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Design of Microcontrollers Based Smart Battery Management System Enhancement for Off - Grid Remote Homes

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Abstract: ***Existing battery management system (BMS) for off - grid standalone solar homes are designed to provide management to the batteries especially to measure and estimate the charge level, temperature, health, state of power and to engage computation that protects the battery. Integration of microcontrollers as smart enhancement for monitoring and control of the BMS extends flexibility in the operation of reliable energy distributions to the users. The design also integrates additional functional features to the existing solar photovoltaic (PV) system and communication facilities that cater for deployment of controls that utilizes load management in the BMS. Besides, load management is seen as a vital aspect that manages the power in an off - grid system. Variation of loads which put stress on the battery can be managed through battery selectors that have multiple batteries connection and can be selected upon the capacity of battery and the users desired. It also integrates a demand load controller that prioritizes the loads with reference power setting. Moreover, the need for balance in the energy chain enables the maximizing of incoming charges from the renewable energy (RE) for which the BMS will monitor and control the charges in and out of the battery. In an off - grid PV system, solar has made a substantial stand in generating electric energy for the users, but due to the limitation in solar irradiance and angle of incidence between the direction of the sunlight and PV panel during different times of the day have put challenges for the design of solar tracking system. The existing BMS provides less information to the users especially on - site, remotely and distantly. Therefore, the proposed microcontroller based system enables serial communication to transfer imperative data to be displayed on a graphical user interface (GUI) remotely. The design is proposed to utilize the demand in monitoring and protection of the BMS functions as well for off - grid solar PV system.***

Keywords: Battery management system, graphical user interface, priority load control, remote monitoring and controls, renewable energy sources

1. Introduction

Due to the evolution of battery technology and its application in energy storage, it has gained attention as a device of choice for use in electric vehicles and smart grid applications. These batteries must be managed carefully to avoid stress which can lead to a potentially catastrophic scenarios such as explosions and fire [37]. A battery management system may be termed as an electronic device or a system that manages rechargeable batteries and enable optimum usage of energy preserved in the battery. Different BMS have been developed over the years concerning the types of batteries being used and their application. A typical BMS system has the following basic functional devices; measuring devices, decision - making devices, isolation devices, and display devices. It should also contain accurate algorithms to measure and estimate the functional status of the battery and at the same time, be equipped with mechanisms that protect the battery from dangerous conditions [2].

The off - grid power system for remote homes consists of solar panels, maximum power point tracking (MPPT), batteries, inverter, and the AC or DC loads. The integration of RE and standalone power system has provided a way for generating electric power for appliances used by people living in off - grid or in remote areas. However, there are some controls and management drawbacks from the off - grid power system in terms of storage and distributions. In terms of controls, the MPPT provides controls by checking the output of the PV module, compares it to the battery voltage, and analyzes proper voltage power and current that the PV module can supply the charging phenomena of the battery effectively [5]. In terms of management, distribution variations of loads requires data acquisition to calculate the amount of power dissipated, and the level of voltage and the amount of current drawn out of the battery.

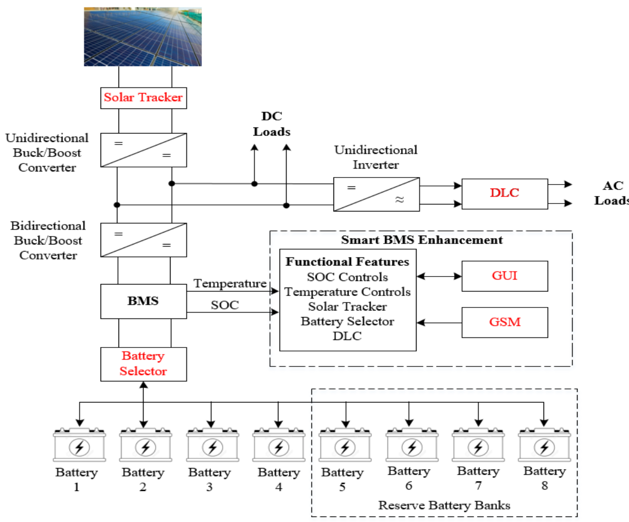

Figure 1.1: Integration of smart BMS to an off - grid system

The design of microcontroller based smart BMS enhancement for off - grid remote homes focuses on the following additional features to the existing BMS that are available on the market, targeting standalone homes:

1) ***Design of Single - axis Solar Tracking System:*** It responsible for the positioning of the solar PV panel adjacent to the direction of the sunlight.
2) ***Design of State of Charge Monitoring and Controls:*** It is responsible for measuring the state of charge (SOC) using open - circuit voltage method for number of batteries used in standalone homes.
3) ***Design of Temperature Monitoring and Protection:*** the design is responsible for measuring the temperature of the batteries that are used in standalone homes.
4) ***Design of Load Management:*** It is responsible to perform two types of measurement and provides controls related to their respective functionality as in battery selectors and load controller.
5) ***Design of Remote Monitoring and Controls using GUI:*** It is a display and control interface responsible for display the parameters of the BMS and provides control for load management and their functionality. It is facilitated using serial communication to bridge information transmission between the smart BMS enhancement and a personal computer.
6) ***Design of Distant Controls using GSM:*** It is a wireless channel mobile to smart BMS responsible to utilize the load management especially the battery selectors. It utilizes the use of global system for mobile communication (GSM) module to transmit control data for battery selectors.

