Journal of Energy Technology and Environment Vol. 5(1) 2023 pp. 26 - 39 ISSN-2682-583x

NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Design and Construction of a Remote Battery Monitoring and Control Device Using the Internet of Things (IoT)

P.T. Aikhoje* and O.W. Ofuzim

Department of Electrical/Electronic Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria

*Corresponding Author Email: prophet.aikhoje@uniben.edu

Article information

Article History
Received 4 December 2022
Revised 6 January 2023
Accepted 18 January 2023
Available online 16 March 2023

Keywords:
PIC16F887 Microcontroller, A6 GSM/GPRS Module, Internet of Things (IoT), State of Charge

https://doi.org /10.5281/zenodo.7741111

https://nipesjournals.org.ng

Abstract

The Internet of Things (IoT) has found numerous applications, one of which is in the realm of smart power monitoring and control systems. This work explores the potential of the IoT in designing and constructing a remote battery monitoring and control device. The purpose of the device is to monitor the state of charge (SOC) of the battery and control its charging process remotely, addressing issues of self-discharging and overcharging of deep circuits. The device is designed using a PIC16F887 microcontroller and an A6 GSM/GPRS module, serving as the IoT platform, providing platform-independent monitoring and control capabilities through web browsing devices such as mobiles and laptops. The microcontroller is tasked with controlling the system's various functions, while the GPRS module allows for communication with the web server and remote monitoring and control. To validate the design, a series of tests were conducted. The power supply test ensured that the voltage regulators 7805 and LM317 were able to produce the required 5V and 4.2V, respectively, to power the various components of the system. The GPRS module test confirmed that the module was able to communicate effectively with the microcontroller. The switching circuit test verified that the relay actuator pins were connected properly to power and ground, allowing for proper switching and control. Finally, the system test was conducted to cross-examine the entire circuitry for errors, such as short circuits and improper IC pin connections, before powering up the system. The successful implementation of this remote battery monitoring and control device demonstrates the potential of the IoT in creating practical and efficient solutions for power monitoring and control. This device can provide valuable insights into battery performance and usage, enabling remote management of battery charging systems.

1. Introduction

The Internet of Things (IoT) has revolutionized the way we live and work [1], connecting everyday devices and enabling them to collect and share data. With this technology, the design and construction of a remote battery monitoring and control device become possible. In today's world, efficient and effective management of energy resources, particularly batteries, is of utmost importance. From portable devices to home appliances, batteries play a crucial role in powering our daily lives and also the widespread use of batteries in various applications such as renewable energy systems, electric vehicles, and backup power systems. As a result, the design of a remote battery monitoring and control device using IoT technology presents an exciting opportunity to manage energy resources more efficiently [2]. However, conventional battery monitoring and control methods often involve manual checks, which can be time-consuming and prone to errors [3]. To address this issue, there is a growing interest in developing automated systems for remote battery monitoring and control using IoT technology.

Battery monitoring and IoT has an increasing crucial relevance in energy management, particularly in remote locations where the reliability of power supply is an issue.
The idea of a "smart home" and it’s latest trends and development [4] [5] [6] [7] [8] has been gaining traction in recent years, and this technology has been applied to the field of home health and care [9], specifically for people living with dementia [10] [11], and innovative solutions to improve home energy managements systems [12] The use of assistive technology, such as this remote battery monitoring device, can provide caregivers with valuable information about the battery status of devices used by the individuals they care for. This information can then be used to ensure that devices are working properly, reducing the risk of failure and promoting the safety and well-being of those in the home.

Battery power management has become increasingly important in the design of portable devices [13]. As technology advances, batteries are becoming more powerful and are being used in a wider range of applications, from laptops and smartphones to electric vehicles and renewable energy systems. The development of a remote battery monitoring device that uses IoT technology could provide valuable information about battery performance, allowing for improved power management and optimization of battery life. This makes battery power management systems [14] and IoT extremely relevant to the emerging Internet of things marketplace [15] and the energy power market, and innovative ideas have been developed in improving the power market [16].

As the integration of renewable energy sources into the electrical grid is rapidly increasing, and ideas to minimize the cost and storage utilization in renewable energy [17], the applications of smart grids are becoming very relevant [18] [19] [20]. These grids require real-time monitoring and control of energy storage devices [21] [22]. To ensure a stable and efficient power supply this device will be very important to the growth of smart grid.

Another relevance is in the field of electric vehicles (EVs). Knowing the battery is the most critical component of an EV and needs to be constantly monitored to ensure safe and efficient operation [23]. By using a remote battery monitoring and control device, EV owners will be able to monitor their battery’s status and control its charging process from a remote location, making EV ownership more convenient and user-friendly.

The purpose of this research project is to design and construct a remote battery monitoring and control device that utilizes IoT technology. The device will be capable of monitoring the performance of batteries in real-time and transmitting the data to a remote location where it can be analyzed. This research project also aims to contribute to the growing body of literature on the use of IoT technology in battery monitoring and control. The results of this research will provide valuable information for engineers and researchers in the field of energy management and the internet of things (IoT) technology. The results will also have practical applications for businesses and organizations that rely on batteries for power in remote locations.

