Design a Battery Monitoring System for Lead-Acid Battery

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Abstract— An efficient energy-management system for Lead Acid Battery, using Matlab and Arduino, was developed and tested. The system uses an ACS712 sensor to detect current and voltage in the circuit while LM35 Thermistor is used to detect the temperature. The data output from these sensors is stored and manipulated through Arduino (microcontroller). The State of charge (SOC) of the battery is the index which shows the amount of charge present in the battery. The SOC depends upon various parameters, such as current, voltage, temperature and pressure. In this experiment the temperature, current and voltage are considered for determining the SOC.

Keywords: State Of Charge (SOC), Electric Vehicle (EV), Open Circuit Voltage (OCV), Battery Monitoring System (BMS), Lead-Acid Battery.

I. Introduction

With the boom in the EV industry, there is a drastic demand for an efficient battery management system but for that initially monitoring of the battery is required. In India we are able to see an exponential increase in the number of electric Rickshaws which use Lead Acid battery instead of the using a more efficient lithium-ion battery. The main reason being the cost of the lead acid battery which way lesser than the lithium-ion battery, hence it is important to build a battery monitoring and management system for lead acid battery.

These lead acid battery works well in the ambient temperature but gives poor performance at lower temperature. The current system currently used are not adaptable to different atmospheric conditions and in a country like India temperature places an important role in determining the performance of the battery because the temperature here can go as high as 51.0 °C (123.8 °F) Phalodi, Rajasthan and as low as −45 °C (−49 °F) in Kashmir. Hence it is important to study the behavior of the battery at different temperatures which could help us design a system that more adaptive to the surrounding conditions.

For making a better and more efficient battery pack we have to keep a lot of factors in mind like Cell and Battery Voltages, Charge (or Amp hour) Capacity, Energy Stored, Specific Energy, Energy Density, Specific Power, Amp hour (or Charge) Efficiency, Energy Efficiency, Self-discharge Rates, Battery Geometry, Battery Temperature, Heating and Cooling Needs, Battery Life and Number of Deep Cycles. Working on these parameters and getting more precise values will help us design more effective BMS which will enable the user to take the best decisions according to the requirements.

II. Lead Acid Battery

This research work is focused on use of Lead Acid Batteries (LABs). LABs has been around for over 100 years and will be a market force for the foreseeable future due to its low cost, established manufacturing base and wide acceptance due less complexity and better safety [2]. The significance of LABs is evident from the extensive use in automobiles as start-lighting-ignition (SLI), with power inverters in form of stationary power backup, and recently in Electric Vehicles (EVs) like e-rickshaws, Mahindra Reva, Hero 2-wheelers and several others.

The electrodes are made of lead grids to maximize its surface area. The anode grid is filled with finely divided spongy lead (Pb) and the cathode grid is packed with lead dioxide (PbO2). Both electrodes are submerged in sulfuric acid solution having a specific gravity of about 1.25 that acts as the electrolyte. Anode and cathode grids are separated by insulators like strips of wood, rubber or glass fiber. Overall Reaction in LAB is given below:

$$Pb(s) + PbO2(s) + 4H^{+}(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO4(s) + 2H2O \quad (l)$$

Significance of Temperature

The performance, life and cost of any EV is strongly affected by its battery pack. Operating temperature of the battery is critical to its performance and influences the availability of discharge power (for start-up and acceleration), energy, and charge acceptance during energy recovery from regenerative braking. These affect vehicle drive-ability and driving range. Higher operating temperature is responsible for degrading the battery life. Therefore, ideally, batteries should operate within an optimum temperature range for the best performance and life. The desired operating temperature depends on electrochemistry, for a LAB it is 25°C to 45°C. However, since an EV will operate in a much wider temperature range (icy winters up to hot summers), therefore a smart Battery Monitoring System plays crucial role and must be designed to take into account temperature effects while SOC estimation and charging process.

