Low-cost battery monitoring circuit for a photovoltaic system based on LoRa/LoRaWAN network

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ABSTRACT

In this paper, an inexpensive electronic circuit will be designed to monitor the cells of battery cells' voltage in a Lithium-ion bato monitors paper, we will use three battery packs made up of lithium cells connected in a series, and we will test the individual cell voltages, design a simple circuit with op-amps, and send the results via long-range (LoRa) technology to an Arduino base station, where they will be displayed on an liquid crystal display (LCD) screen. This paper deals with the development of a photovoltaic (PV) system battery performance-monitoring unit. This will be done by using an Arduino and long-range wide area networking (LoRaWAN) as a control and monitoring system. The measurement values and data will be sent to a personal station by using an RFM95 LoRa module (as a Universal Asynchronous unit) and the data can be visualized in LCD. One of the parameters of the battery monitoring system is the voltage of the PV system. The goal of the project is to design a new circuit for monitoring the charging condition, discharge depth, and ampere-hour (AH) of the battery, and this all will be analyzed to prove the performance of the battery in the independent photovoltaic system.

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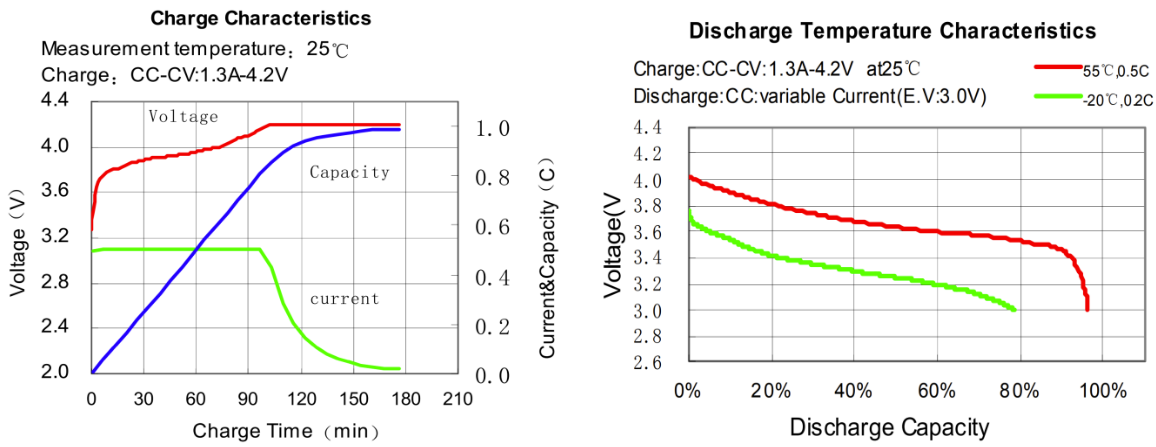
1. INTRODUCTION

Due to photovoltaic (PV) fluctuation systems, power generation, and the energy's chaotic nature consumption by loads, grid-connected energy storage systems have grown in popularity for smoothing power flows and providing high-quality electric power. Energy storage devices with battery banks are a common way to increase the amount of variable electricity from generators that are connected to the grid. Control tactics for sources of power that are effective are required for the efficient operation of a DC microgrid. One of them is the battery control circuit and monitoring system. The technology keeps track of vital system parameters and can detect potential blackouts early. It suggests that each source's monitoring system might have a significant impact on the on-system grid's dependability and security [1]-[7].

As seen in Figure 1, each battery has its own set of charging and discharging characteristics as shown in Figures 1(a) and 1(b). The battery backup duration, as well as the battery life, may be reduced if the charging and discharging rate do not adhere to their own set of specifications. At different times, batteries may be depleted if the load sharing of a battery bank is not based on the battery's rated capacity and intended features. At that time, as a load, the empty battery will be used, requiring a grid charge [8].