2. Materials & Methods

Materials used in this work are PIC16F887 Microcontroller, Resistors, Transistors, Capacitors, Diodes, Crystal Oscillator, Relays, Voltage Regulator 7805 & LM317, A6 GSM/GPRS Module, Temperature Sensor, Electronic Switch, LCD (Liquid Crystal Display), Electronic Connectors.
The tools used for the construction of the project and the casing of the project are as listed: Soldering Iron, Lead, Screwdriver, Drilling machine, Jig Saw, Wire Cutter, Multimeter, Desoldering Pump, and Pliers.

To achieve the objectives, the following procedures were carried out:
1. Design and simulation using Proteus Design Suite.
2. Construction Procedure.
3. Mobile Application Development and Web Server.

2.1 DESIGN & SIMULATION USING PROTEUS DESIGN SUITE

The design for the Battery charging, monitoring & control device is shown in figure 1. It depicts the various blocks for the overall design.

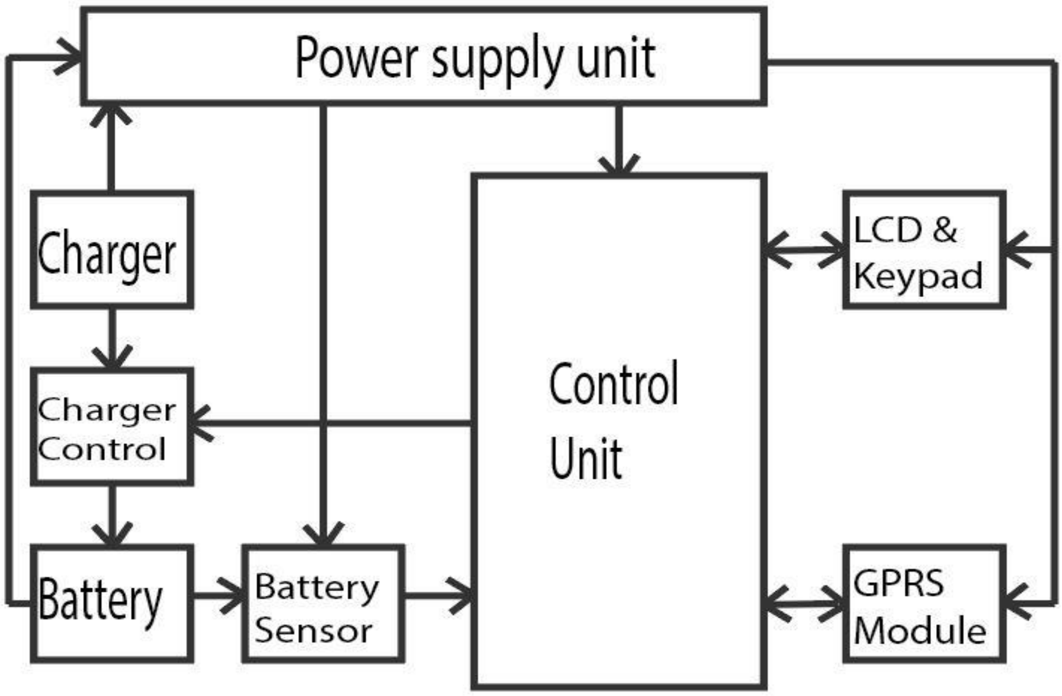

Figure 1: Block Diagram of the Battery Charging, Monitoring & Control Device

The block diagram components are listed as follows:
1. Power Supply Unit
2. Control Unit
3. Battery Voltage Sensor
4. Charger controller Unit
5. GPRS Module
6. LCD & Keypad
7. Display Unit
8. Temperature Sensor

2.1.1 DESIGN OF THE POWER SUPPLY UNIT

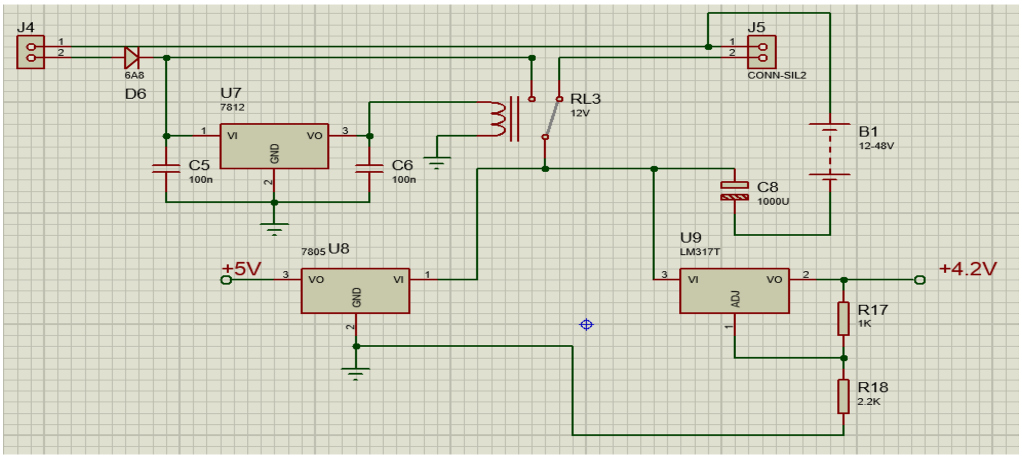

Figure 2: Power Supply Unit

The power supply unit supplies the device with the necessary source of power for the operation. Its first source of power is when it is in operation mode and the battery charger has converted the AC wall power source to DC, which is used to operate the device, the second source is the battery it is connected to when it has been disconnected with the wall source but needs to still be on, while it still monitors the SOC of the battery in real-time and dictates when the wall source should be connected back to charge the low battery. The device is meant to run 24/7, all year round, and is fixed to the battery, improving the life of the battery in the long run.