III. SOC Estimation

Various battery parameter are used to determine the health of the battery matter while determining the performance of the battery, one of the main parameters that has been considered is SOC. In general, the SOC of a battery is defined as the ratio of its current capacity ((t)) to the nominal capacity (Qn). The capacity of a battery shows the maximum amount of charge that can be stored in the battery and is stated by the manufacturer [5]. The SOC can be defined as follows:

$$SOC(t) = \frac{Q(t)}{Qn}$$

There are various method used for determining the SOC of the battery. These methods are mainly classified into the following categories– Direct measurement, Book-keeping estimation, Adaptive systems and Hybrid method.

A. *Direct Measurement*

Direct measurement methods refer to some physical battery properties such as the terminal voltage and impedance. There are many different direct methods have been employed to determine the SOC such as: terminal voltage method, open circuit voltage method, impedance measurement method, and impedance spectroscopy method.

B. *Book-Keeping Estimation*

Book-keeping estimation method uses battery discharging current data as input. This method permits to include some internal battery effects as self-discharge, capacity-loss, and discharging efficiency. Two kinds of book-keeping estimation methods have been employed: Coulomb counting method and modified Coulomb counting method.

C. Adaptive Systems

Recently, with the development of artificial intelligence, various new adaptive systems for SOC estimation have been developed. The new developed methods include back propagation (BP) neural network, radial basis function (RBF) neural network, fuzzy logic methods, support vector machine, fuzzy neural network, and Kalman filter. The adaptive systems are self-designing ones that can be automatically adjusted in changing systems. As batteries have been affected by many chemical factors and have nonlinear SOC, adaptive systems offer good solution for SOC estimation.

D. Hybrid Methods

The object of hybrid models is to benefit from the advantages of each method and obtain a globally optimal estimating performance. Since the information contained in the individual estimating method is limited, hybrid method can maximize the available information, integrate individual model information, and make the best use of the advantages of multiple estimating methods thus improving the estimation accuracy. The literatures show that the hybrid methods generally produce good SOC estimating results compared to individual methods. The hybrid methods combine different approaches such as direct measurement method and book-keeping estimation method.

In this paper, Hybrid method is used, in which booking-keeping estimation method is used for finding the static SOC based on OCV & temperature and direct estimation for determining the dynamic SOC based on charge flow.

IV. Data Acquisition

Initially the data is fetched through the sensors (Temperature, voltage and current) and are converted through respective algorithms into temperature, current and voltage. These data are then fetched by the PLX-Data Acquisition software to save it in a excel format. This data can further be used for precise determination of the SOC and analysis in different software such as Matlab, Sage, Mathematia etc. The data fetched is processed and printed on the LCD screen (real time). Figure 1 shoes Graph of Voltage VS DOD for Lead acid battery.

