ABMS
Advance battery management system

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1 Introduction

A battery management system (BMS) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it.

Purpose:

- Measuring of various battery parameters like voltage and state of charge.
- Protecting cells from over charging and discharging.
- Balancing cells in order to maximize the capacity of batteries.
- Regulate the output voltage and current.
- Providing interfaces to enable communication with the main controlling unit.
- Detecting short circuits and other anomalies.

2 Battery

We are using **ICR 18650**, this number comes from the dimensions of the cell. It's 18 millimeter in diameter and 65 millimeter in length.

2.1 Li-ion battery

Lithium ion is extremely lightweight, and has high energy density. So it's ideal for portable computers, mobile phones, and other hand-held devices such as tablets, also.

Lithium ion has become very popular because of its many performance benefits. Lithium ion provides higher energy in a smaller package and much better capacity retention in storage than the nickel-based systems. But the main drawback of lithium ion batteries is that they require precision electronics for monitoring and control, and this is needed to ensure safe and reliable operation. But despite this drawback, lithium ion has become the most popular choice for a huge variety of portable electronic devices.

2.2 Internal chemistry of battery

- Cathode:- Lithium cobalt oxide ($LiCoO_2$)
- Anode:- carbon/silicon and graphite
- Electrolyte:- Organic solvent with lithium hexafluorophosphate ($LiPF_6$) as the salt.
- Separator:- The separator is needed to prevent shorting of the cell and allows ions to pass through its porous structure.

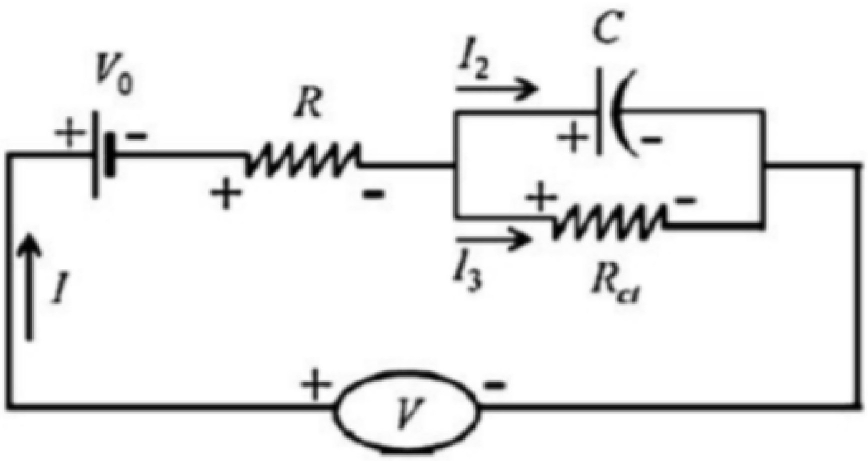

Figure 1: Empirical diagram of Battery

The positive (cathode) electrode half-reaction in the lithium-doped cobalt oxide substrate is:

$$\mathrm{CoO_2}^{+}\,\mathrm{Li}^{+} + \mathrm{e}^{-} \rightleftharpoons \mathrm{LiCoO_2} \tag{1}$$

The negative (anode) electrode half-reaction for the graphite is:

$$\mathrm{LiC_6} \rightleftharpoons \mathrm{C_6} + \mathrm{Li}^{++}\,\mathrm{e}^{-} \tag{2}$$

The full reaction (left: charged, right: discharged) being:

$$\mathrm{LiC_6} + \mathrm{CoO_2} \rightleftharpoons \mathrm{C_6} + \mathrm{LiCoO_2} \tag{3}$$

3 Charging And Discharging of Li-ion Battery

Lead and lithium-based chargers operate on *constant current constant voltage* **(CC/CV)**. The charge current is constant, and the voltage is capped when it reaches a set limit. Reaching the voltage limit, the battery saturates; the current drops until the battery can no longer accept the further charge and the fast charge terminates.So to Understand the whole process, we will focus on these two different tasks.

3.1 To Maintain CC/CV

We maintain CC/CV through DC to DC converters.A constant current (CC) converter and a Constant Voltage operates in similar ways.For example,in a CC converter,the control loop adjusts the duty cycle to maintain a constant output current regardless of changes to the input voltage and output resistance.A change in output resistance will cause the output voltage to adjust as the load resistance varies; the higher the output resistance, the greater the output voltage.