The power supply is a DC power supply with dual sources and dual voltage outputs. The sources are; rectified AC – DC battery charger and a battery, however, only one power source is used at a time. The switching of the power sources is done using a 12V relay. To stabilize the power going to the relay, a 12V voltage regulator (7805) was used because the power sources can be greater than 12V. The output of the power supply is 5V and 4.2V with a combined current of two amps. Figure 2 is the circuit diagram of the power supply.
Diode D6 is meant to prevent reverse current flow.
Capacitors C5 and C6 are decoupling capacitors (100nF Recommended by 7805 manufacturer)
Capacitor C8 is meant for storing power which is meant for supplying power to the circuit during power source switching. The value of the capacitor can be from 470uF and above. 1000uF was chosen due to availability.

In the 4.2V circuit, Lm317 was made use of. Below is the formula for calculating resistor values used for biasing Lm317

$$Vout = Vref \times \left(1 + \frac{R18}{R17}\right) \quad (1)$$

Vout = Output voltage = 4.2
Vref = Voltage reference = 1.25 (Stated in the datasheet of Lm317)
R = Resistor connecting Lm317 output pin to adjustable pin
R17 = 1k (Recommended value by Lm317 manufacturer in the datasheet)

$$R18 = \left(\frac{Vout}{Vref} - 1\right) \times R17 \quad (2)$$

$$R18 = \left(\frac{4.2}{1.25} - 1\right) \times 1000 = 2.36\ k\Omega$$

R18 = 2.2K (2.2K was chosen due to availability)

2.1.2 DESIGN OF THE CONTROL UNIT

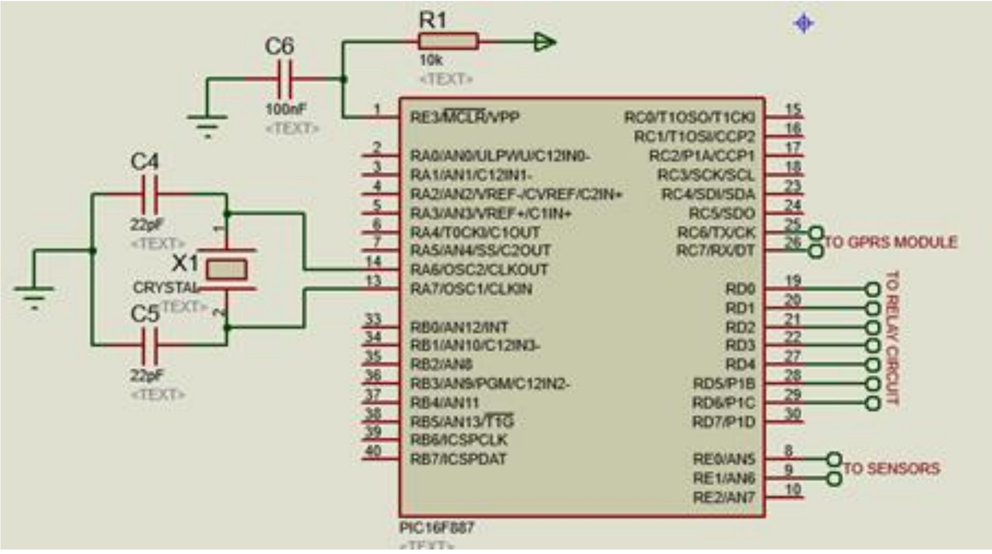

Figure 3: Control Unit

The control unit acts like the brain of the device and it is hard coded in mikroC to give the whole device-specific controls and to interface with the application software on the android device, and the whole units.

Figure 3 is the circuit representation for the control unit. The control unit comprises the microcontroller (PIC16F887), crystal oscillator circuit, and the master clear reset circuit which in turn consists of a resistor and a capacitor. The microcontroller is the main control unit, it controls the GPRS module, gets data from the GPRS module, and turns on/off the relay based on the data gotten from the GPRS module. The microcontroller equally takes data from the sensors and sends them to the server through the GPRS module. The crystal oscillator controls the timing of the microcontroller which means the time at which the microcontroller executes one instruction. The microcontroller frequency is one-fourth of the crystal oscillator frequency. The master clear reset circuit prevents the microcontroller from resetting by connecting the master clear pin of the microcontroller to power through a resistor (R1) and a capacitor (C6) to the ground. Fig 3 is the circuit diagram of the control unit. C4 and C5 are meant for the stabilization of the crystal oscillator.
R1 = 10K (Recommended in PIC microcontroller datasheet)
C6 = 100nF (Recommended in PIC microcontroller datasheet)
C4 = C5 = 22pF (Recommended in PIC microcontroller datasheet)