Figure 1.1 shows integration of the proposed smart BMS enhancement to an off - grid system. The smart BMS encapsulates all the specific design that is involved to upgrade the monitoring and protection of the battery using PIC microcontrollers. The detailed design is presented in the research design sections. The design method was initiated by the following procedures and methodology as shown in **figure 2**.

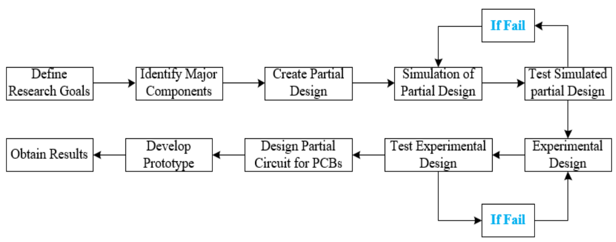

Figure 1.2: Block diagram of the methodology

The methodology provides the procedures in which the approaches were used to obtain the overall results. The design comprises of partial design that uses simulation, experimental, and prototyping to obtain the results. The simulations are done using PROTEUS design suite to verify the working principles of each design.

2. Research Design

The research design shows the detailed design that is used for each partial design for the microcontroller based smart BMS enhancement for off - grid remote homes. It comprises of six (6) major designs that is opted to be of additional features to the existing BMS to off - grid power system for standalone homes. The partial design of each section is described by the following two outlines: 1) block diagram and 2) simulation circuit.

2.1 Single Axis Solar Tracker

The single axis solar tracking system utilizes seven (7) stationary positions each with 30˚ angle apart starting from east to west directions. The circuit diagram shows the PIC microcontroller (MCU) that is associated with sensing and controlling peripherals that performs the operation of single - axis solar tracking system as shown in **figure 2.1**.

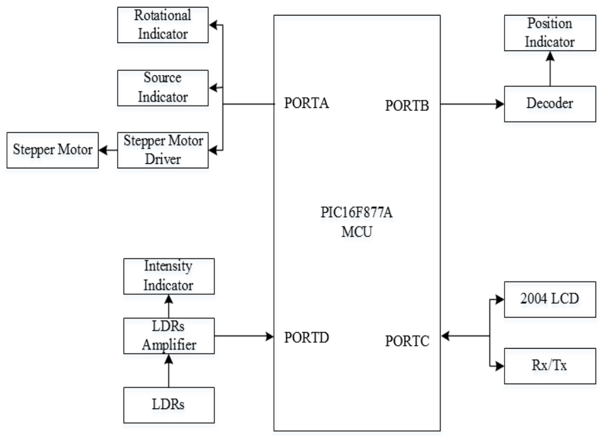

Figure 2.1: Single axis solar tracker circuit diagram

The schematic and simulation of the single axis solar tracking system is used to test and verify the outcomes of the algorithms used in the design as shown in **figure 2.2**.

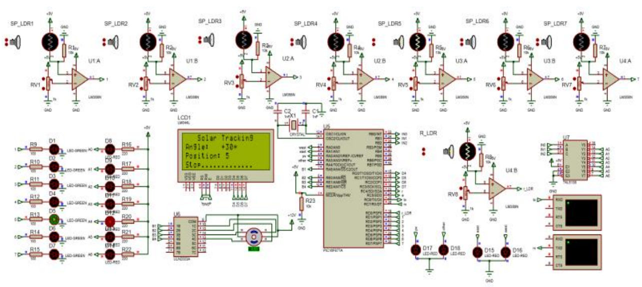

Figure 2.2: Schematic of single - axis solar tracker under simulation

The results of single - axis solar tracking are presented in the results/simulation section 3.1.

2.2 State of Charge Monitoring and Controls

The state of charge using OCV methods is used to monitor and control the switch - on charging and switch - off charging of each of the battery pack used in the design. It uses loop algorithms to monitor each battery with a delay of 1000 milliseconds. Figure 2.3 shows the circuit diagram of SOC monitoring and controls.

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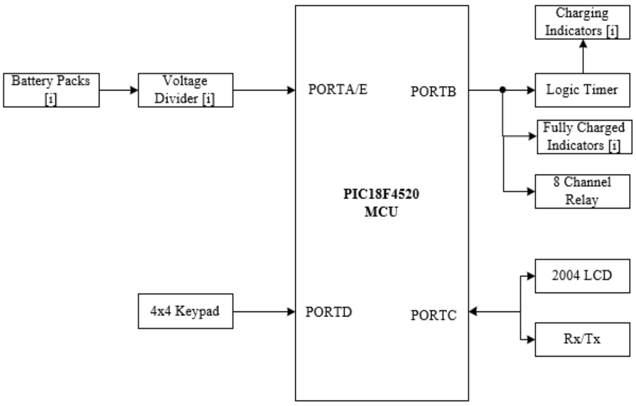

Figure 2.3: Circuit diagram of SOC monitoring and controls

The schematic and simulation of SOC monitoring and controls is shown in **figure 2.4** which is used in conjunction for testing the virtual outcomes of the algorithmic operations.