(a) (b)

Figure 1. Properties of the lithium-ion battery (a) charging and (b) discharging [8]

Based on their specific needs, the appropriate battery monitoring systems. It has been applied to standalone photovoltaic lighting systems and renewable energy storage systems, automotive power systems, and other industries [9]-[13]. Wireless communication is now being used in various systems to receive and transfer data. This describes a battery monitoring system that uses the internet of things (IoT) to track battery operation and performance in a smart microgrid system [14]-[17]. The authors demonstrated a complete battery monitoring system in [18]. To keep track of each battery cell, wireless sensors in the system measured voltage and temperature. The status of charge and health of the battery were estimated using a central battery control device that combined cell readings with current readings. The internet of things is used to develop and rectify real time monitoring systems for sundry lead-acid batteries [19]. The suggested system tracked and recorded characteristics Such as the acid level, charge status, voltage, current, and remaining charge capacity of the lead acid battery in real time. Shell *et al.* [20] present a bluetooth-enabled wireless battery management system. In comparison testing, the performance of the port system was similar to that of a wired system with significantly reduced weight and points of failure. The authors demonstrate an online remote monitoring system for operating a lead-acid battery pack in telecommunication stations. The system achieved data transfer between remote acquisition units and the data service center by combining internet connections that are used for generic packet radio service communications.

In this paper, we plan to build and carry out an unrivaled new battery monitoring system using long-range wide area networking (LoRaWAN) wireless communication. It uses previous data results and a software algorithm to anticipate the battery's remaining capacity, enabling real-time surveillance Warning of an error in the health of the battery. Furthermore, the system incorporates the Arduino Uno as a microcontroller unit circuit, LoRaWAN for wireless communication, and battery cell voltage measurement circuits for appropriately and effectively reducing the battery status collector's volume. The hardware design of the modules, in addition to details of the planned system, including software and algorithms, as well as effectiveness of the hardware created [21]-[24].

2. RELATED WORKS OF BATTERY MONITORING SYSTEM

The main purpose of this paper involves the design and testing of a new circuit for monitoring the status of battery cells, which will be used in a photovoltaic system. This system will be made up of many interlinked loops for battery feedback control and PV system power management based on IoT application and LoRaWAN technology. Individual battery cells are monitored to see how they're doing. All cells must be kept within their functioning parameters. In the event of an emergency, the battery is isolated, and we are provided with information about the battery's state of charge. When compared to a new battery, this measurement indicates the condition of the used battery. Related works of battery monitoring system Table 1.

This section describes the system that was created and compares it to related work in the same field. Such as research that used other methodologies, such as different types of voltage, current, and temperature sensors, wireless communication technology, and monitoring systems. Table 1 shows the lists of the battery monitoring techniques utilized in prior proposals.

Table 1. List of related works for battery monitoring system

Related Work, Year, [Reference]	Type of Sensors	Communication System	Monitoring System
Dhotre *et al.* 2014 [25]	Voltage and Current	GSM	SMS
Luo *et al.* 2013 [26]	Voltage and Temperature	GPRS	internet
Rahman *et al.* 2017 [27]	Voltage, Current, and Temperature	ZigBee	LCD
Menghua and Bing 2017 [28]	Voltage, Current, and Temperature	Wi-Fi	Mobile app
Mathew *et al.* 2012 [29]	Voltage and Current	2.4GHz Radio Transmission	SMS

3. SYSTEM METHOD

The major constituents of the proposed wireless battery monitoring system for photovoltaic applications come in two parts (hardware and software). Battery monitoring system, the hardware includes long-range (LoRa) wireless communication technology, DC voltage sensors, and an Arduino UNO. For this application, the software programs are developed In C in an Arduino integrated development environment (IDE), data is collected from voltage sensors attached to the battery cells [30], [31]. The full-proposed system of the battery monitoring is presented in Figure 2.