Design of CC/CV

Figure 2 outlines a typical discrete implementation of a CC/CV converter. The converter requires a sense resistor (Rsense), an amplifier and a voltage regulation circuit (v_z). The current flowing through Rsense sets the voltage across RFB, which is the feedback voltage of a controller. In this way, the current is regulated. As Rout increases, the voltage on the output rises to a point where the Zener diode conducts, and the device transitions from a CC converter to a CV converter.You can Refer from the image below.

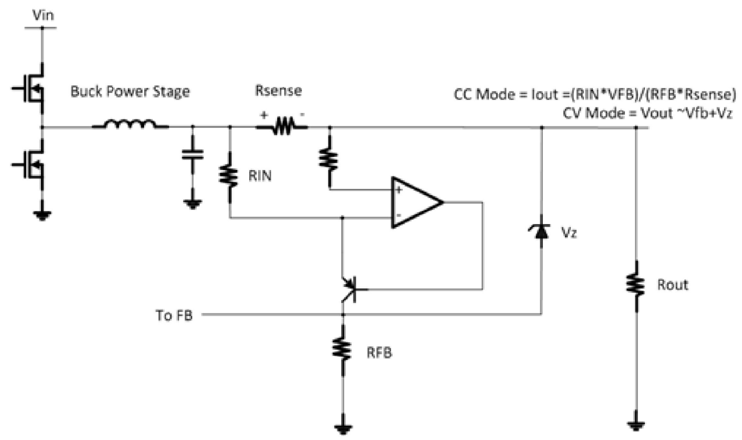

Figure 2: Circuit Design of CC/VC Converter

Making it with IC's

The TP4056 is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Its SOP package and low external component count make the TP4056 ideally suited for portable applications. Furthermore, the TP4056 can work within USB and wall adapter.See the figure 3 for reference.

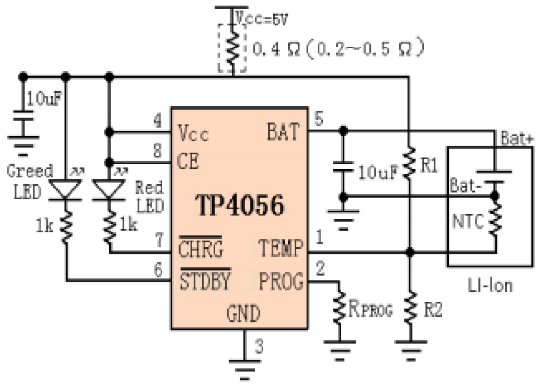

Figure 3: Schematic Daigran of **IC TP4056**

3.2 Protection from Overcharging

Overcharging of lithium batteries leads to irreversible damage to cell components and may cause serious safety problems.

3.2.1 How they Work

Battery protection ICs typically use MOSFETs to switch lithium cells in and out of circuit. Lithium cells of the same age and part number can be paralleled and share one protection circuit.MOSFETs with low RDS(ON) should be used to achieve high efficiency. Use MOSFETs with low Vt because the battery protection IC may only have 23 V to drive the gate.

3.2.2 Implementation Through Electronics

We are Using 5S 12V 18650 Lithium battery protection board for Overcharging protection. It has Over voltage range around 4.25-4.35v 0.05v with Over-discharge voltage range: 2.3-3.0v0.05v. It has Maximum operating current around 6-8A with Internal resistance less than 100m. It has Charging voltage around 12.6v 13V with Working temperature like -40 +50.

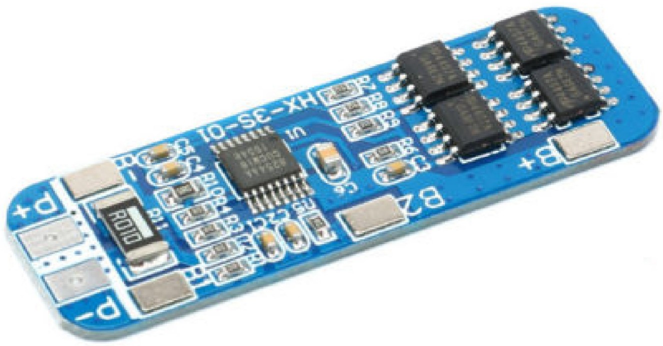

Figure 4: A 3S 12V 18650 Lithium battery protection board

4 SOC and its Components

The abbreviated form of SOC is State Of Charge. It actually defines the battery percentage that the stacks of cell has, like the one present in the right most corner of the mobile (the indication). Primitively the SOC is determined by the-

1. Capacity
2. Voltage across the battery.

Basic Definition of SOC:

$$\mathbf{SOC} = \frac{PresentCapacity}{Max.Capacity} * 100$$

4.1 Capacity

This method is commonly known as Coulomb counter. The fuel gauge has a current shunt with an amplifier and measures the consumed current, sums it over time and compares it to the programmed battery capacity.

