Battery Condition Prognostic System using IoT in Smart Microgrids

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***Abstract*—This paper presents an idea to share the battery condition monitoring parameters among the stakeholders like manufacturer, market dealers, users etc. by using latest Internet of Things (IoT) technology. Upon accessing such parameters, corrective actions can be taken to improve the battery life. By placing sensors on the battery, which can send the battery parameter data over internet to cloud database. This database can be accessed by manufacturer, dealers and users to monitor the health condition of battery. This will help to enhance the efficient use of battery and improve the life. Also, it can track the number of batteries in use with usage profile. The hardware prototype of the proposed system has been developed and tested with a lead acid SMF battery. The Mean Square Error (MSE) of the measured quantities are with in acceptable limits.**

***Index Terms*—Lead Acid Battery, IoT, Battery Condition Monitoring Systems, Raspberry Pi, ESP 8266.**

I. Introduction

Storage facilities are integral part of any energy supplying systems, especially batteries. Rapid growth in renewable energy projects, standby energy systems like UPS and electric vehicle technologies, increases the use of batteries. Also, in smart microgrids, batteries are used to store electric energy when there is excess generation than load. This stored energy can be utilized when the demand comes above generation. Hence battery plays a vital role as demand side management strategy to balance supply and demand. The annual production of batteries is increasing exponentially and it become very difficult to provide service solutions to end customers by the manufacturer or market dealers. Usually batteries are having two type of uses, Cycle use and Standby use. In cycle use, the battery is either fully or partially, charged or discharged as per the requirements. And in standby use, it may be in idle state by having trickling charge. The use in electric vehicles and UPS systems is cycle use and standby use respectively. The battery manufacturer would be specifying separate cycle life for these uses.

Most of the times, battery manufacturer would not be knowing about the use of battery by the end users, since there will be market dealers in between. In certain instances, the market dealers would not be able to provide better suggestions in operating procedure to improve the life, which can be done by the manufacturer. If the manufacturer can monitor the battery parameters, they can give necessary advice directly to end users. Then battery parameter data need to be accessed by the manufacturer and this makes the manufacturer to handle huge amount of data. At this stage, latest Internet of Things (IoT) technology can provide solutions to manage such big data issues with the help of cloud computing.

There are numerous techniques to estimate the health of battery by using voltage, current, temperature, specific gravity of electrolyte etc. In most of the cases, State of Charge (SoC) of battery is estimated and by using predication algorithms, health condition is forecasted. A real time battery monitoring system using Labview and Arduino is proposed in [1], in which battery voltage and current are monitored in real time and displayed the data in excel format. An online battery monitoring system for electric vehicles is developed in [2] in which GPRS technology is used to send the data over wireless networks. This system monitors voltage, temperature and SoC and stores the data for further analysis.

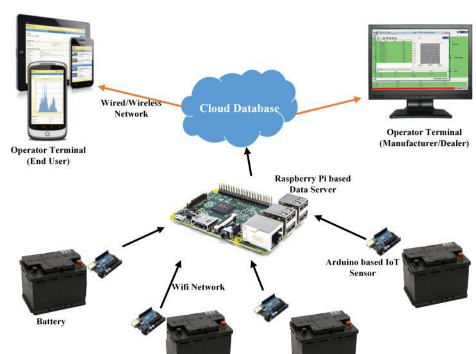

Fig. 1: Proposed System.

Microcontroller based battery monitoring systems were developed [3] electrolyte level and its temperature, number of back up hours left etc. were monitored. The measured quantities are displayed in a computer screen with characteristic plots. The state of health (SoH) of vehicle batteries is estimated using voltage measurements at the time of vehicle starting time [4]. The critical voltage values are identified from the measured values and SoH is estimated.

IoT based battery monitoring system for smart grid applications were developed [5] in which the system collects voltage, current and temperature values of the battery and data is made available to users through cloud database. The trends of different parameters like temperature, SoC etc were recorded. They have used digital communication platform for acquiring and storing the data with satisfactory speed levels which increases the reliability of battery monitoring system.

The rest of the paper is organized as follows. Section II will describe about the proposed system along with algorithms. The hardware prototype development and experimental validation setup is elaborated in section III, while, section IV discusses the results along with required plots to show the effectiveness of the developed hardware. Section V concludes the work presented here.