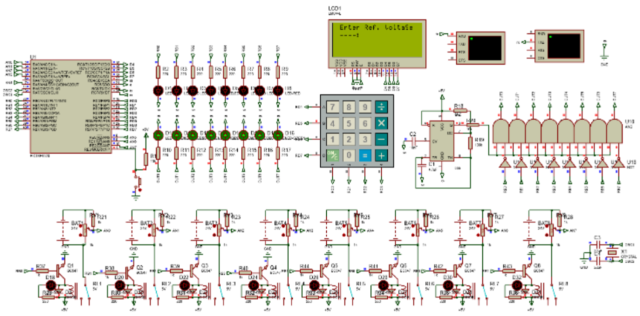

Figure 2.4: Schematic of SOC monitoring and controls

The results of SOC monitoring and controls are presented in the results/simulation section 3.2

2.3 Temperature Monitoring and Protection

The design of temperature monitoring protects the batteries from over - heating. The MCU circuit diagram with all necessary peripherals is shown in **figure 2.5**.

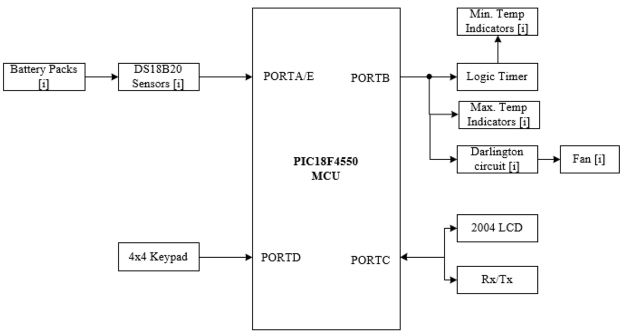

Figure 2.5: Circuit diagram of temperature monitoring and protection

The schematic and simulation diagram are used to verify the operation of the design. **Figure 2.6** shows the simulated schematic using PROTEUS.

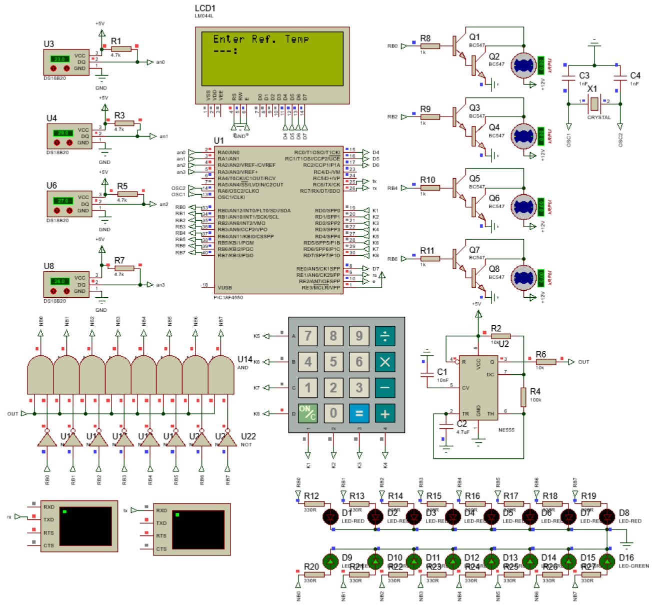

Figure 2.6: Schematic of temperature monitoring and controls

The results are presented in the results/simulation section 3.3.

2.4 Load Management

The load management is responsible for two operations, 1) battery selectors and 2) demand load controller. The circuit diagram is shown in **figure 2.7**.

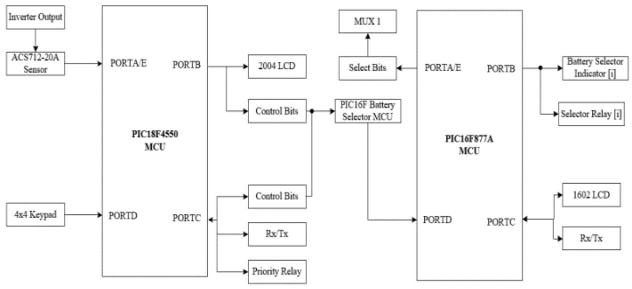

Figure 2.7: Load management circuit diagram

The simulation diagram in **figure 2.8** presented the schematic used for simulation and prototyping of the design.

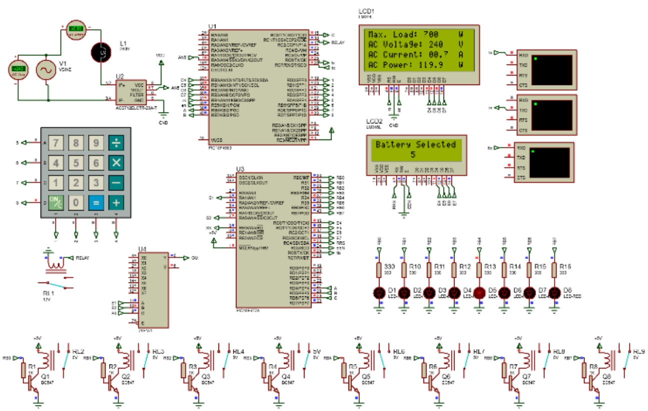

Figure 2.8: Schematic of load management design

The results are presented in results/simulation section 3.4.