4.2 Voltage across the battery

This primitive method is the mapping of overcharged and undercharged voltage with SOC For Ex:- 4.2 : 3.5 :: 0 : 100.

Coming to accuracy these are less accurate as SOC also depends on temperature and the internal resistance and it is not as linear as we do in the coulomb counting.To make the accurate algorithm for determining the SOC we require the EFK(Extended Filter Kalman). So to determine the current, voltage and the temperature across the battery we use the
DS2756 High-Accuracy Battery Fuel Gauge

4.3 SOC relationship with OCV,Internal Resistance

This Could be understand from the graph below.

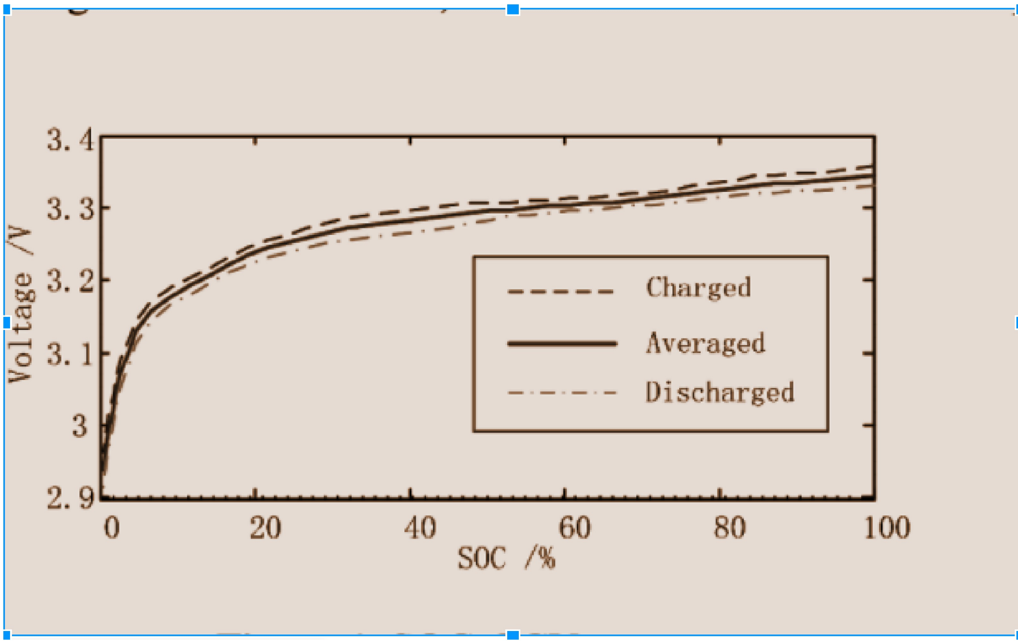

Figure 5: Relationship between OCV and SOC

4.4 Determining SOC

Usually, SOC cannot be measured directly, but it can be estimated from direct measurement of variables in two ways: offline and online. In offline techniques, the battery desires to be charged and discharged at a constant rate such as Coulomb-counting. This method gives a precise estimation of

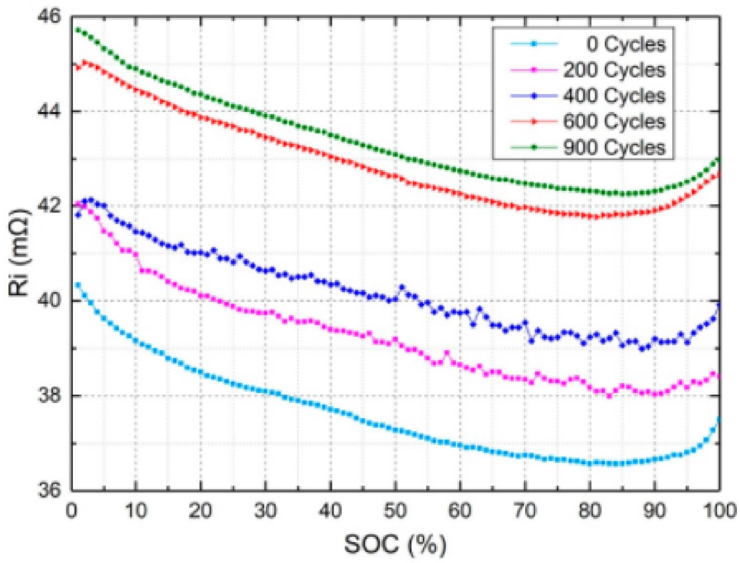

Figure 6: Relationship between Internal Resistance and SOC

battery SOC, but they are protracted, costly, and interrupt main battery performance. Therefore, online techniques are favored.