2.1.3 DESIGN OF THE BATTERY VOLTAGE SENSOR UNIT

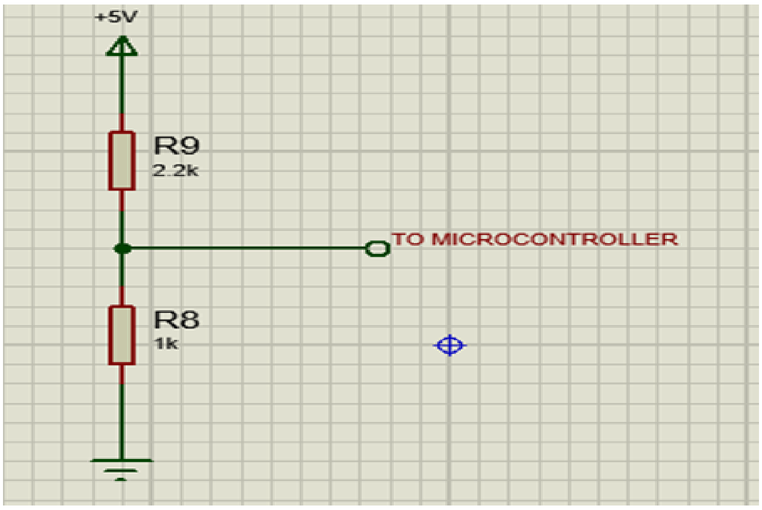

Figure 4: Battery Voltage Sensor unit

The battery voltage sensor unit informs the control unit of the exact battery status, and controls the charging voltage and charging current.
The battery voltage sensor comprises solely two resistors (R8 & R9) voltage dividers as shown in figure 4.
For resistor selection the voltage divider equation was used:

$$Vout = Vbat\left(\frac{R8}{R8+R9}\right) \quad (3)$$

Where Vbat is the Maximum battery voltage (14.4V) and Vout is the Maximum microcontroller sensing voltage (5V).
Substituting in (3)

$$5 = 14.4\left(\frac{R8}{R8+R9}\right)$$

$$\left(\frac{R8}{R8+R9}\right) = \left(\frac{Vout}{Vbat}\right) = \left(\frac{5}{14.4}\right) = 0.3472$$

$$\therefore R8 + R9 = \left(\frac{R8}{0.3472}\right) = 2.88R8$$

R9 = 1.88R8
NB: The resistor connected to the microcontroller pin and ground (R8) should be of high impedance greater than 1K (Stated in the microcontroller datasheet).
R8 = 1K (Selected due to availability)
R9 = 1.88 X 1000 = 1.88K
R9 = 2.2k (2.2k was chosen due to availability)

2.1.4 DESIGN OF THE CHARGER CONTROLLER UNIT

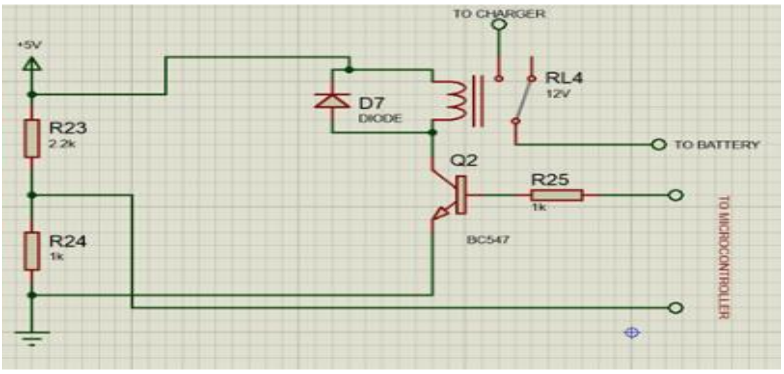

Figure 5: Charger Controller Unit

The charger controller unit regulates the flow of electricity from the charger to the device, it comprises the Battery Voltage sensor and a switching circuit for the regulation.
The charger controller unit comprises of two-resistor voltage divider circuit.

To determine R23 and R24 equation (4) was used

$$Vout = Vbat\left(\frac{R24}{R24+R23}\right) \quad (4)$$

Where,
Vbat = Maximum charger voltage (15V)
Vout = Maximum microcontroller sensing voltage = 5V

$$\therefore \left(\frac{R24}{R24+R23}\right) = \left(\frac{Vout}{Vbat}\right) = \left(\frac{5}{15}\right) = 0.333$$

$$\therefore R24 + R23 = \left(\frac{R24}{0.333}\right) = 3R24$$

R23 = 2R24
NB: The resistor connected to the microcontroller pin and ground (R24) should be of high impedance greater than 1K (Stated in the microcontroller datasheet).
R24 = 1K (Selected due to availability)
R23 = 2 X 1000 = 2K
R23 = 2.2k (2.2k was chosen due to availability)

Relay Diode D7 protects the transistor from feedback that might emanate from switching off the relay because a relay armature is an inductive device.
Resistor R25 is a current-limiting resistor to limit the current supplied to the transistor from the microcontroller.

$$R25 = \frac{Vcc-Vc}{I} \quad (5)$$

Vcc = Supply voltage = 5V
Vd = Voltage drop = 0.7 (Knee Voltage for silicon transistor)
I = Maximum transistor current = 10mA = 10^{-2}

$$R25 = \frac{5-0.7}{10-2} = 4.3 \text{ X } 100 = 430\Omega$$ (430 Ohms is the minimum resistor);

R25 = 1000 = 1K (1K was chosen due to availability).

