated regulation, and data-driven decision-making capabilities to enhance collaboration amongst different infrastructure components within these industries. Especially as climate change intensifies its impact on us, renewable energy sources are finding their place as critical elements in this digital revolution being led by smart grids. Intelligent management systems use advanced computation and wireless communication to efficiently determine energy usage while reducing waste and improving overall system efficiency. IoT plays a pivotal role in these systems as it enables smooth data transfer and remote monitoring [9].

A range of projects making significant contributions to our understanding of integrated digital solutions for the energy sector have emerged over time. For instance, "Development of an IoT Based Smart Inverter for Energy Metering and Control," a project by Umar et al., serves as an important contribution to the field's evolutionary landscape. This project's solar inverter system blends hardware functionalities with the simplicity of software interfaces, aiming for efficient power resource allocation. However, certain issues such as mobile application security hurdles associated with system capacity enhancement and the integration of camera modules or GSM modules among others need to be resolved [10].

Rathy's work on "IoT Based Smart Controlled Inverter" leverages Wi-Fi technology for two-way communication, which allows real-time tracking and load regulation capabilities to emerge. Meanwhile, another piece that adopts an all-encompassing approach for monitoring power consumption is Islam et al.'s "IoT Based Solar System Monitoring and Load Management for Small Farm." The research integrates meter tools like current sensors and voltage meters alongside IT tools like NodeMCU relay modules and the Sinric Pro app for real-time monitoring and load regulation [11].

The research papers discuss IoT-based systems for monitoring and managing batteries in microgrids with renewable energy sources. These systems utilize sensors to collect real-time data on battery parameters such as voltage, current, and temperature [12]. IoT technology enables remote monitoring and control of energy generation and consumption, facilitating efficient energy management [13].

A mobile application was created specifically for managing inverter systems, improving its overall usability and utility for home energy requirements. The application is made functional with the Blynk app's remote control features together with a special control device powered by an ESP32 microcontroller for energy-efficient operation.

Performance assessments indicate an accuracy level of roughly 94%, as well as exceptional precision at close to 1% [14].

A proposition was made to develop an online real-time surveillance and management system for a hybrid renewable energy system that consists of wind, photovoltaic (PV), and battery systems. The foundation of this setup is a Supervisory Control and Data Acquisition (SCADA) system integrated with the network infrastructure of National Cheng Kung University [15].

In the quest to find inexpensive and open-source SCADA solutions for remote inverter control and monitoring, the ESP12E-based Wi-Fi stood out as the most economical option that fit perfectly for customer-facing interfaces. Moreover, wireless remote surveillance and management systems were installed in solar PV distributed generators intended for use in microgrid applications [16].

The study concentrates on several initiatives aimed at boosting the productivity and safety of BMS. These comprise embedding ZigBee-based wireless sensor networks into PV systems for real-time oversight and regulation. It also involves creating an energy control system using lithium-ion batteries and building an Android-operated security and house automation system. The ZigBee-based scheme gives comprehensive data concerning the performance and condition of every PV unit, showing the benefits of Wireless Sensor Networks (WSN) such as self-fixing, self-arranging, and adaptability. The remote inverter BMS introduces improvements like better scalability, effective load handling, and an upgraded user interface [17].

The Android operated security and home automation system amplifies protection at house entrances and vehicle doors while giving control over room appliances through Bluetooth connectivity. This arrangement also synchronizes with three different frameworks, house security, house automation, and vehicle lock by Bluetooth communication protocol [18].

BMS are crucial for protecting and optimizing Li-ion batteries in electric vehicles and energy storage systems. This research has focused on developing cost-effective and reliable BMS designs using passive cell balancing techniques and Arduino microcontrollers [19].

This research has focused on optimizing BMS for Valve Regulated Lead-Acid (VRLA) batteries using the Coulomb Counting (CC) method. This approach accurately estimates the State-of-Charge (SOC) during charging and discharging cycles [20].

conducted studies on BMS, smart home automation, and smart home systems. Haq et al.'s project concentrated on the development of a BMS for Lithium Ferro Phosphate battery cells that measures battery parameters precisely, monitors unbalanced cell voltages, prevents overcharging and over-discharging while the BMS also acts as an effective data acquisition system that facilitates real-time monitoring and logging of battery performance [21].

Hasan et al.'s research, “Microcontroller Based Smart Home System with Enhanced Appliance Switching Capacity” has achieved a remarkable improvement in smart home automation where up to 208 appliances can be remotely controlled using a microcontroller-based Arduino UNO board and android application. The system however uses external circuitry thereby widening its versatility and user experience [22]

Hasan et al.’s paper “Smart Home Systems: Overview and Comparative Analysis” assesses various smart homes automation systems highlighting their strengths and weaknesses. The paper identifies Bluetooth-based solutions, voice recognition-based systems, IoT & Wi-Fi based systems as well as gesture-controlled automation for their simplicity and accessibility. Nevertheless, there are identified challenges that come alongside such approaches [23].