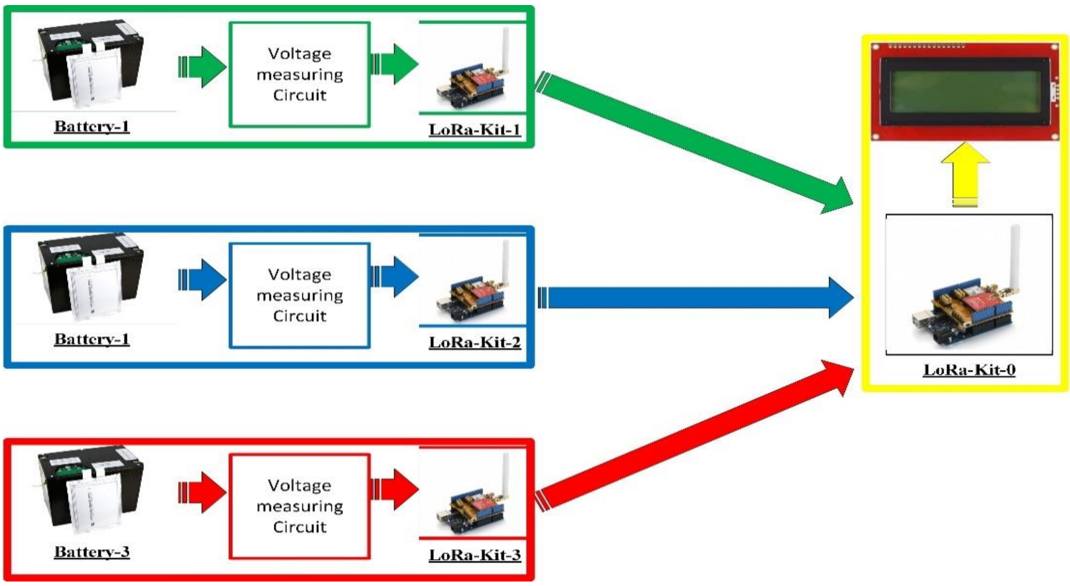


Figure 2. The proposed system for the overall network based on LoRaWAN

3.1. Hardware of the monitoring system

This section consists of four parts and presents all hardware components of the full system that were used in this work to monitor the voltage of the battery cells. The first is about the DC measuring sensors, the second part is about the communication unit responsible for transmitting the signal, the third part is about the control and monitoring unit, and finally, the results display unit.

3.1.1. DC mustering sensors unit

The problem with measuring the voltage of each cell connected in series inside the battery pack is the fact that the reference point does not change. The whole DC voltage measurement circuit is shown in Figure 3. As illustrated in Figure 3, three cells of the battery are employed at a voltage max. value of 4 volts for simplicity. Now, f we were to use a microprocessor (like an Arduino UNO) to test the cells' voltage, we wouldn't have a problem with the voltage across the first cell that measures the voltage because the other end is connected to the ground. However, for other cells, must measure the voltage of that cell in conjunction with the voltage of the preceding cells; for example, while measuring the voltage of the third cell, we'll take voltage readings from all three cells at the same time. This is because the infected point cannot be moved from the ground case [32], [33].

As a result, we will need to add an extra circuit to enable individual voltages to be measured by us. The most basic method is to map down the voltage levels with a potential divider and then measure them; however. This method reduces the accuracy of the reading value to more than 0.1 V [31]-[32]. We'll use a Differential Op-Amp circuit for measuring the difference between the terminals of each individual voltage measuring cell. The last element in the circuit has been used Zener diode with (4.9 V) to protect the microcontroller because the Arduino UNO can measure the voltage of fewer than 5 volts.