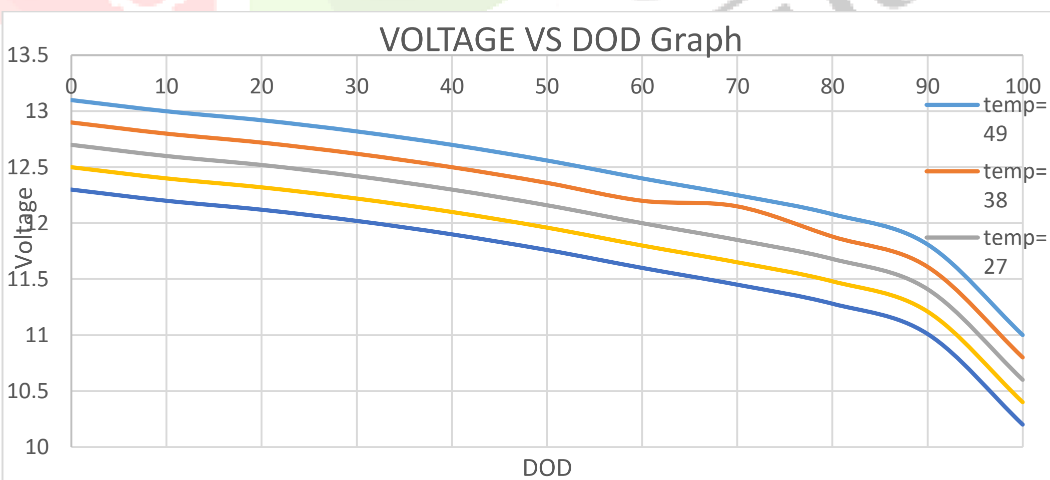

Figure 1: Graph of Voltage VS DOD, where DOD% = 100 – SOC% (This graph is made using the sample data)

V. Battery Monitoring System

In this system, the values of temperature, current and voltage are been taken through various temperature and are processed by the Arduino microcontroller. The data is then fetched and collected in an excel sheet using PLX-DAQ software. The real time SOC, charging or discharging conditions and voltage are then displayed on a LCD screen. The sensor used for measuring the temperature is LM35 and the sensor used for measuring the voltage and the current is ACS712 (5A).

A. Temperature Sensor LM35 [2]

The LM35 is a temperature sensor which gives voltages which are proportional to the temperature in degree centigrade. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. This device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾° cover a full −55°C to 150°C temperature range. The device is used with single power supplies, or with plus and minus supplies. The LM35 draws only 60 µA current from the supply hence it has very low self-heating of less than 0.1°C. The LM35 device is rated to operate over a −55°C to 150°C temperature range, while the LM35C device is rated for a −40°C to 110°C range (−10° with improved accuracy).

B. Current and voltage Sensor ACS712 [4]

The use of this device is for AC or DC current sensing in commercial, industrial and communications systems. The device consists of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. This device basically works on the principle of Hall Effect. The current in the circuit flows through the copper coil which generates a magnetic field which is then sensed by the integrated Hall IC and converted into a proportional voltage. Device accuracy is optimized through the close proximity of the magnetic signal to the Hall transducer. It is also being used as a voltage sensor for measuring OCV.

C. SOC Calculation

One of the most important problems faced while developing a BMS for an electric vehicle is the accurate measurement of the SOC of the battery. The SOC of the battery does not only depend on the Temperature, voltage and current but also on factors like number of deeps cycles, self-discharge rate etc. It becomes very complicated to work on all these parameters on the same time and determine the SOC. Hence the methods used do not yield the exact values because of the accumulative errors throughout the duty cycles.

In this paper, we have used a sample data of the Lead Acid battery at different temperatures to determine initially the SOC's at different OCV's. After that we are able to determine the SOC at the given voltage and temperature. Figure 2 shows circuit diagram of the Setup using Arduino microcontroller, LM35 sensor, ACS712 current and voltage sensor. Figure 3 shows developed Arduino based Battery Monitoring System.