The project entitled "Enhancing Smart Battery Management System for Off-Grid Remote Homes through Design of Microcontrollers" is a major step forward in off-grid energy management. The incorporation of microcontrollers into the current BMS provides enhanced monitoring and control, thereby improving energy transmission efficiency and reliability to remote dwellers. The highlights include one axis solar tracking, SOC monitoring and controls, temperature monitoring and protection, load management; remote monitoring and controls using Graphic User Interface (GUI) and GSM [24].

Nonetheless, these systems have their own shortcomings, such as design complexity, which may call for specialized technical know-how in its installation and maintenance as well as dependence on GSM for remote controls. Another study by Hasan et al., 2019 explores the drawbacks of existing microcontroller-controlled smart home systems, with particular emphasis on appliance switching capacity limitation and manual switches integration. This proposed circuit allows for controlling over 208 appliances enhancing the functions to smart home systems making them more practical and versatile in everyday life [25].

Efficient battery management in residential applications becomes another project discussed by Pal et al., 2020. Monitoring parameters such as SOC, temperature, and current in a solar panel system linked with batteries for use at homes have been the main focus of this study, whose intention is increasing battery life and system effectiveness [26].

In the mid-20th century, SCADA systems marked the onset of smart energy technology. Smart meters, advanced metering infrastructure, and grid automation have grown, but concerns about cyber security and interoperability still exist. Distributed energy resources (DERs) and demand response programs are some of the trends shaping the traditional energy landscape [27].

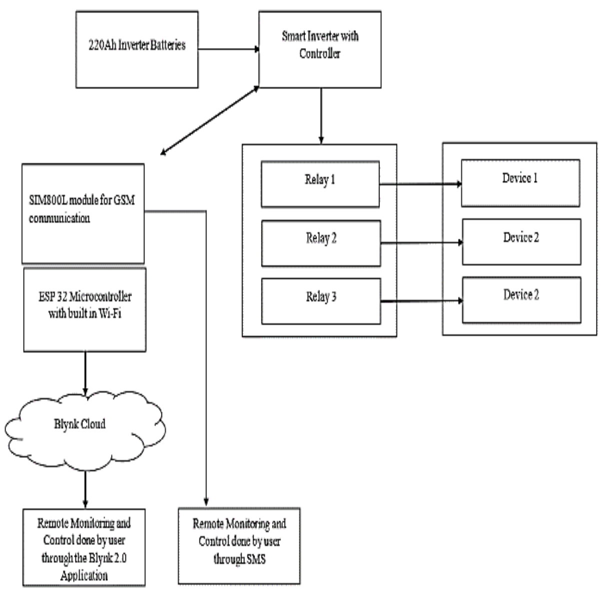

Figure 1: Block Diagram Integrated Smart Inverter Battery Management System

III. METHODOLOGY

A. Design and Analysis

This section gives a deep look into the research, which is very wide-ranging and the specific methodology that was used to achieve the project objectives. Financial resources are constrained; hence it becomes important to set clear and precise goals so as to avoid buying components that may not be right for the project. Thus, having a block diagram as shown in Figure 1 that maps out the research process is essential. It serves as a roadmap enabling researchers to identify appropriate methods consistent with the aims of their projects. This will enable them make effective use of its resources and keep it within designated limits toward achieving desired outcomes.

The methodology involved in this system includes different parts: The LILYGO module, The TTGO development board, The T-Call module, and ESP32 Development Board: primary controller board containing ESP32 chip for Wi-Fi/Bluetooth capabilities plus SIM800L module for GSM communication. The board serves as the Central Processing Unit (CPU) which is responsible for executing codes such as battery monitoring and load automation.

Additionally, a visual monitoring Artificial Intelligence (AI) camera is part of the system; thus, it allows users to monitor battery status or check for intruders in the installation environment. This 30A relay manages loads with high power capacities based on automation rules set in the system, making it capable of controlling heavy loads. The addition of 1N4001 Diode helps prevent any possible damage that may result from reverse current passing through a circuit, especially when used in power supply circuits.

Also, this 3mm Green Light Emitting Diode (LED) works as a light that gives some signals about the systems condition such as when you turn on your system, when you charge your battery or when a specific component of a circuit is activated. There is also a 60A Terminal Block which securely connects heavy-duty wires carrying current either from the battery or to loads. The ADS1115 Analog to Digital Converter (ADC) Module ensures precise measurements of analog signals like battery voltage by converting them into digital format compatible with the ESP32.

