DETAILED DESCRIPTION

The present disclosure relates to a system that predicts when maintenance of a battery may be needed and what actions might be required. It further elaborates upon a system that can enable prediction of the required maintenance of rechargeable batteries such as Lithium ion batteries.

The system (as described in Figure 1) uses real-time monitoring of battery status to leverage data collected to identify systematic divergence of voltages of cells and data-based indicators of the battery to predict whether maintenance of battery is required. The proposed system requires a standard battery management system (BMS) with appropriate sensors for current, voltage and temperature of a battery. The BMS continuously receives in real-time, battery data from the battery and provides the battery data to a data-logger that may in turn provide the battery data to the proposed system using an appropriate communication means such as Internet or mobile data from a telecom network or Bluetooth or WiFi or any other communication mode. As can be readily understood, the BMS can be as well integrated with the proposed system. This proposed system may be configured to be in operative communication with a server/ public cloud and an appropriate database such as Amazon AWS server and MongoDB database. Further, a charger for the battery will be required.

Proposed system is used for a battery that is assembled by putting 16-cells of the same grading (i.e. same internal impedance and capacity). Each cell has a nominal capacity of 72 Ah and operating voltage range of 2.5 to 3.65 volt. Each cell is connected with a sense wire that is further connected with the Battery Management System (BMS). The battery is operatively connected to the BMS and the data-logger for real-time battery health and performance data collection and monitoring. An initial battery component calibration is performed. This ensures proper balancing of the cells of the battery and calibration of various values (for instance voltage, current) for the battery to function properly. The BMS can monitor various parameters pertaining to the battery (capacity, current, cell-voltage, cell temperature, interchangeably termed as battery data herein) in real-time and report the battery data to the data-logger via a communication port/cable.

The data-logger can in turn transfer the battery data using GSM 2G/3G/4G network or WiFi or Bluetooth or any other communication mode to the server (that may be remote from the battery) in which the proposed system is configured. The server and database settings can be appropriately configured. The proposed system can use RESTful API, Amazon AWS server, and MongoDB database for data collection and real-time monitoring of battery health and performance. Once the data-logger transfers the battery data to the proposed system configured in (or operatively connected to) the server, proposed system can use various data pre-processing steps to sort and clean the raw data for detailed data-analysis as further elaborated, to proactively determine any battery maintenance related issues. The real-time battery data generated can be leveraged using data science to determine, for instance, state of any loose connection in one/more cells by means of divergence in cell voltages from an initial stage of proper operation of the battery with all cells balanced.

In this manner, proposed invention assists in rapid estimate of maintenance requirements by real-time monitoring and leveraging analysis of data thus generated. Described proposed system uses voltage, current, temperature, capacity, and gps coordinates trends of the battery.

In the above-mentioned Figure 1, there are following key connections (wire/wireless):

(1) Electrodes to BMS electrical connection
(2) BMS internal connection
(3) BMS to Data-logger (DL) connection
(4) Data-logger's internal connection
(5) Battery to charger connection
(6) Data-logger's to server

A calibrated battery has its all the connections set and there are following two ways to monitor the battery: (1) Physical first and (2) Data first. Under physical first, battery system is manually monitored and under latter approach, data is monitored prior physical inspection.

We concluded that from data we could monitor and predict following loose state of connection:

(1) Case: 'Data-logger's to Server'

a. Data-logger transfer data using GSM signal and strength in the area using a sim-card and therefore, loose state of connection simply means due to poor GSM connectivity or sim-related issues (damaged sim, old sim, type of sim provider) data transfer did not happen. In the case when no data is transferred to server at the time of battery use, either data is not recorded at the server or data is recorded late.
b. Key identification of the loose state of connection from data-logger side to server side is based-on the date and time stamps recorded at the time of battery use and at the time when data was recorded at server. If the difference in the both the timestamps is zero or reasonable (or as planned), then no need to conduct a predictive maintenance. However, if no current data is recorded or there is a gap in the timestamps, one can be sure of one of the following cases might happen:
    i. Sim related issues
    ii. Poor GSM signal and strength or battery system is in enclosed environment
    iii. Other damages to data-logger
c. Diagnostic actions will be focused on root-cause-analysis of the above-mentioned causes. For predictive maintenance, one need to monitor gaps in the timestamps and anomalies when no data is being transferred.
d. To provide battery-user's support and to prevent fraud/theft of the battery, it is necessary to overcome such issues where no data is recorded (data-loss) or data is recorded late (data-lag).
e. Predictive modeling can be based on the identification of such geographical zones where GSM strength is poor.