II. System Description

The proposed battery monitoring system consists of sensors for data acquisition, arduino board with wifi module and data server to send the measured data to cloud database. The schematic drawing of the proposed system is shown in Fig.1.

In this work, three sensors are used to measure battery parameters and they are, voltage sensor, current sensor and temperature-humidity sensor. These sensors measure the data and sends the data to arduino microcontroller. The arduino is having wifi module to communicate with data server developed on Raspberry Pi. Hence, there will be arduino based IoT sensor system as many as the number of batteries. But there will be only one data server for one location to which all arduino-IoT sensor systems communicates. The Raspberry Pi data server sends the stored data into cloud database from which the stakeholders can access and monitor the battery parameters. Wifi communication is enabled between ardunio and Raspberry Pi using IEEE 80211.n protocol which utilizes a MIMO based technology in order to achieve higher efficiency and transmission range. Data collected is transferred to the cloud using onboard wifi module in Raspberry Pi 3. The details of sensors and other components used for the work is given in Table I.

TABLE I: Component Specifications

Sl. No.	Item	Specification
1.	Voltage Sensor	Range: 0- 25V DC Resolution: 0.00498V
2.	Current Sensor	Range: +/- 30A DC Resolution: 185mV/A
3.	Temperature Sensor	Range: -40- 80o C Error: +/- 5o C Working Voltage: 3.5-5 V
4.	Humidity Sensor	Range: 0-100% Error: +/- 2%C
5.	Wifi Module	ESP8266, 2.4 GHz 10bit ADC, 16 I/Os
6.	Arduino Microcontroller	ATmega 328 Microcontroller 14 I/Os, 16MHz
7.	Raspberry Pi3	ARM 7 Microprocessor 1GB RAM, in-built Wifi Data Card Slot

A. Data Acquisition Algorithm

Data acquisition plays an important role in the battery monitoring system. The sensor values are continuously monitored at every 15 minutes interval. But, when there is a change in current value or direction (charging/discharging), at that instant the values will be measured. This helps to identify the change in operating mode as, charging (C), discharging (D) and idle(I).

There are many approaches available in literature to find the state of health of the battery [6].The operating status of battery is having relationship with temperature and hence, the battery status is defined with respect to temperature values as given in (1). In the work presented here uses a lead acid battery, that has maximum operating temperature of 60^{o}C.

$$\text{Status} = \begin{cases} \text{Normal}, & \text{if temperature} \leq 60^{o}\text{C.} \\ \text{Critical}, & \text{if temperature} > 60^{o}\text{C.} \end{cases} \quad (1)$$

In order to estimate SoC of battery, there are numerous tech-niques developed which includes coulomb counting method, open circuit voltage method, impedance method, Kalman filter estimation, neural network estimation etc. [7], [8], [9], [10], [11], [12], [13]. Out of this, coulomb counting method has its own advantages, since the SoC can be estimated from current as given in (2).

$$SoC(t) = SoC(t-1) + \frac{I(t) \times \triangle t}{\text{Battery Capacity (Ah)}} \quad (2)$$

where,

SoC (t) represents the present value of SoC (Ah).

I (t) represents the battery current (A).

Thus incorporating these mathematical background, the data acquisition algorithm can be formulated as given in Fig. 2.

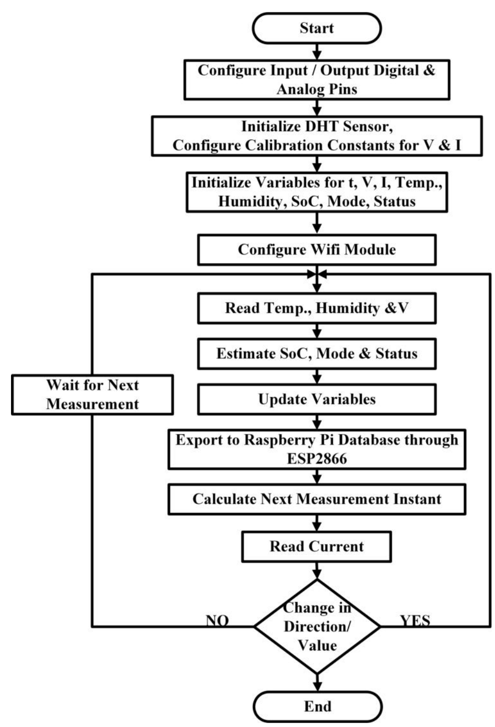

Fig. 2: Data Acquisition Algorithm.