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2.5 Remote Monitoring and Controls using GUI

GUI allows users to communicate serially with the smart BMS through the use of graphical icons. The block diagram in **figure 2.9** shows the overall interaction of the smart BMS and the monitoring and control parameters that are active for these operations.

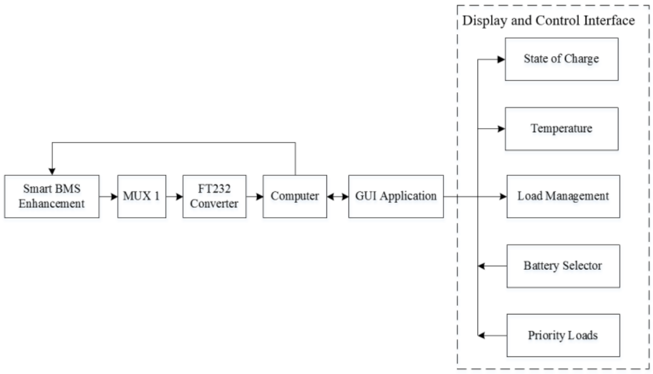

Figure 2.9: Block diagram of GUI design

The interface or GUI application is designed using visual basic as seen in **figure 2.10**.

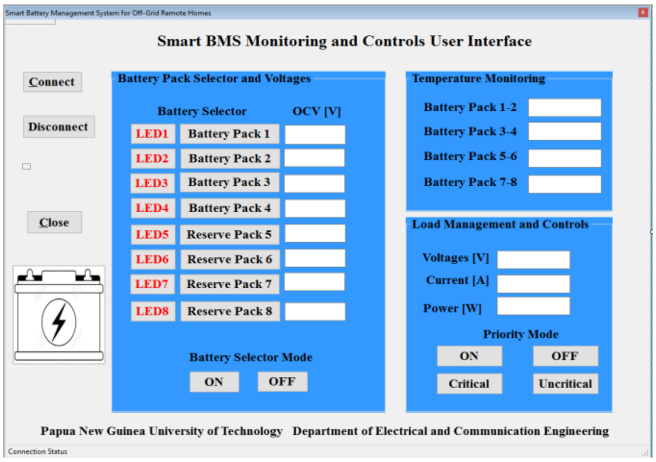

Figure 2.10: GUI control and monitoring visual interface

The results are presented in the results/simulation section 3.5.

2.6 Distant Controls using GSM

The distant control is designed specifically to facilitate the battery selectors. Users initialized the control command through the use of short messaging service (SMS) in their mobile phones and communicate to the GSM module which is attached to the smart BMS. The block diagram in **figure 2.11** shows major components that are being used in this section.

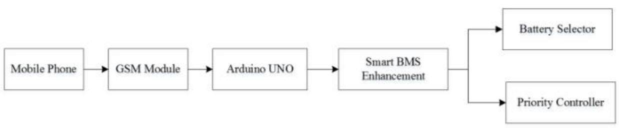

Figure 2.11: Block diagram of GSM distant controls

The circuit diagram in **figure 2.12** shows the MCU and the peripherals that are used in the operation of distant control using GSM.

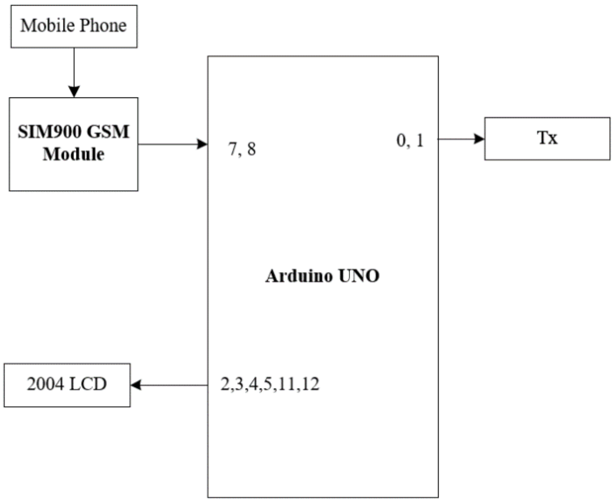

Figure 2.12: GSM design circuit diagram

The results are presented in results/simulation section 3.6.

2.7 Complete Design

The overall scope of the design of microcontroller based smart BMS enhancement for off - grid remote homes is presented here, and the prototyping model as well. The overall design is shown in **figure 2.13** and prototyping model in **figure 2.14**.