2.1.5 DESIGN OF THE GPRS MODULE UNIT

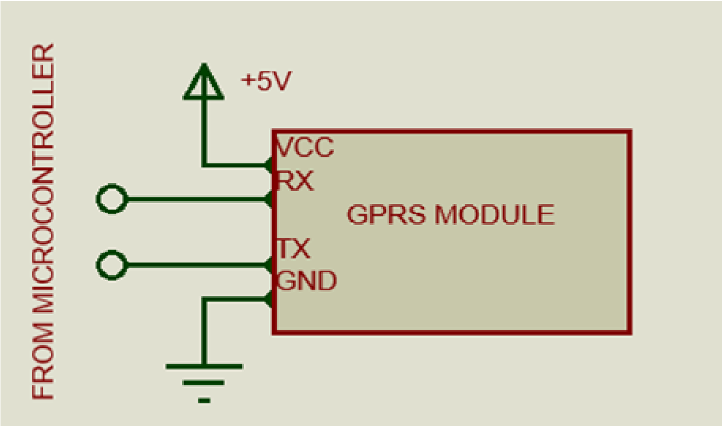

Figure 6: GPRS Module Unit

GSM/GPRS module

The A6 GSM/GPRS cellular chip is from Ai-Thinker (Manufacturer of ESP8266 WIFI modules). It communicates with a microcontroller over UART and supports the baud rates from 1200bps to 115200bps with Auto-Baud detection. It is connected to the microcontroller using just two wires, one for receiving from the microcontroller and one for sending to the microcontroller. The GPRS module is equally powered by the power supply. Figure 6 is the circuit diagram of the GPRS module.

2.1.6 DESIGN OF THE KEYPAD (Button Circuit)

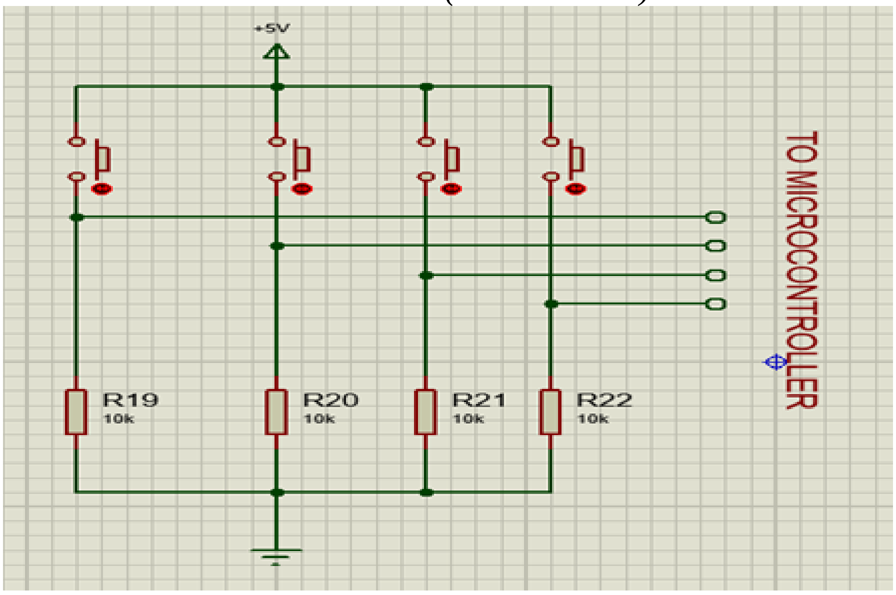

Figure 7: Button Circuit

The button circuit is used to shorts or completes the circuit for the circuit when it is pressed, it triggers the display circuit too**.**

The button circuit is a pull-up button circuit which means the buttons are connected to power directly and connected to the ground through a 10K resistor. On pressing any of the buttons, the corresponding pin is momentarily connected to power which is sensed by the microcontroller and action will be carried based on the button pressed and according to the program running in the microcontroller. Figure 7 is the button circuit.

R19 = R20 = R21 = R22 = 10K (Recommended for pull-up button configuration in microcontroller datasheet)

2.1.7 DESIGN OF THE DISPLAY CIRCUIT

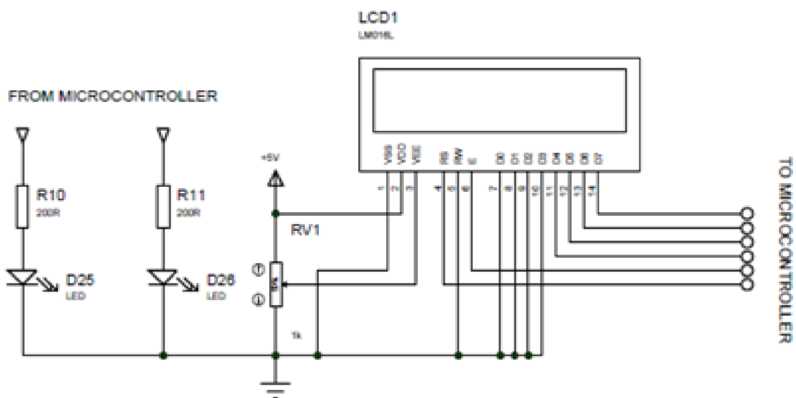

Figure 8: Display Circuit

The display circuit is mainly used to present visual information about the battery and show the conditions of the battery while charging.

The display circuit consists of the Liquid Crystal Display (LCD) circuit and the indicator circuits which comprise two light-emitting diodes each with a series resistor. Below in fig 8 is the display circuit and the potentiometer (RV1) connected to the LCD is meant to control the contrast of the LCD.