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B. Data Networking Algorithm

In order to export data into cloud database, data has to be transferred to Raspberry Pi data server. The collected data from sensors are transferred to Raspberry Pi using ESP2866 and it is configured by using Arduino microcontroller. AT commands are written in embedded C programming to configure ESP2866 and transfer data to Raspberry Pi server . The algorithm for data transfer is given in Fig. 3. A web application is developed in HTML to display the monitored battery parameters by stake holders. This will give the data in tabular format as well as in trend fashion to improve the data interpretation efficiency of viewers.

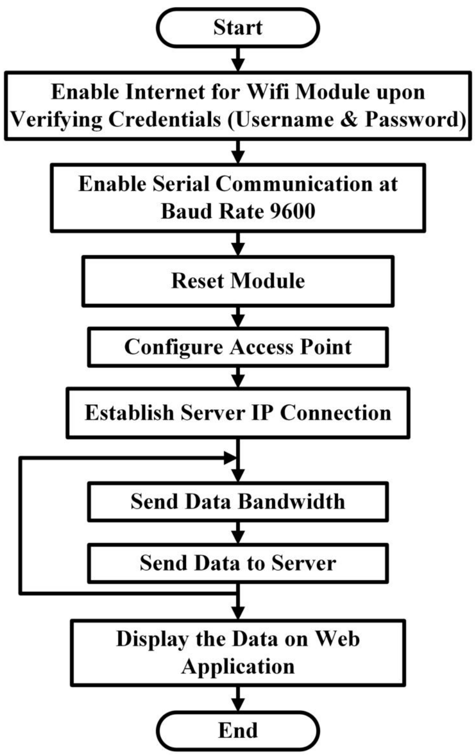

Fig. 3: Data Networking Algorithm.

III. Hardware Prototype Development & Testing

A. Hardware Design

The hardware prototype of the proposed is developed and used to monitor a lead acid battery. The embedded circuit configuration of hardware developed is shown in Fig. 4. The voltage sensor input terminals are connected across the battery, the current sensor input terminals are connected in series with the battery current circuit and the temperature sensor is placed near the battery terminals.

B. Testing

In order to experimentally validate the developed hardware prototype, an experimental setup power circuit is arranged which consists of battery, charging supply and load to test the developed hardware. The electric circuit of the experimental setup is given in Fig. 5. The battery is charged and discharged

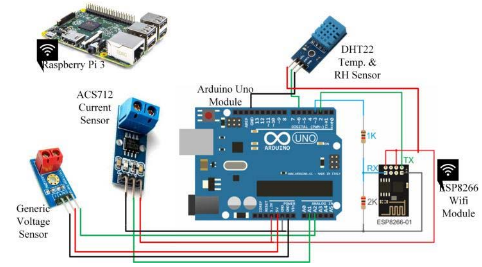

Fig. 4: Hardware Embedded Circuit.

with the help of DC regulated power supply and rheostat load. The control switches placed between battery, DC supply and load determines the mode of operation, ie, charging, discharging and idle. When switch S1 is closed and S2 is opened, the battery gets charged and in the reverse configuration, the battery gets discharged to load. When both switch are in open condition, the battery is in idle state. Battery cycle test is carried out in this experiment and hence both switch in closed condition is not analyzed. The details of hardware setup is given in Table II.

To compare the values measured by sensors through IoT network, manual measurements were also done. The details of instruments used for the same is also given in Table II. The testing is carried out as follows. The battery is connected to DC power supply for charging. It is seen from the literature that, the SoC of the battery can be estimated from terminal voltage and internal impedance [14], [15]. The equation given in (3) along with battery datasheet [16] are used to calculate the present value of SoC of the battery.

$$SoC(t) = \frac{V(t) - V_{MIN}}{A_{SOC}} \tag{3}$$

where,

$V(t)$ represents the present terminal voltage.

V_{MIN} represents the battery voltage at zero level of SoC (V).