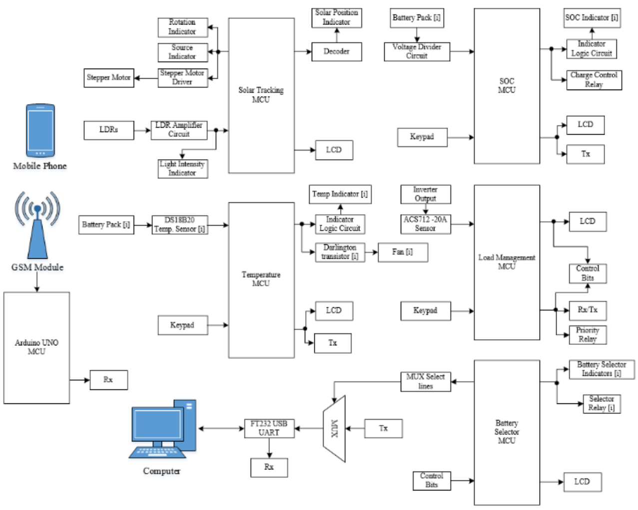

Figure 2.13: Overall design of smart BMS

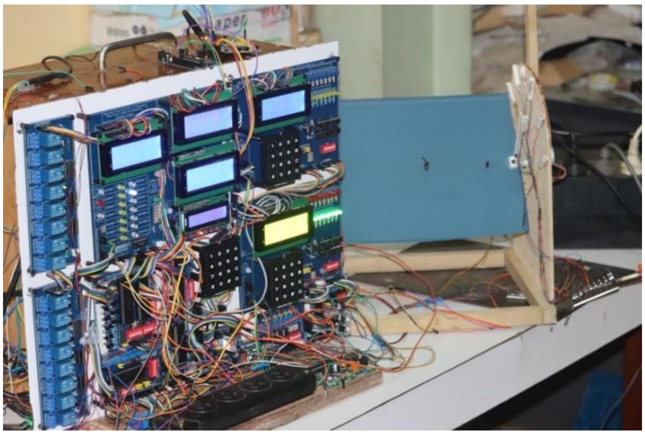

Figure 2.14: Overall prototyping model

The prototyping model consists of 4 layouts, 1) main board, 2) wireless GSM control, 3) Single - axis solar tracking model, and 4) battery pack model.

1) Main Board

The main board is labeled with the major functional component as shown in **figure 2.15**.

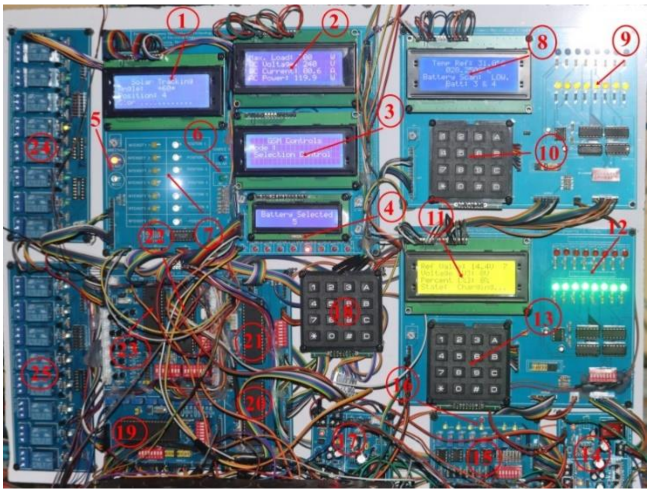

Figure 2.15: Main board design and labels

Main Board Hardware Components		
Component Number	Physical Component	Functionality
1	2004 LCD	Display the parameters of a single - axis solar tracking system especially the angle of solar PV panels, positions, and the direction of motion.
2	2004 LCD	Display the computation of power consumption especially the reference power, voltages, current, and the power in AC.
3	2004 LCD	Display the GSM parameters as in the mode of receiving or waiting of incoming controls, and selection controls of what is required to perform.
4	1602 LCD and LED Indicators	The LCDs display the battery number being selected and the indication [i] indicates what battery [i] is selected.
5	LED Indicators	Indicators that indicate the direction of rotation (east or west) for single - axis solar tracker in blinking mode.
6	LED Indicators	Indicators that indicates the active RES (solar PV or other) being used for charging the battery and the loads
7	LED Indicators	Indicators that indicate the active intensity and the position of the PV panels.
8	2004 LCD	Display the temperature parameters as in reference temperature, active temperature reading [i], the status of the battery's temperature reading, and the battery paired in a battery case.
9	LED Indicators	Indicators that indicate the battery [i] charging and fully charged status.
10	Keypad	Used to set and reset the reference temperature.
11	2004 LCD	Display the OCV SOC reading of battery [i] as in reference voltage, active voltage reading [i], the computation in percentage form and the state of the battery [i].
12	LED Indicators	Indicators that indicate the status of the battery [i] whether in charging mode or fully charged mode.
13	Keypad	Used to set and reset the reference nominal voltage for a battery system.
14	5VDC power module board 1	Used to step down DC voltages ranging from 9VDC - 30VDC to constant 5VDC output voltage.
15	Solar Tracker LDRs Signals Amplifier	Used to amplify LDRs [i] signals and to adjust the light intensity signal.
16	LED Indicators	Indicators that indicate the level of light intensity concerning SP_LDRs and R_LDR.
17	5VDC power module board 2	Used to step down DC voltages ranging from 9VDC - 30VDC to constant 5VDC output voltage.
18	Keypad	Used to set and reset the reference power and battery selector.
19	PIC18F4520 MCU	Used as a controller to read and computes OCV variables and perform controls upon the specific instruction set embedded into it.
20	PIC16F877A MCU	Used as a controller for facilitating the battery selector functionality using control bits from load management controller.
21	PIC16F877A MCU	Used as a controller to facilitate the operation of a single - axis solar tracker.
22	PIC18F4550 MCU	Used as a controller to facilitate the operations of load management as in battery selector and priority load control.
23	PIC18F4550 MCU	Used to facilitate the operation of battery's temperature monitoring and controls.
24	8 Channel Relay	Used for battery selector especially to choose a battery to cater for the loads.
25	8 Channel Relay	Used for controlling switch - on charging and switch - off charging.