LED SERIES RESISTANCE CALCULATION
The voltage drop of Led (Vd) = 1.8V
The output of Microcontroller (Vs) = 5V
The forward current of the LED = 20mA
LED series resistance = $\frac{(Vs-Vd)1000}{20}$ = 160 Ohms; (7)
R10 = R11 = 200 Ohms

2.1.8 DESIGN OF TEMPERATURE SENSOR
The voltage is the actual representation of the soc (state of charge) of the battery, but the voltage reading can be inaccurate as the temperature fluctuates, see figure 9 for a typical voltage to change in temperature relationship.

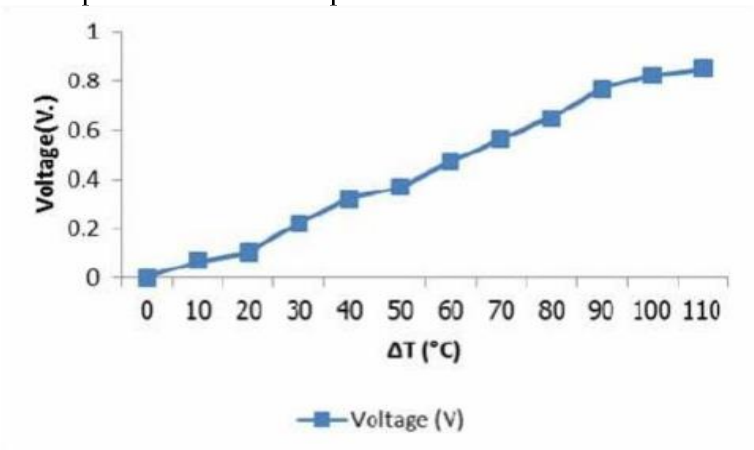

Figure 9: Graph the relationship between Voltage and Temperature Difference.

A temperature sensor is used to measure the temperature of the battery as well as, consciously calculate the actual reading of the battery's state of charge. Using this relationship that 1'c rise in temperature will warrant a 0.0073V drop in the actual measurement.