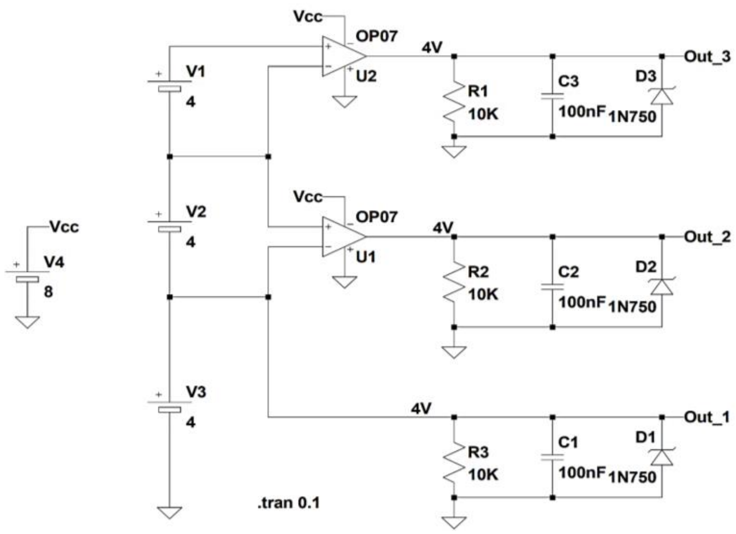


Figure 3. The voltage measuring circuit for battery cells

For cell no. 1 we did not use an op-amp, because it could not measure the voltage directly. The first Op-Amp-1 calculates differential voltage between cell no. 3 terminal and the first cell terminal, which is used to measure the voltage of the battery's cell no. 2. (8v-4v). The Op-amp-2, on the other hand, measures the voltage in cell no. 3.

3.1.2. The comunication unit

In this paper, the LoRaTM unit in Figures 4, Figures 4(a) and 4(b) was utilized to deliver and receive data across a wireless communication network. The LoRaTM long range modem in the RFM95W transceivers provides extremely long-range extended-spectrum communications with high interference immunity with very little power draw. Using Hope RF's LoRaTM modulation technology and a low-cost, bill-of-material crystal, the RFM95W can achieve a sensitivity of more than -148 dBm.

High capacitance assembly and a built-in +20dBm power amplifier result in an industry-leading link budget, making it ideal for any application that demands range or durability. In terms of blocking and selectivity, LoRaTM bypasses traditional modulation schemes, solving the basic design compromise between range, interference immunity, and power consumption. These devices support also a high-performance (G)FSK modes like WMBus and IEEE802.15.4g. The RFM95W performs better than competitors in terms of phase noise, selectivity, receiver linearity, and IIP3 while using a fraction of the power. The main performance of the RFM95W is presented in Table 2.

Table 2. The performance of the RFM95W

No.	Properties	Description
1	Package	16*16mm, 16 pins SMD
2	Interfaces	SPI*1,DIO*6
3	Sensitivity	-111dBm to -148dBm
4	Modulation	LoRa,(G)MSK, and OOK
5	Power Supply	1.8V to 3.7V
6	RF Output Power	Up to +20 dbm

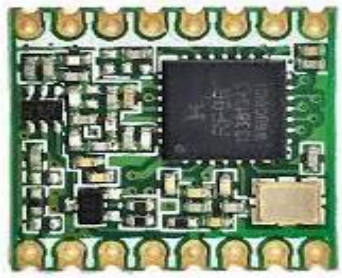
3.1.3. The monitoring unit

The Arduino UNO in Figure 4(c) is an open-source microcontroller board based on the Microchip ATmega328P, designed by Arduino. cc. The board contains many types of digital and analogue input/output (I/O) pins that can be used to connect to expansion boards (shields) and other circuits. The board has 14 digital I/O ports (six of which may produce PWM) and 6 analog I/O pins and can be programmed using the Arduino IDE and a USB Type B connector. It can be charged via a USB cable or an external 9 V battery and operates at a voltage of 7-20 V. It is a microcontroller that is similar to the Arduino Nano and Leonardo.

The hardware reference design is licensed beneath a creative commons attribution-share-alike 2. permit and can be found on the Arduino website. Layout and manufacturing files are also available for some versions of the hardware [11]-[13].

3.1.4. The visualized unit

The liquid crystal display (LCD) in Figure 4(d) is a flat panel display, electronic visual display, or video display that uses liquid crystals to modulate light. 20x4 indicates that each of the four rows of the 20x4 LCD can display 20 characters, for a total of 80 characters displayed at any given time. The PCF8574 I2C chip in the I2C Module translates I2C serial data to parallel data for the LCD. The default I2C address for these modules is currently either 0x27 or 0x3F. Check the black I2C adapter plate on the underside of the unit to see which version you have.