2) Wireless GSM Controls

The wireless GSM controls are shown in **figure 2.16** with labels.

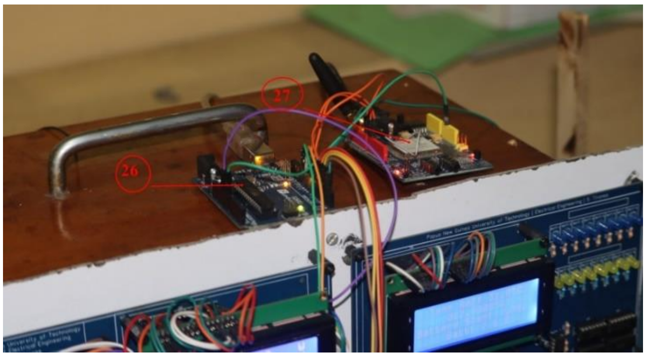

Figure 2. 16: Prototype model of wireless GSM design

GSM Hardware Components		
Component Number	Physical Component	Functionality
26	Arduino UNO MCU	Used to facilitate the operations of GSM especially receiving of text command in the form of SMS to control the functionality of load management in terms of battery selector and priority load control.
27	SIM900 GSM Module	Used to establish communication between the user’s mobile phone to receive text messaging command to be sent to the Arduino UNO.

3) Single Axis Solar Tracking Model

The model for the single axis solar tracking system is shown in **figure 2.17**.

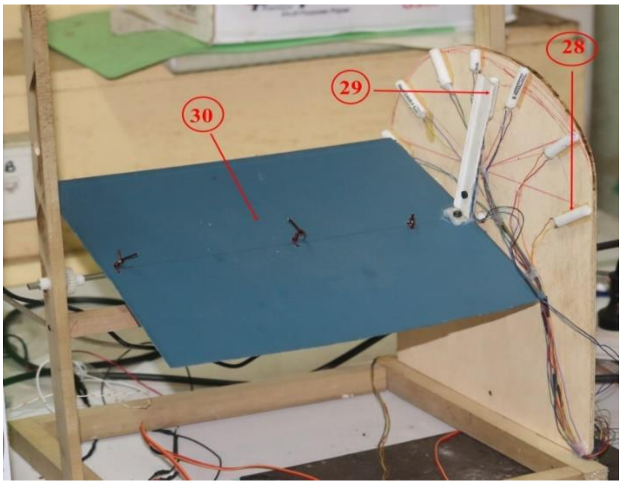

Figure 2.17: Prototype model of single axis solar tracker

Solar Tracker Hardware Components		
Component Number	Physical Component	Functionality
28	Stationary Position LDRs (SP_LDR [7])	Used to detect the position of the sunlight with higher intensity.
29	Rotational LDR (SP_LDR)	Attached to the solar PV module and to compute the equivalent bits with the SP_LDR while in rotation.
30	Solar PV Model (plastic board)	Used as a demonstration in place of solar PV module.

4) Battery pack Model

The battery pack model is shown with labeled in **figure 2.18**.

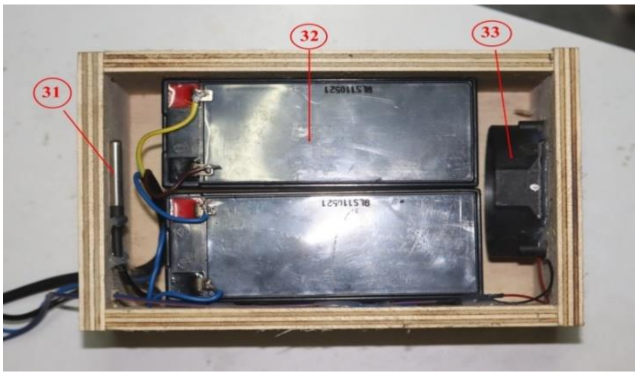

Figure 2.18: Battery pack model with labels

Battery Pack Components		
Component Number	Physical Component	Functionality
31	DS18B20 Digital Temperature Sensor	Used to measure the temperature of the battery pack towards the terminal side of the battery.
32	12V 9AH Battery	The battery used in the demonstration of the battery pack.
33	12VDC Fan	Is used to provide cooling for the battery pack.

3. Results/ Simulation

The results in this section are partitioned into partial design as in methodology. Moreover, it is obtained mainly from the prototyping model and simulations. The result is presented using flow chart which also distinguishes the relationship of the programing algorithms codes used in the microcontrollers.