Moreover, this Tactile Switch can be clicked manually to achieve different functions within the system such as resetting and changing operational modes. A 12V, 10A power Supply provides the necessary power for the system's operation, especially for components requiring more power than the ESP32 board can directly provide. The 817C Optocoupler offers electrical isolation between the high-power and low-power sides of the system, safeguarding the microcontroller from voltage spikes.

The Buck converter is useful for reducing the voltage to a level that is suitable for components requiring low voltages. Furthermore, this 2004 Liquid Crystal Display (LCD) display shows real-time information of the system's state, such as battery voltage and current load. Eventually, the I2C Interface Adapter makes communication between microcontrollers and peripherals using I2C protocol easier; it reduces the number of connection pins required.

This system provides a holistic solution for energy monitoring and management by combining hardware components with software programming. Moreover, the integration of Blynk application allows users to get access to real time data concerning their energy consumption, alerts on over-consumption, and tracking their efforts in saving power. By doing so, this methodology guarantees a user-friendly interface and smooth communication between the smartphone application and energy meter thus enhancing end user overall experience while promoting energy savings.

1) ESP32 Devkit Module:

No calculations were carried out for the ESP32 devkit board shown in Figure 2, The microcontroller was programmed using Arduino IDE, the C programming language was used.

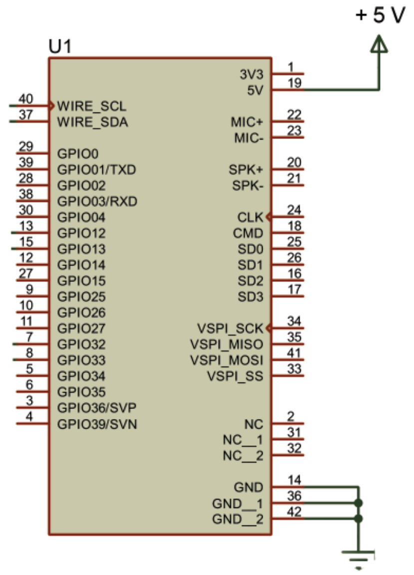

Figure 2: Schematic model of ESP32 devkit on proteus

2) Voltage Sensor:

The system is capable of reading voltage up to 100Vdc. Since this voltage is too high for the components used, it is scaled down to 5Vdc using a voltage divider, which is typically two resistors connected in series as shown in Figure 3. In the ESP32 code, there is a gain that multiplies this input to get the actual voltage. Using voltage divider formula shown in equation (eqn) 1:

$$V_{out} = \frac{R10}{R9+R10} \times V_{in} \quad (1)$$

$V_{out} = 5V$, $V_{in} = 100V$ and R4 = R10 = 10KΩ, from eqn 1, Solving for R9 and substituting these values into the resulting eqn, we have:

$$R3 = R9 = \left(\frac{V_{in}}{V_{out}} - 1\right) \times \ 10K\Omega \quad (2)$$

$$R9 = R3 = 190K\Omega$$

The desired value for the resistors in the voltage divider is given by eqn 2, however, there is no 190KΩ resistor with 5% tolerance so 180KΩ was chosen. To prevent inverse polar and overvoltage from the input, two diodes are connected to form a clamp.
For the positive Input:

$$\text{Max voltage} = 5V + 0.7V = 5.7\ Vdc$$

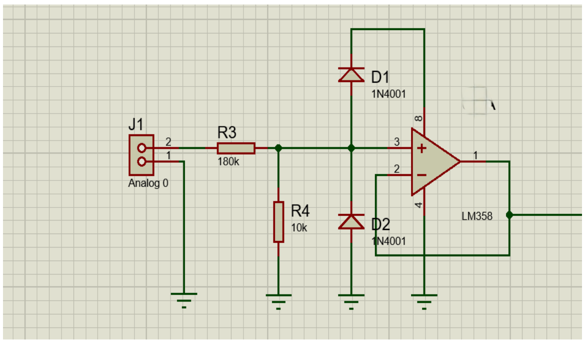

Figure 3: Voltage sensor using resistive divider and LM358 op-amp

3) ADS1115 Module:

The ADS1115 module converts the analog voltage from the voltage sensor into in digital signal and communicate the voltage to the ESP32 using Inter Integrated Circuit (IIC) protocol. The figure 4 below shows the connection.