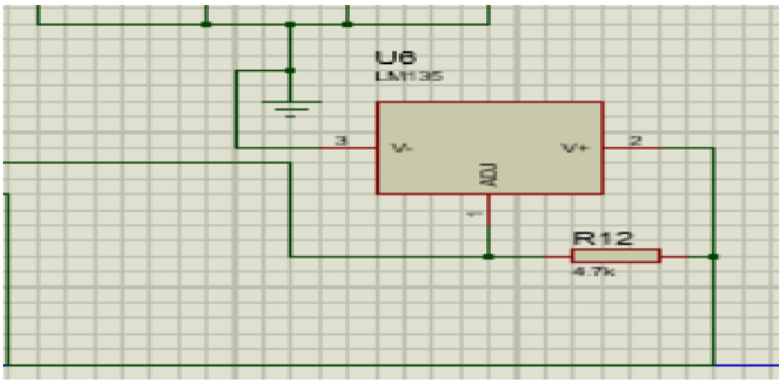

Fig. 10: Temperature Sensor Circuit

3.1.9 CIRCUIT DIAGRAM

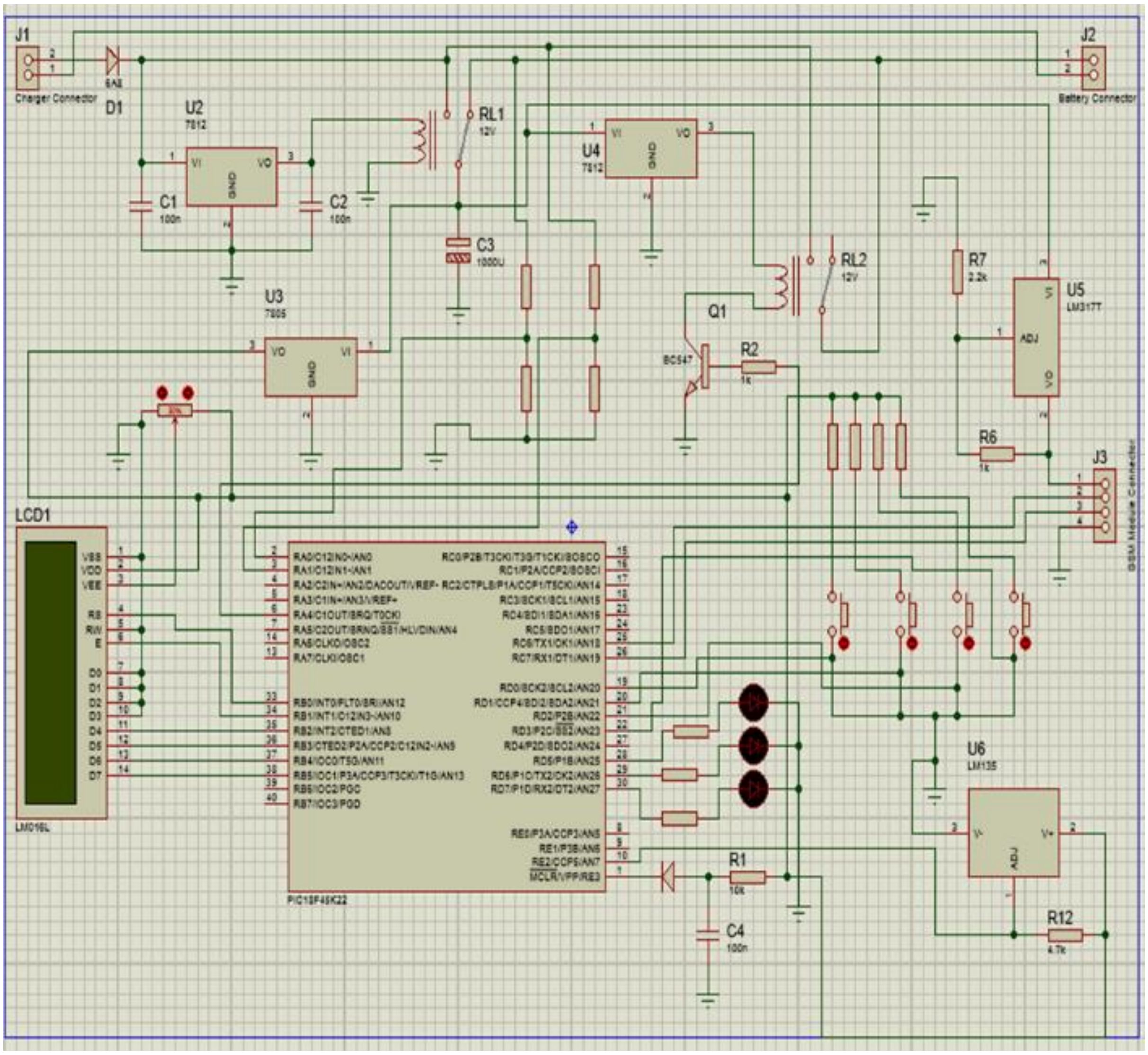

Figure 11: Circuit diagram

2.2 CONSTRUCTION PROCEDURE

The project was constructed after a careful design of the circuit diagram and the necessary calculations have been carried out. Components were sourced and purchased based on the calculated values and recommended specifications/manufacturers.

The design was partially simulated with Labcenter Proteus with the power supply circuit able to light up a LED in the simulation before the power supply and other circuitry such as the control unit, gsm/GPRS module, battery & charger voltage sensor, and switching circuits were soldered on Veroboard which forms the main panel board. The main panel board is placed in a circuit box casing.

The main panel board was constructed by placing and soldering the power supply components first which include filtering capacitor, and voltage regulators which were followed by soldering of the IC socket for the microcontroller, soldering of the crystal oscillator, soldering of the master clear circuit, soldering of the sinking transistor, soldering of the relays, soldering of indicator LED, placement of ON/OFF switch, and soldering of connecting wires for the relays.

The main panel, the indicator LED, the liquid crystal display (LCD), and the ON/OFF switch were cased in a casing box as shown in fig below.

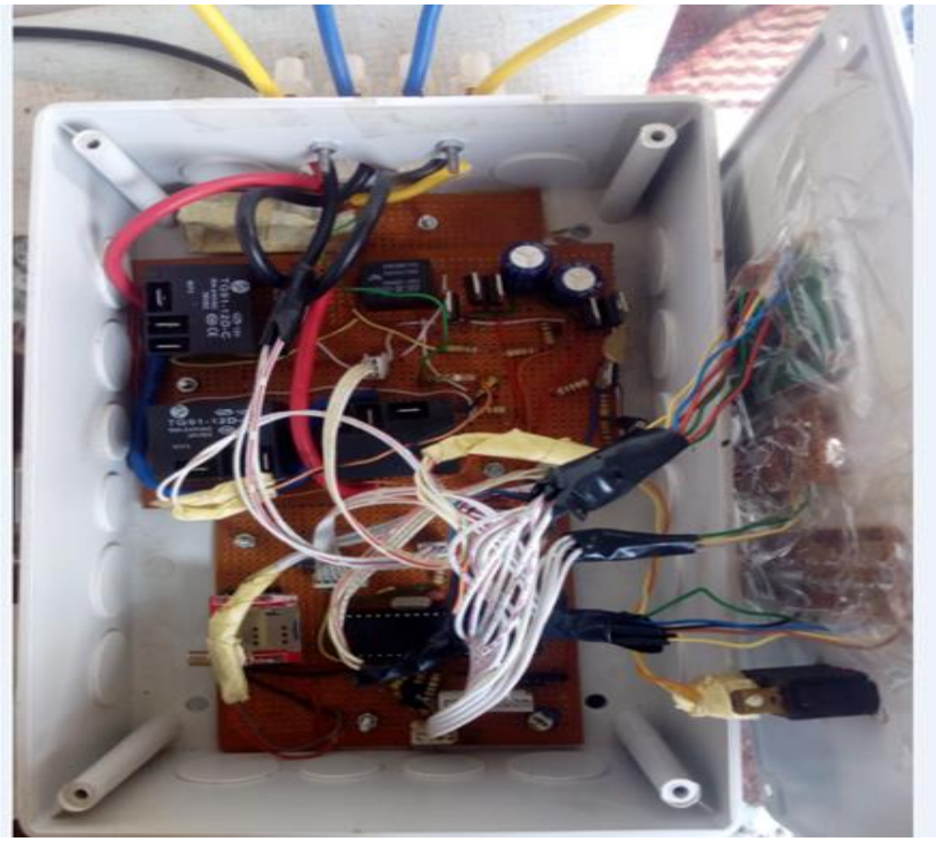
Figure 12: Image of Constructed Circuit

2.3 MOBILE APPLICATION DEVELOPMENT AND WEB SERVER

The mobile application was developed in an android studio and the development was done using Java. Thereafter, the APK file was generated for installation on android phones.