3.1 Single Axis Solar Tracker

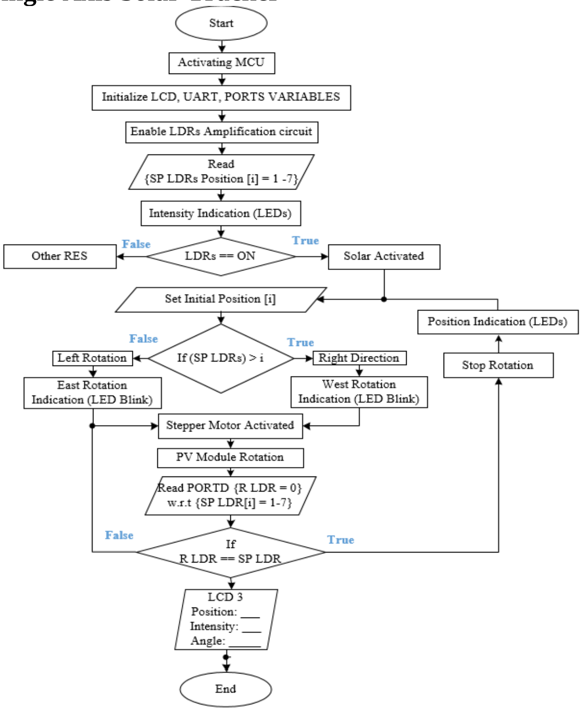

Figure 3.1: Flow chart results for single axis solar tracking system

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3.2 State of Charge Monitoring and Controls