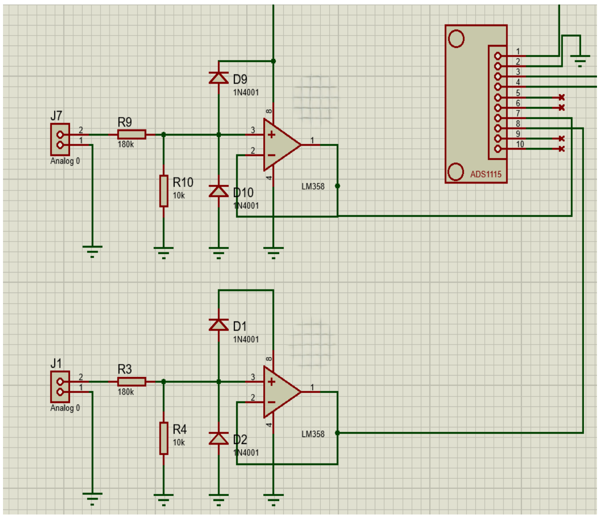

Figure 4: ADC using ADS1115 module

4) Relay:

The relay used is a T91-12V-C-5P, which is a relay rated 12V 30A with internal resistance of 400ohms.

Choice of Resistors: The BC337 acts as a switch, when closed the current through the relay is gotten using eqn 3:

$$I_{relay} = \frac{rated\ voltage}{rated\ resistance} = \frac{12}{400} = 30mA \qquad (3)$$

For the transistor to act like a switch eqn 4 has to be satisfied,

$$I_C = 10 \times I_B \qquad (4)$$

The factor of 10 in the eqn 4 comes from the current gain or DC current gain of the BC337 transistor. This parameter defines how much base current I_B is needed to control a specific collector current I_C when the transistor is used as a switch.

$$I_C = I_{relay} = 30mA$$

And, From eqn 4, making I_B subject and substituting our value for I_C we have,

$$I_B = \frac{I_C}{10} = \frac{30mA}{10} = 3mA \qquad (5)$$

This base current in eqn 5 comes from the phototransistor of the Opto-coupler as shown in figure 6. The forward voltage of the indicator LED (V_{Fi}) is 2.1V (GREEN LED), forward voltage of the photodiode of the Opto-coupler (V_{Fo}) is 1.2V (from the PC817C Opto-coupler datasheet), also from figure 6, it is seen that the resistor is connected to Vcc which is 12V. For the relay to be on, the voltage from the ESP32 pin must be 0v (logic 0), Hence the value of the resistor ($R = R6 = R8 = R12 = R14$) can be gotten using eqn 6:

$$R = \frac{V_{CC} - V_{Fi} - V_{Fo}}{I_B} = \frac{12 - 2.1 - 1.2}{3mA} \qquad (6)$$

$$R = \frac{8.7V}{3mA} = 2900\Omega$$

A 3kΩ resistor would be a close standard value, balancing protection and current flow. If the voltage (V_{Eo}) at the ESP32 pin is 3.3V (logic 1), we can calculate the current flowing through the resistor using eqn 7

$$I_{resistor} = \frac{V_{Eo} - V_{Fi} - V_{Fo}}{R} \qquad (7)$$

$$I_{resistor} = \frac{3.3 - 2.1 - 1.2}{3k\Omega} = \frac{0}{3k\Omega} = 0A$$

Hence no current flow. This calculation and circuit design is repeated four (4) times to obtain a four-channel control as shown in Figure 6. The 1kΩ resistor for the LED (R5=R7=R11=R13) is so placed to limit current for the indicator.

5) SIM800L Module

The Sim800L module also uses a Microcontroller from Simcom. It communicates with the ESP32 using UART with a Baudrate of 115200bits/sec. The connection is as shown below in Figure 5.