(2) Case: 'Identification of loose 'electrodes to BMS electrical' connection

a. Damages to battery or cells
   This is an extreme scenario where physical, thermal, mechanical, or chemical damages to cells can influence functioning of battery or might lead to further damages to BMS. There is no easy way to predict such damages, only precautionary measure can help.
b. As described in the Table 1, if cells are not calibrated or of different grades than the voltage difference in the cells' even in initial charging-discharging cycles. This is one of predictor of poor calibration/assembly of cells and therefore, from data one can predict if the cells are calibrated. To predict if cells are calibrated or not, charge-discharge profile can be compared.
c. Connections related – if the sense wires are not or loosely connected to the cells, then cells' voltage will have a relatively high variance w.r.t to other cells, and it could be identified based-on the voltage range/variance listed in Table 1.1, which indicate how the voltage difference in cells' voltages w.r.t minimum cell voltage can be used to conduct identified actions.

(3) Case: BMS internal connection

a. BMS has many electrical components and integrated circuits. In case one of the circuit or components are malfunctioning then BMS will not be able to manage the battery, and data may not be transferred to Data-logger. Predictive monitoring and testing shall be taken in advance for functioning of key-components such as mosfets, LDOs, and similar electrical components need to be checked often to avoid BMS getting short-circuit, issues of current calibration, and failure in managing BMS.
b. In this case, data helps in predicting BMS internal connection failure by identifying current withdrawal from battery. When key components such as mosfet and LDOs fails then current (ampere) may go beyond threshold values. Additionally, if temperature sensors are connected to BMS then the

value of temperature might be above historical-average values indicating the failure of few of electrical components.

c. Therefore, to predict BMS failure one can monitor current and temperature of BMS. For instance, in many such observations, we noticed that temperature of BMS was 20-30 degree centigrade higher than average historical values of 50-60 degree centigrade.

(4) Case: BMS to Data-logger (DL) connection

a. BMS is connected to Data-logger using communication port and sense–wires. BMS transfers the collected data to data-logger at a certain frequency and data-transfer rate. This connection (As described in Table 2) is loose only in following conditions, given that set of BMS and Data-logger are working okay:

    i. Connecting wires are loose

    ii. Pin and communication port related

b. When BMS to data-logger (DL) connection is loose, no data will be transferred to server. Additionally, local data storage option (such as SD card) in data-logger will not help.

c. When a well-functioning BMS is placed on the battery, it is entirely possible that its performance may vary. Therefore, it is necessary to monitor data to identify such scenarios. In the data, if the data-loss is observed or values are all zero then the connection in between BMS and data-logger should be assessed (as described in below listed table). Therefore, diagnostic actions will be to replace the pins/port or connecting sense-wire and/or to restore the connecting wires.

(5) Case: Data-logger’s internal connection

a. A data-logger ideally have following key components: a micro-processor, GPS chip & antenna, GSM chip & antenna, and other electrical components.
b. To understand data-logger's internal connection, two of the above listed key components are described in detail and described in Table 3.
    i. GPS is used to track the latitude/longitude of the battery user (an EV driver). A GPS chip in the data-logger records the latitude and longitude of the battery all the time. To assess whether GPS is functioning as needed, GPS coordinates analyzed from the data. Key maintenance related issues with GPS can be due to following 2 factors –
        1. GPS chip and antenna related
        2. GPS strength in the ambient setting

    To predict GPS loss zone, geospatial analytics can be performed as described. Geospatial analytics will use
c. GSM architect is necessary for an IoT device to connect with cloud server and usually a 2G/3G/4G sim is used for network connectivity along with a GSM chip. If the sim is damaged or in no coverage area or lost the connectivity due to other reasons, no data will be transferred to server. This is further listed in the below mentioned Table.

(6) Case: Charger to battery connection

a. Battery is charged using a charger of adequate specification. Be a slow charger or a fast charger, it should be connected through a connector/joint that can withstand the application and condition. When a connector is loosely connected then there are high chances of current/charge losses leading to relatively high time to charge. In some cases, loose connector may also short-circuit the BMS.
b. A charger connection should not be loose, one can identify loose connection based-on the time taken to charge or values of current. In some instance, current values are recorded to be lesser than the specified

current values of charger. In the data (as described in Table 4), if the current values are recorded to be less than the specified current limit for the large/whole duration of charging or it is taking higher than usual time to charge the battery then the connector or joint should be checked. This has been listed in the below mentioned Table.