A_{SOC} represents the slope of battery voltage change with SoC $\frac{V}{AH}$.

When the battery is charged to satisfactory level, it is kept idle, then taken for discharging using the rheostat. While it is discharged almost completely, it is gain kept idle. Hence one full charge-discharge cycle is completed in testing.

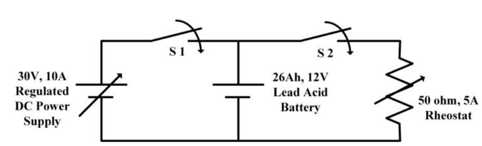

Fig. 5: Experimental Circuit.

IV. Results & Discussions

The hardware prototype of the proposed system is developed and tested. The measured values using IoT and manual measurements using calibrated instruments given in Table II, are compared.

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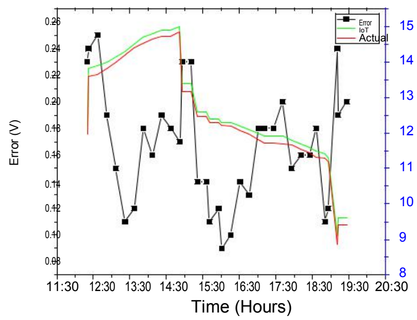
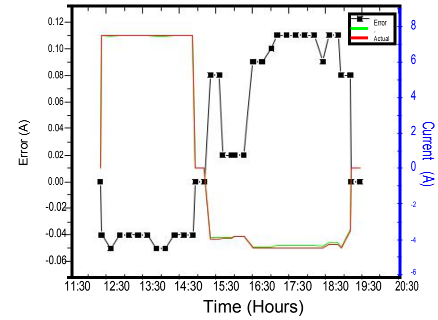
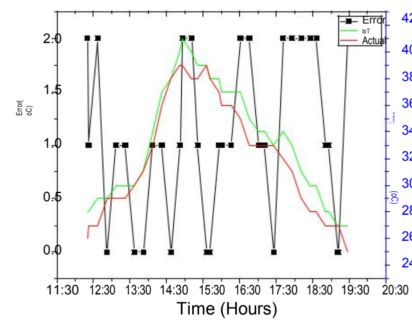


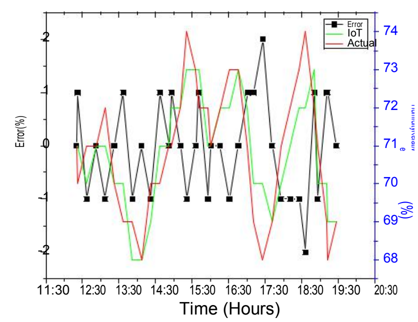
(a) Voltage Trend



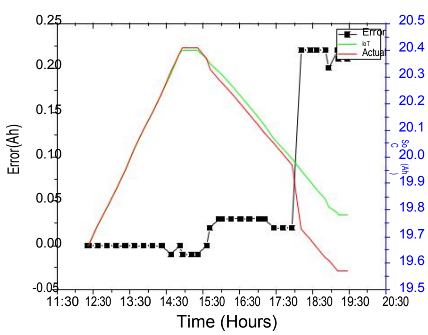
(b) Current Trend



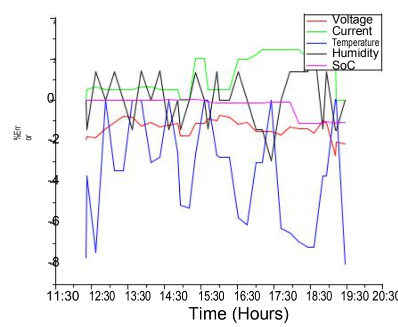
(c) Temperature Trend



(d) Relative Humidity Trend



(e) SoC Trend



(f) Percentage Error Trend

Fig. 6: Hardware Prototype Test Results

The measurement error is plotted along with the measured values and it is seen that, the measurement error in various sensor outputs are with in acceptable limits. The various trends along with percentage error in measurement of battery parameters are given in Fig. 6. The Mean Square Error (MSE) in measured values are tabulated in Table III. The obtained MSE values are very less and these values can be expected with sensors having accuracy levels given in Table I. If it is required to reduce MSE values further, more accurate sensors can be employed in the hardware prototype.