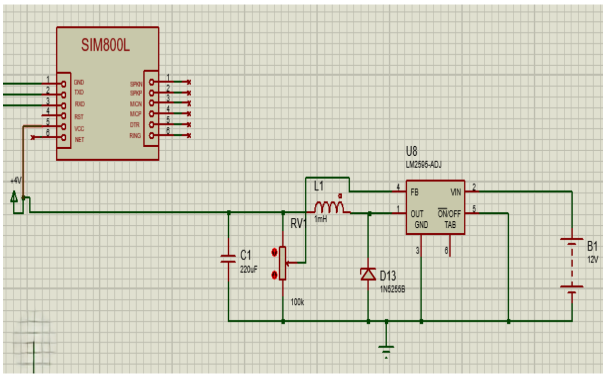

Figure 5: Sim800L interfaced with ESP32 Dev board

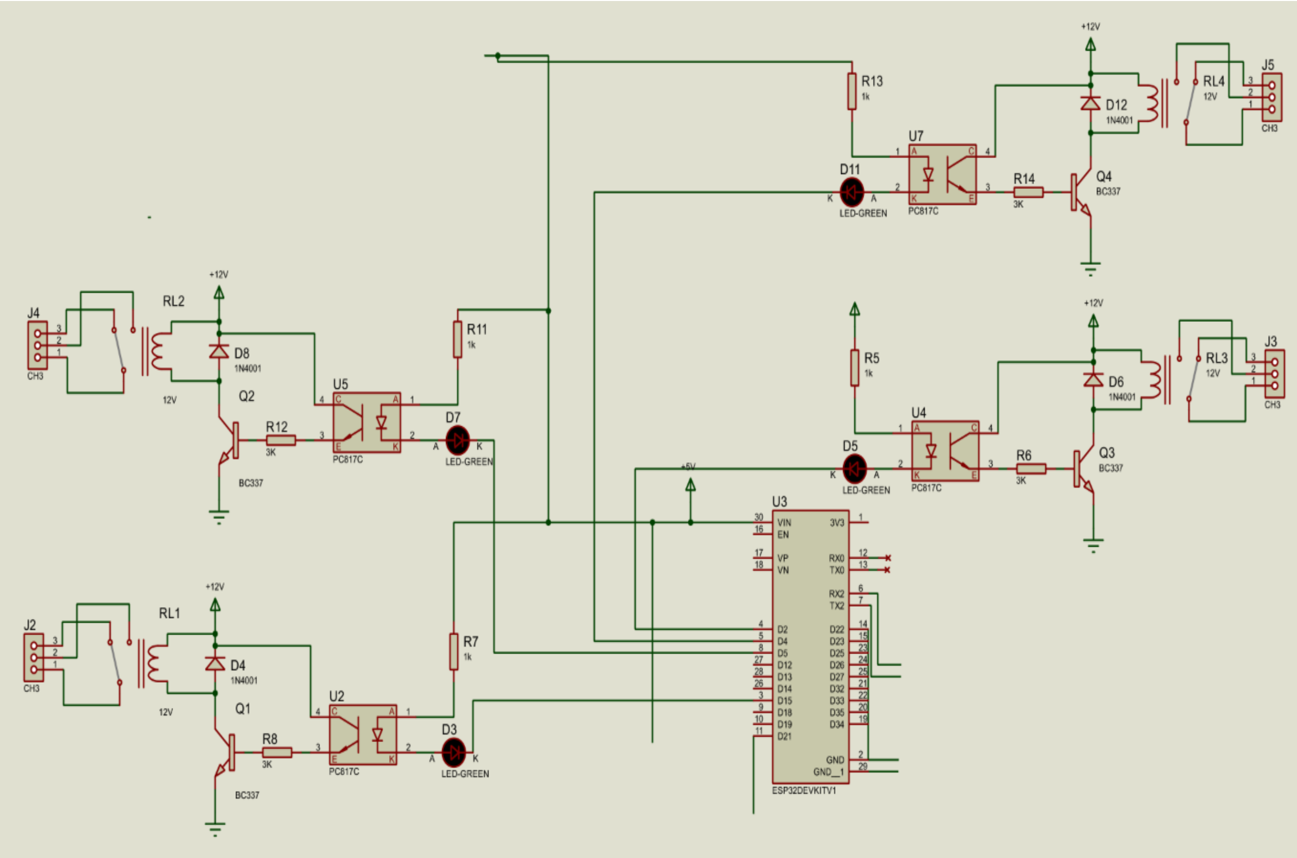

Figure 6: Relay circuit interfaced with ESP32 module

6) LCD 2004 DISPLAY (PCF8574T)

A 2004 LCD display with PCF8574 IC to convert the 16pins of the LCD display to 2 pins (SDA and SCL IIC). The LCD communicates with the ESP32 using IIC protocol. Figure 7 below shows the connection.

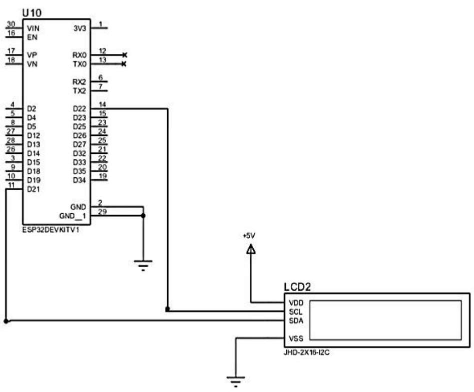

Figure 7: Interfacing LCD2004 I2C with ESP32 dev board

7) LM2596 DC/DC Buck Converter:

The LM2596 shown in Figure 8 is a buck voltage regulator IC designed to efficiently convert higher input voltages to lower output voltages. The schematics and component values used were the recommended values from the datasheet.