The website was developed in visual studio 2019 and the development was done using Asp.Net C# language. After development, it was subsequently uploaded to an asp.net server (IIS) which is batterymonitor.sightdev.net for access. The web server solely comprises two API endpoints which are an endpoint for the hardware to communicate with and an endpoint for the software.

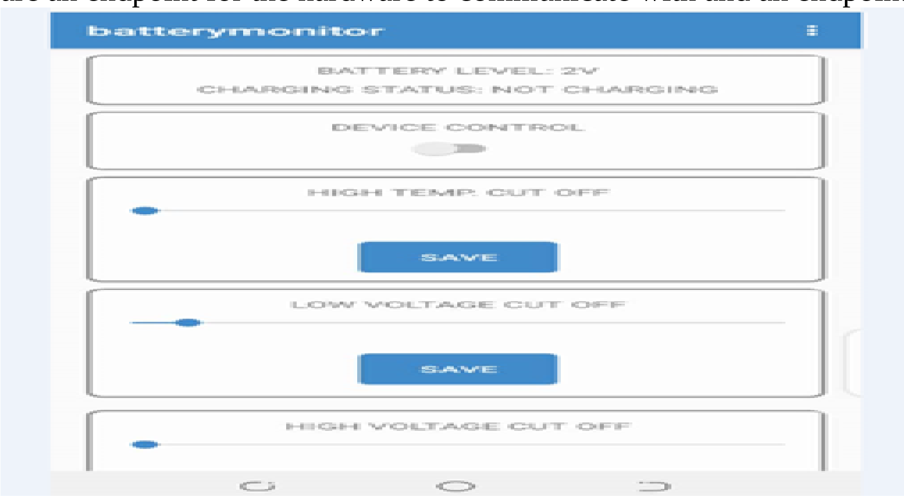

Fig 13: Mobile Application Interface

3.0 Results and Discussions

3.1 TESTING

In the course of constructing the project, tests were carried out before everything was assembled. Each of the various blocks in the block diagram was tested separately before they were all assembled. The sequence of tests undertaken to ensure successful project work is as follows

1. Testing of the individual components
2. Power supply test
3. GPRS module test
4. Switching circuit test
5. System test

3.1.1 TESTING OF THE INDIVIDUAL COMPONENTS

Components were tested individually before fiddling with them to remove the bad ones. This test will be a satisfying test measure for individual components which is basically done by using the multi-meter (e.g., testing of the transistor, diodes, LEDs, etc.) and also powering some of the components with a 5V power supply from the battery to ascertain their workability.

3.1.2 POWER SUPPLY TEST

The power supply test was carried out after it was soldered on the Veroboard and the power supply’s input was connected to a battery to determine if the voltage regulators 7805 & Lm317 produce 5V and 4.2V respectively which they did during the test.

3.1.3 GPRS MODULE TEST

The GPRS module test was carried out after its power pins have been connected to power and its communication pins connected to the microcontroller. The sim in the module was called to ascertain if the module has a signal because GSM and GPRS use the same signal. A subsequent test was carried out to determine if the GPRS module can communicate with the microcontroller which it did during the test.

3.1.4 SWITCHING CIRCUIT TEST

The switching circuit was tested after being soldered to the main panel board. Each actuator pin of the relay was connected to power and ground to determine if the relays will actuate which they did during the test. In addition, each relay was tested if it can be controlled by the microcontroller which was successful during the test.

4.1.5 SYSTEM TESTING

This involves testing the entire circuitry and cross-examining it for errors like short circuits, lead flux joining unwanted links, proper insertion IC pin layout, and checking of ICs and their PINs. After this check, the system was cross-examined once again before powering the system.

4. Conclusion

This paper has demonstrated the feasibility of designing and constructing a remote battery monitoring and control device using IoT technology. The device was designed using a PIC16F887 microcontroller and an A6 GSM/GPRS module, providing platform-independent monitoring and control capabilities through an android application and device. The tests carried out validated the design of the device and confirmed its effectiveness in controlling and monitoring the state of the battery.

The device was able to measure the voltage level of the battery constantly and perform various functions such as low voltage cut-off and high-temperature cut-off as set by the user. The user can control the device configuration both manually and through a mobile application via the internet, providing the user with greater flexibility and control over the battery charging process. The GSM module and the website interface were tested successfully from different locations, demonstrating the device's portability and wide compatibility.

This research project highlights the potential of IoT technology in providing practical and efficient solutions for power monitoring and control. The successful implementation of the remote battery monitoring and control device has the potential to provide valuable insights into battery performance and usage, enabling remote management of battery charging systems. Overall, this project represents a significant step forward in the field of smart power management and control and has the potential to bring about significant improvements in the way we manage and control batteries.

The following are some recommendations from the work

1. Using this system as a framework, the system can be expanded to include various other options which could include monitoring and management of different energy sources in a home or office and monitoring and control of equipment, devices, or machines.
2. 3G or 4G modules should be used for faster internet communication.
3. This system can be incorporated into PWM/MPPT chargers to make them smarter.
4. The system can be expanded for energy monitoring or weather stations. This kind of system with respective changes can be implemented in hospitals for disabled people or in industries where human invasion is impossible or dangerous, and it can also be implemented for environmental monitoring.

The design and construction of this device will be commercially valuable.

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