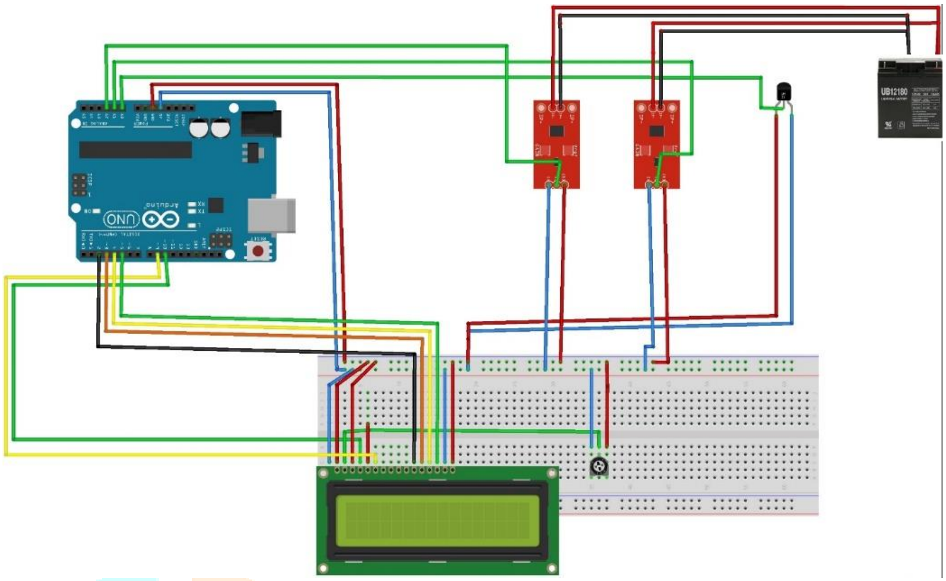

Figure 2: Circuit Diagram of the Setup using Arduino microcontroller, LM35 sensor, ACS712 current and voltage sensor

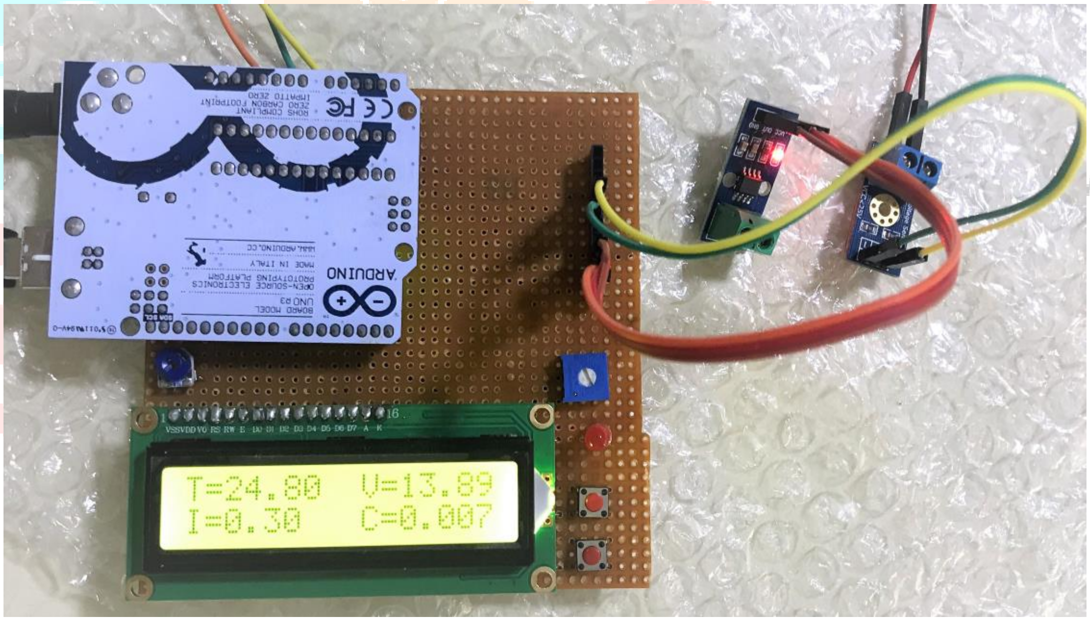

Figure 3: Arduino based Battery Monitoring System

D. Conclusion

The amount of charge in the battery varies significantly with the temperature. To develop a better BMS we need to have a good understanding of the relation of the temperature with the SOC. Also, the precession has to improve with time and hence we should try to incorporate more hybrid methods with which problems like early discharge could be avoided. These days the trend of electric cars is catching its pace and the demand of the market looks for a better solutions for EV's and this technology can be best incorporated in the E-Rickshaws because of their extensive use of the Lead Acid battery. It could possible to combine controller for motor drive and BMS. With the help of good understanding of the batteries in various condition and smarter battery management system can achieve a better efficiency and power at the same time.

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