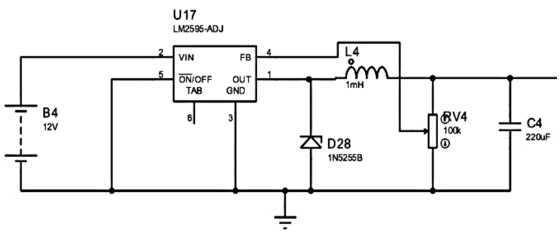

*Figure **8**: Buck converter*

8) AC-DC Converter:

The AC-DC Adapter was chosen to be 12V because of the 12V 30A relays, and then the max current was chosen to be 10A to provide the current needed by every component of the circuit. Hence a 12V, 10A ac-dc adapter.

9) YI IoT AI Camera:

YI IoT cameras are a popular choice for security in homes and businesses because they are cost effective, have great video quality, wide viewing angles and two-way audio capability. They provide motion detection and alarms so that real-time monitoring and communication can be done through the camera. For quick and safe access to video recordings, YI also provides cloud storage alternatives. They are flexible and easy to use because of their simple setup procedures, installation processes as well as compatibility with smart home systems. On the whole; YI IoT cameras do possess many capabilities that make them a great choice.

10) Blynk IoT Software:

Blynk IoT as shown in Figure 9 is an adaptable platform for IoT apps that features a user-friendly interface and works with many device types. It has dashboards which can be set up by users depending on their needs, thus making device control and monitoring a simple-to-use software feature. Blynk's cloud connectivity offers remote access, hence suitable for home automation or remote monitoring of devices via internet connection from anywhere around the world, especially when it comes to cloud services rendered by Blynk which makes this one perfect solution for homeowners who want to have all their gadgets interconnected within Blynk framework. To facilitate integration into projects, the platform provides libraries and APIs in multiple programming languages. Blynk is affordable for small scale projects or hobbyists who can enjoy its freemium model while upgrading if necessary to give room for some additional functions that may be found useful during further development of projects based on it alone. All things considered, Blynk IoT is a strong platform that offers the resources and adaptability required to develop cutting-edge IoT solutions.

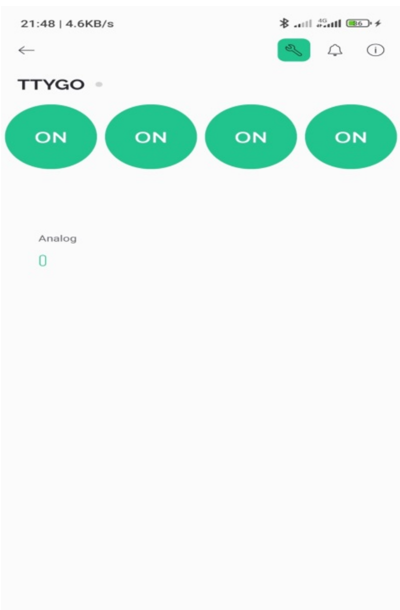

Figure 9: Blynk IoT

B. Working Principle

The Sim800L module searches for an available network after being powered on, depending on the SIM card inserted. The ESP32, on the other hand, starts executing its code and waits for the SIM800L to locate a network. When it is done with this process, then the SIM800L receives a signal from the ESP32 via universal asynchronous receiver-transmitter (UART) that will enable it to establish an internet connection. Therefore, the Access Point Name (APN), username, and password for internet configuration are entered into the ESP32 and saved in the Sim800L module.

Once successfully connected to the Internet, ESP32 requests that the Sim800L module create a connection with the Blynk web server to allow project control. After that, the Application Programming Interface (API) key and template key are sent to Sim800l from ESP32. Once this connection has been made, you can now use the device remotely.

Loads connected to the device can be remotely controlled through Blynk IoT software using Internet and SMS messages sent and received by the Sim800L module, to which loads are connected. Signals received by ESP32 are processed before they are transmitted to the relay.

A voltage sensor circuit mentioned earlier is employed to obtain battery readings from a battery. Consequently, the battery's voltage is transmitted as an analog signal into the ADS1115 ADC converter and converted into a digital signal. From here, it is sent to ESP32 through I2C for further processing. Once it is processed, the battery voltage value is displayed on the LCD screen using I2C communication.

On the other hand, this AI surveillance camera has auto face detection and intruder detection; hence can detect intruders and send alerts to its owner over the internet. This AI camera has its own controller that runs unique code, unlike other components in the system.

The complete circuit diagram is presented in Figure 10.