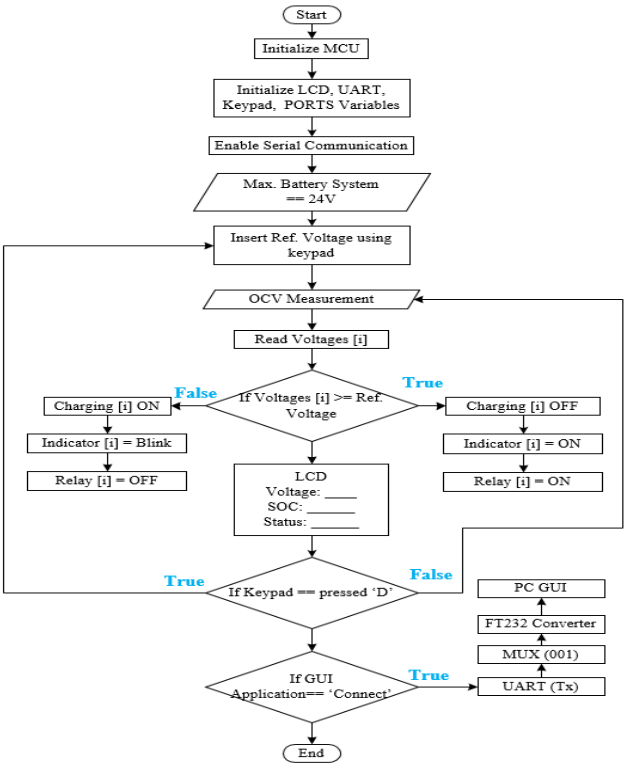

Figure 3.2: Flow chart results for SOC monitoring and controls

3.3 Temperature Monitoring and Protection

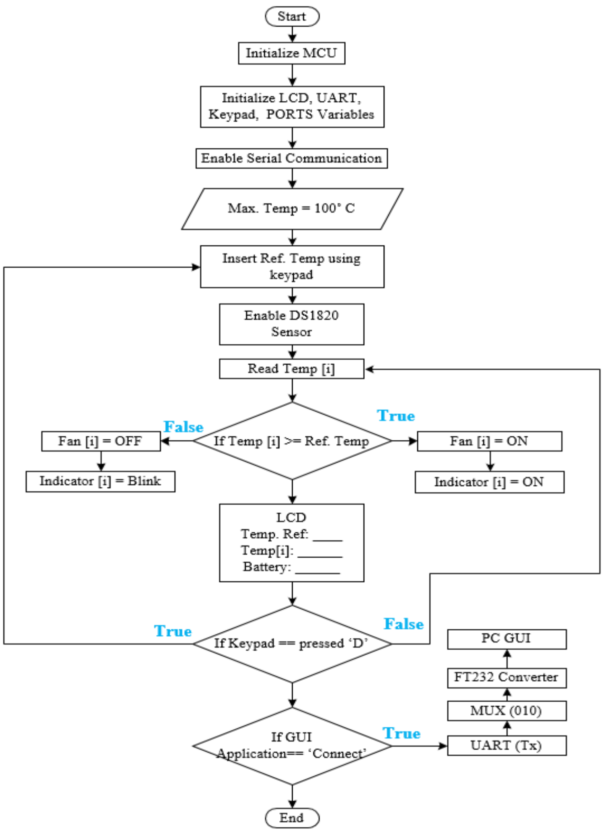

Figure 3.3: Flow chart results for temperature monitoring and controls

3.4 Load Management Monitoring and Controls

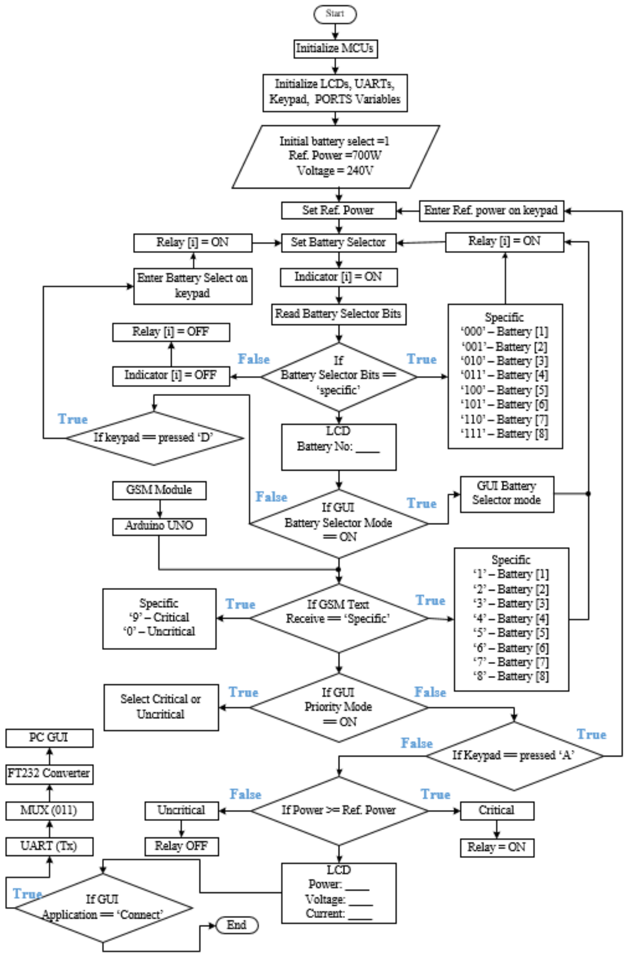

Figure 3.4: Flow chart results for load management design

3.5 Remote Monitoring and Control using GUI

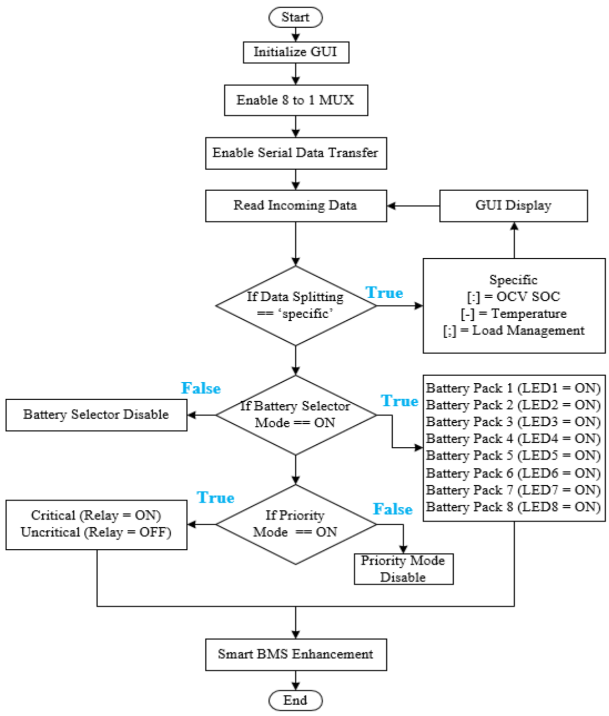

Figure 3.5: Flow chart results for GUI monitoring and controls

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3.6 Distant Control for Load Management using GSM

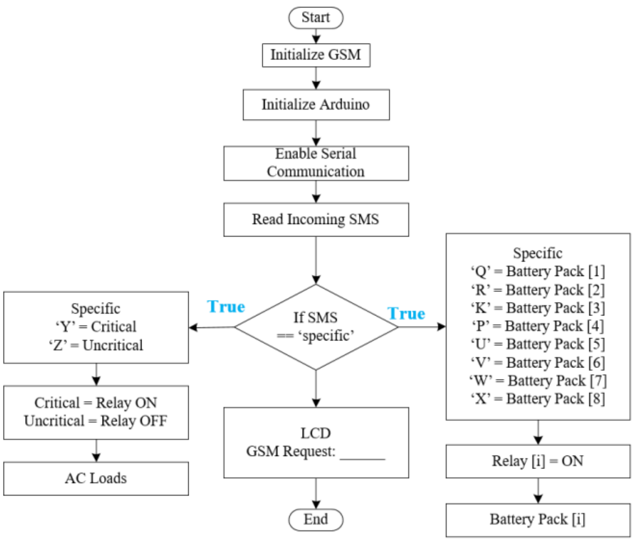

Figure 3.6: Flow chart results for GSM controls design

4. Conclusion

The smart BMS enhancement is vital for standalone homes which require renewable energy for energy production. Microcontrollers based system utilizes the available functionality to deliver smart performance to existing BMS and that also integrate additional features as in solar tracking system. It is designed basically for monitoring and controls purposes. Moreover, it adapts the overall generation, data collection and processes, and distribution of electric energy to off - grid remote homes. It is also intended to extend flexibility to other renewable energy sources such as pico - hydro, wind turbine electric generator, and other imperative renewable energy that is available for medium and mass electricity generation.

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