(a)

(b)

(c)

(d)

Figure 4. System hardware elements: (a) LoRa module, (b) LoRa module with Arduino shield, (c) Arduino UNO, and (d) 20*4 LCD with I2C

3.2. Software of the monitoring system

This part consists of two software; the first one is for the measuring unit and the second for the monitoring unit. Figure 5 presents the flowcharts of the full system.

a) The Measuring unit software: The Measuring and LoRa technologies make up the hardware development circuit. Arduino-based circuits are used as a tool for measuring the real-time parameters of the battery in the measurement part. The initial diagnosis will be carried out using Arduino-based voltmeter circuits, with the results being sent via the LoRaWAN network. Before sending the results to the main station, A serial number will be assigned to a set of battery banks for each battery. Figure 5(a) shows the data transmission process in the device, which shows the flow diagram of the measuring circuit.

b) The Monitoring unit software: In this part, the measuring voltages for each battery (3 batteries were used in this project) are received from the wireless monitoring network based on the LoRaWAN network. The readings for each battery are displayed on the LCD and the serial number of this battery recognizes each battery. The Flowchart of the unit is presented in Figure 5(b).

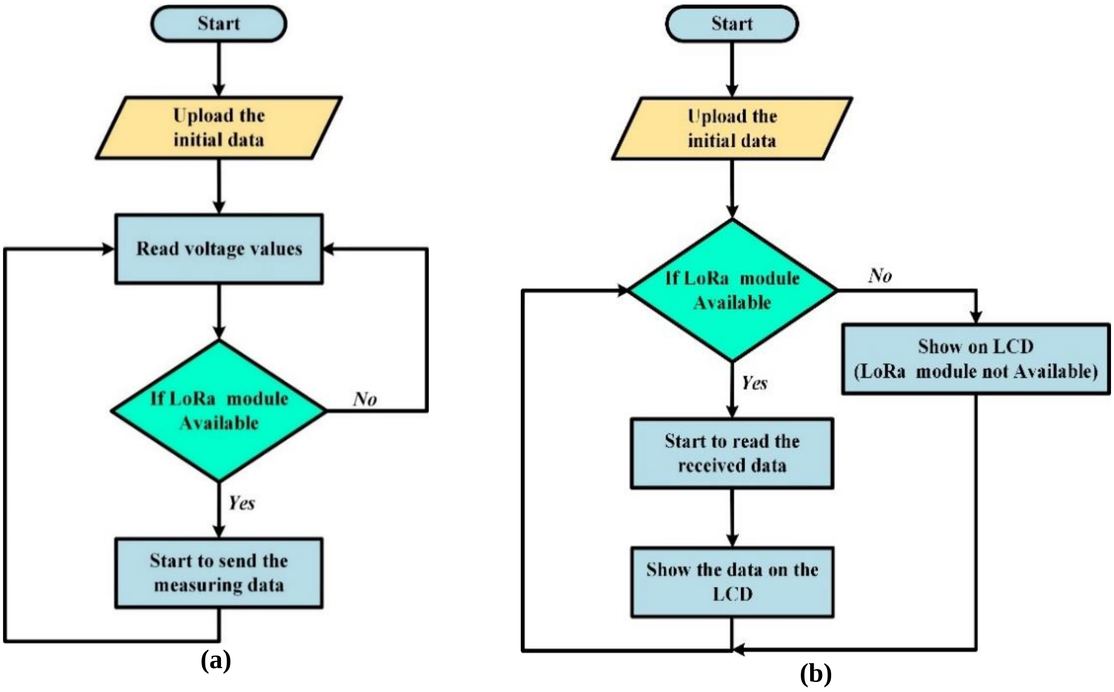


Figure 5. Software flowcharts of the system: (a) transmitter flowchart and (b) receiver flowchart

4. EXPERIMENTS AND RESULTS

After all, the main elements of the proposed system of the battery monitoring circuit of the voltage sensors and the LoRa module were presented in the previous part, all the electronic elements of the overall design of the transmitter circuit were assembled in Figure 6 and the receiving circuit in Figure 7. After the voltage measurement circuit was implemented, a set of readings was taken for one site (battery) over the cells during the day, and the results were presented in Figure 8. The measured results for the battery in Figure 8 represent the voltages of cells 1, 2, and 3, and also the total voltage of the battery (These readings were taken in the transmitter circuit). Figure 9 shows the battery cell readings voltage for each battery for the three sites (Batteries) proposed in our network system at different times for this paper.