C. Step-by-Step operation of the Integrated Smart Inverter Battery Management System

Step 1: Initiating the System

- The 12V, 10A power supply initiates the system by providing electrical power.
- Power is distributed to the LILYGO TTGO T-Call ESP32 Development Board and other components.

Step 2: Battery Management

- The ESP32 reads real-time battery data through the ADS1115 ADC module.
- It monitors essential parameters such as battery voltage, current load, and SOC.
- The ESP32 transmits battery data to the Blynk IoT platform for continuous real-time monitoring.

Step 3: Real-time Monitoring and Control

- The ESP32 establishes communication with the Blynk IoT platform using Wi-Fi/Bluetooth capabilities.
- Real-time monitoring of battery status, load conditions, and security camera feed is facilitated.
- The IoT platform logs and displays data, providing users with comprehensive information.

Step 4: Security Features

- The AI camera captures and monitors the environment for security purposes.
- Intruder detection triggers alerts or actions through the Blynk IoT platform.

Step 5: Load Automation

- The ESP32, based on automation rules and real-time data, controls the 30A relay.
- The relay is utilized to switch heavy loads on or off as per the system's requirements.

Step 6: Remote Control

- The ESP32, based on automation rules and real-time data, controls the 30A Relay.
- The relay is utilized to switch heavy loads on or off as per the system's requirements.

Step 7: Remote Control

- The ESP32, connected to the IoT platform, facilitates remote control capabilities.
- Users can remotely control and monitor the system using an Android app (Blynk 2.0) or Short Message Service (SMS).
- Remote actions may include toggling loads, adjusting settings, or receiving real-time updates.