It can be seen from the error plots that, the error incurred in voltage, current and SoC are lesser than the error in temperature and humidity. It is due to fact that, the low cost sensors used in this prototype is having less resolution to adjust with variations in atmospheric conditions. The photograph of hardware prototype under testing is given in Fig. 7.

A web application is developed to share the monitored parameters to customers, market dealers and manufacturers. There is provision to view the values in tabular form in which latest few values are given. The trends of the parameters monitored can be viewed in the next page. This web interface will help to identify critical issues in battery operating conditions and there values can be used to evaluate the performance of the battery with remaining expected life and number of

TABLE II: Experimental Setup Details

Sl. No.	Item	Details
1.	Battery[16]	Rocket Make, ES 26-12 Model Lead Acid SMF 26Ah, 12V
2.	DC Power Supply	APlab Make, L6410 Model Regulated Supply 0-64V DC, 10A
3.	Clamp Meter	Fluke Make, 376 TRMS Multimeter
4.	Wifi Router	DC Link Make
5.	Temperature - Humidity Sensor	Extech Make AN340 Model
6.	Rheostat Load	50 ohm, 5A

TABLE III: Mean Square Error in Measurement

Sl. No.	Parameter	MSE
1.	Voltage	0.029803
2.	Current	0.004757
3.	Temperature	1.771429
4.	Relative Humidity	0.828571
5.	SoC	0.010814

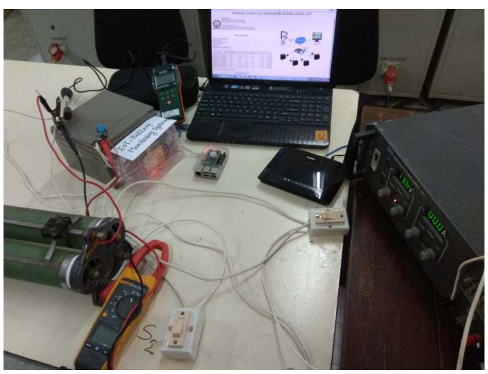


Fig. 7: Photograph of Hardware Prototype.

charge-discharge cycles completed or to be completed. These diagnosis will help to evaluate the buy back cost at any point of time by the stakeholders. The screen shots of the web application is given in Fig. 8 & 9.

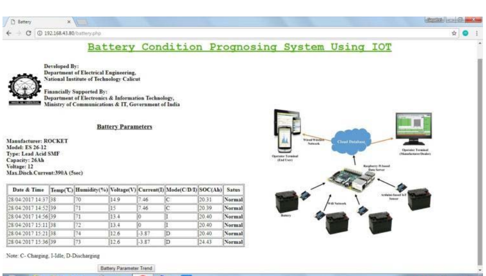


Fig. 8: Screen Shot of Web Application - Page 1.

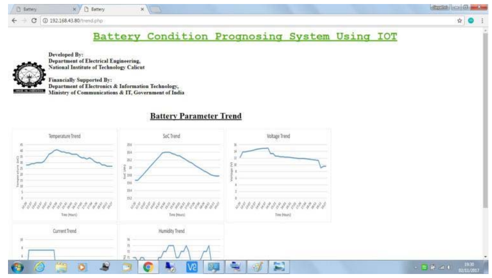


Fig. 9: Screen Shot of Web Application - Page 2.

V. CONCLUSION

This paper has presented a novel idea to monitor a battery by the manufacturer, market dealer once it is deployed for its use. The latest IoT technology enables to acquire battery parameter values with less time and cost. This work would facilitates the battery manufacturer to identify batteries that are in inefficient operating conditions and encourages the user for better efficient use through suggestions and recommendations. The storage becomes necessary for any sustainable energy supply system that uses renewable energy technologies. Also, electric vehicles will deeply penetrates into common man's transportation options. In these two areas, batteries are good option for storage solutions. This makes huge deployment of batteries across the world. Therefore battery management systems that monitors real time trends of parameters and share this knowledge to stake holders becomes highly necessary. This work could demonstrate low cost method to implement the same with the help of emerging IoT technology. The results shows that, the proposed system can be used for designing industrial prototypes.Also it is having an advantage over existing ones, that the parameters can be accesses at any time, any where with the help of IoT which improves the efficiency of corrective actions taken.

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