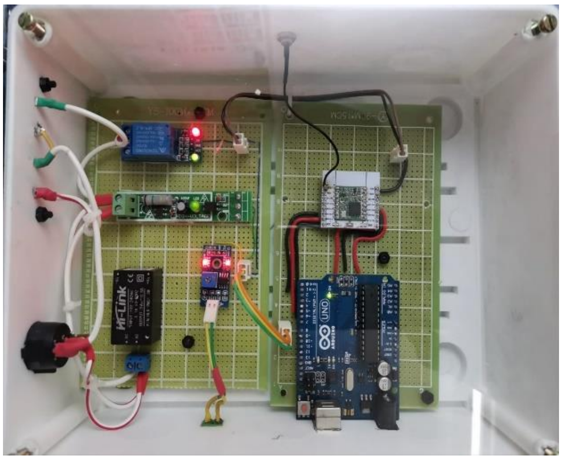


Figure 6. The full transmitter circuit with voltage sensors and LoRa module

Figure 7. The full receiving circuit with LCD and LoRa module

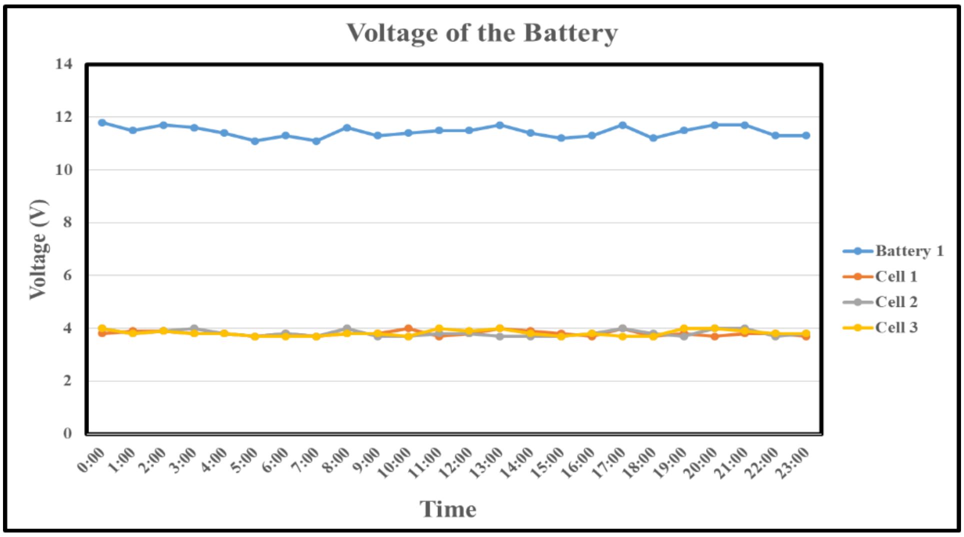


Figure 8. The battery cells readings voltage of the battery during the day in the transmitter circuit

Figure 9. The battery cell readings voltage for each battery in the network in the receiving circuit

5. CONCLUSION AND FUTURE WORK

The paper describes the design and implementation of an IoT-based battery cell monitoring system in real-time monitoring for photovoltaic applications. The circuit for the battery cell monitor and base station with an LCD screen for battery monitoring was developed and manufactured as part of system development by using LoRa/LoRaWAN. The system displays all information about the cell voltages of different batteries in the network at different locations.

As a control and monitoring system, using low-cost electronic components such as a LoRa module and an Arduino UNO. The RFM95 LoRa (as a universal asynchronous unit) is used to send all measurement values and data to a personal terminal, where the data can be displayed on a LCD. Results for the battery voltages of the entire system can be acquired over days, months, or a year for study and evaluation with our system.

The main advantage of this work of monitoring the battery cells from different sites from long distances is using low-cost circuits based on LoRa technology. For future work, further improvements to the system can be made by adding more functions to it, as well as developing smartphone applications It can help users check their batteries and serve as a reminder of energy deterioration. To improve your internet connection, utilize Ethernet or Bluetooth.

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