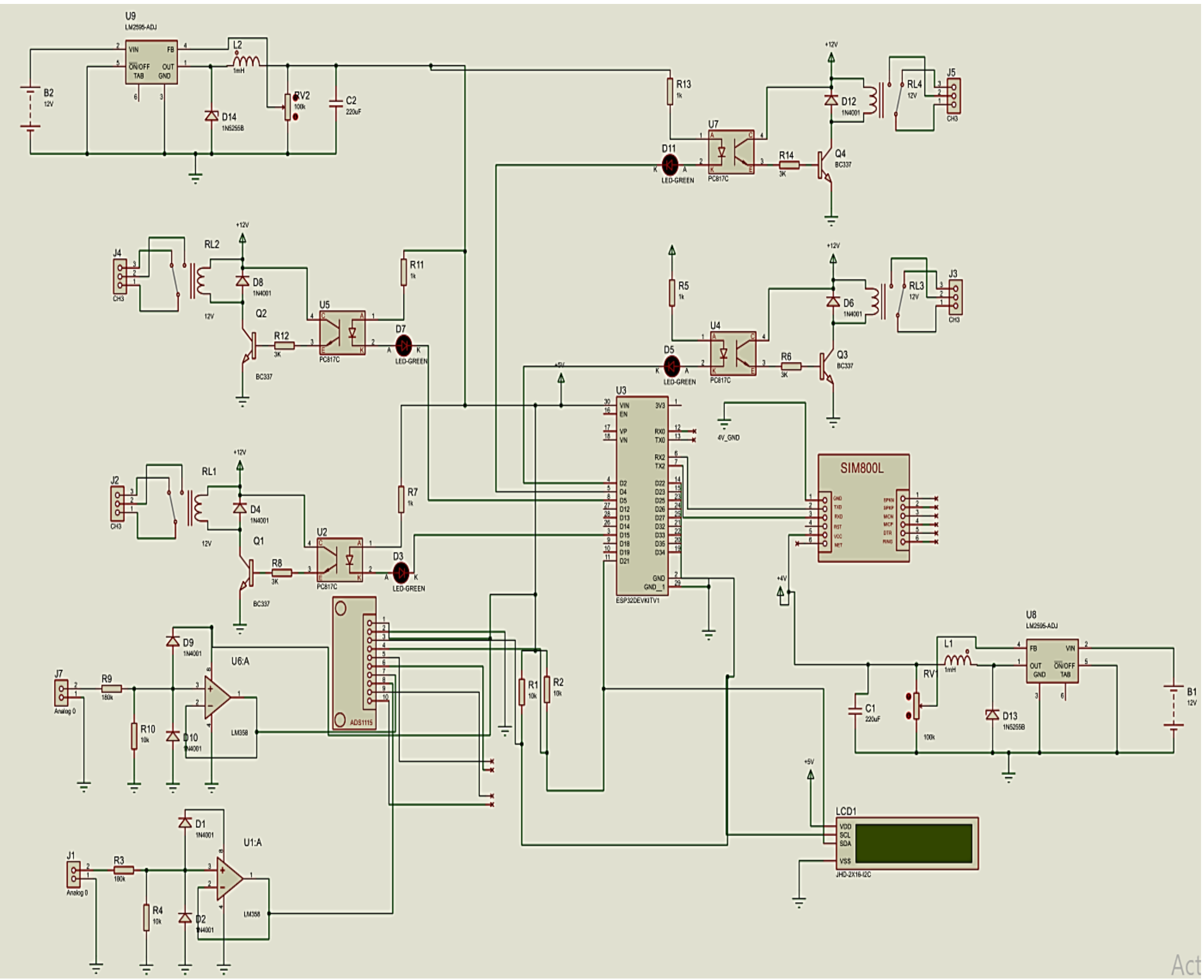

Figure 10: Complete Circuit Diagram

IV. TESTS AND RESULTS

A. TESTS

The study involved a comprehensive testing phase to ensure that the system functioned well, is dependable, and secure. These tests included component testing, power supply test, module test and integration system test. The components underwent rigorous inspection for faults or malfunctions, such as continuity check, insulation resistance checks, voltage checks, functional tests etc (figures 11-13).

Output voltage verification was done on the power supply circuitry through load testing and module testing to ensure sustained and reliable power delivery. Communication testing was done to ensure data transmission and reception reliability, while sensor calibration was carried out for giving accurate measurements within specific ranges.

To make sure all parts worked together properly during operation, System Integration Test (SIT) was performed. Functional integration connects all system components together and ensures that the overall functionality of a system works well, for example acquisition of data, processing it and displaying it on output devices. Interoperability Testing means checking how well different subsystems work together by communicating with each other. Error handling checks if the system can withstand attacks as well as ability to recover from failures.

The device successfully displayed voltage readings or load status, such as: connecting a battery; reading battery values on an LCD screen; toggling load status via Blynk app, viewing camera imaging via the YI IoT app, and checking for SMS alerts on a phone were also successful. Overall, the testing phase aimed to ensure the system's functionality, reliability, and safety.

B. RESULTS

When the power was turned on, a welcome message appeared on the LCD. Once connected to the internet, the ESP32 began receiving signals from both the ADS1115 module and the SIM800L module. The ADS1115 module measured voltages and displayed them on the screen. While the SIM800L module controlled load by toggling a relay.

Figure 11: Circuit Assembled in the casing

Figure 12: External Look

Figure 13: Circuit when connected to power

V. ACKNOWLEDGMENT

We extend our heartfelt gratitude to all collaborators and academic mentors at the Department of Electrical/Electronic Engineering at the University of Benin. Special thanks to our professors and advisors for their guidance and invaluable support throughout this project.

CONCLUSIONS AND DIRECTION FOR FUTURE WORK

A power management system that adapts an existing inverter with bidirectional communication between the user and that inverter has been developed into an IoT-based smart-controlled inverter. This is an environmentally friendly alternative that allows for wireless load control during power outages as well as load current monitoring on the inverter. It is very economical as it only involves a cost-effective way of coming up with a low-cost solar panel as its initial stage investment. The eco-friendly IoT-based smart-controlled inverter is recommended for intelligent households or organizations' loads based on customer preferences using Wi-Fi.

The test findings indicate that what was produced was an IoT-based battery charger monitor and controller equipped with a surveillance camera. Utilizing Blynk IoT software, it provides remote supervision of battery charging levels and automatic control of home appliances anywhere globally. An internet connection and SMS service aid its long-distance functionality. Constructed under a tight budget, the integrated AI camera can also detect unwanted visitors and alert property owners.

Potential improvements for the system include adopting surface-mounted technology (SMT) to reduce both size and power consumption, enhancing the device's efficiency and compactness. While the project initially employed a 2G GSM SIM800L module, performance in areas with poor cellular coverage may be limited due to the constraints of 2G networks.

Replacing this with a more robust, energy-efficient LTE module could significantly improve connectivity and power efficiency, supporting more demanding applications where LTE infrastructure is available.

The initial design used the LILYGO T-call module, but damage encountered during testing led to the adoption of the SIM800L board. A combination of the ESP32 and GSM SIM800L modules was ultimately implemented to balance project costs and maintain manageable power usage. However, it's acknowledged that using LTE technology would better address these needs in future versions.

In addition to hardware improvements, there is significant potential to enhance the software component. Integrating advanced predictive analytics into the Blynk platform could enable optimized battery charging cycles by analyzing historical data and using predictive models. This approach could improve battery longevity and overall system performance. These advanced features are currently beyond the team's capacity due to financial and resource constraints, but they represent valuable directions for future work. Other teams or future research initiatives could build upon these recommendations to implement both hardware and software enhancements, increasing the efficiency, robustness, and overall effectiveness of the system.

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