4.5 Coulomb Counting

This method is effective and one of the simple methods to find the SoC.It works by integrating the active flowing current (measured in amps) over time to derive the total sum of energy entering or leaving the battery pack.
While this is an elegant solution to a challenging issue, losses reduce the total energy delivered, and what's available at the end is always less than what had been put in. In spite of this, coulomb counting works well, especially with Li-ion that offer high coulombinc efficiency and low self-discharge

4.6 Current Sensing

There are two types of current sensing: direct and indirect. Indirect current sensing is based on Ampere's and Faraday's laws. Direct current sensing is based on Ohm's law. By placing a shunt resistor in series with the system load, a voltage is generated across the shunt resistor that is proportional to the system load current.The voltage across the shunt can be measured by differential amplifiers such as current shunt monitors (CSMs), operational amplifiers (op amps), difference amplifiers (DAs), or instrumentation amplifiers (IAs).

We have used op amp for measuring voltage across the shunt. Than taking output voltage in arduino to calculate current through the circuit. In this method shunt resistor and sensing circuitry are electrically connected to the monitored system(op amp and arduino). Therefore, direct sensing typically is used when galvanic isolation(used to eliminate stray currents such as differences in ground potential or currents induced by AC power) is not required. The shunt resistor also dissipates power, which may not be desirable.

Following picture depicts the circuit diagram used and the relation between the $V_(out)$ and $V_(shunt)$.

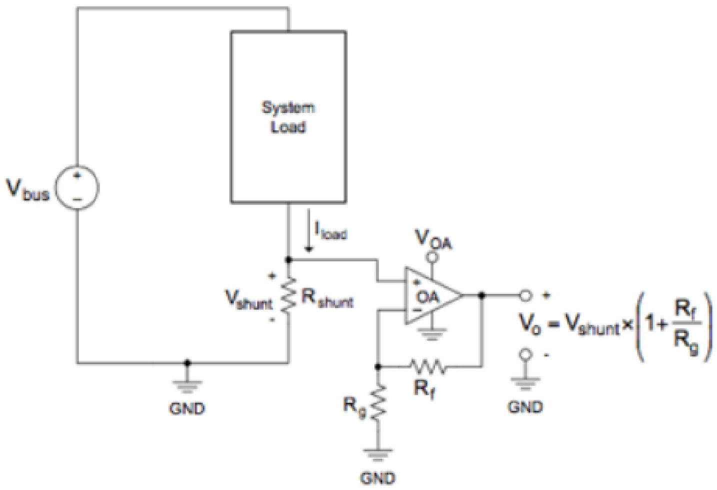

Figure 7: Cureent measurning circuit using op amp

4.7 Kalman filtering

Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone.

It is used to reduce the noise in current measured using op amp circuit.

The Kalman filter is a nonstationary, recursive filter that allows estimation of the useful signal in noisy time series in each moment of time. In steady state Kalman approach to digital filtering signal $x_t$is described by two linear difference stochastic equations:

$x_(t)$ = F*$x_(t-1)$ + B*u + Q(Process Noise)

$z_(t)$ = H*$x_(t)$+ R(Observation Noise)

The first equation describes process of signal generation while the second process of signal measurement. The noises are assumed to be independent (of each other), white, and with normal probability distributions.

For each time step, t:

- It predicts next stage $x_(t)$ = F*$x_(t-1)$ + B*u

  here F=1 is assumed to be constant and B=0 as ther is no control input to the system.

- Predict next covariance $P_(t)$ = F*$P_(t-1)$*F^T + Q

- Copmute the Kalman gain K = P_t*H^T/(H*P_t*H^T + R)

  here out put coefficent H=1 as it is only .

- Update the state estimate $x_t = x_t$ + K*(measurement) - H*$x_(t)$

- Update covariance estimate P_t = (1-K*H)*P_t

  We have assume the process variance is very low and the measurement variance is calculate by taking a large no. of data and getting its variance.

Using these steps starting from the initial estimates x_0 and P_0vone can obtain estimates of vector state x_t for any time 't'.

5 Active cell Balancing:-

Cell balancing is a way to improve battery life. It is of 2 type Active and Passive. Active cell balancing is a more complex technique that redistributes charge between battery cells during the charging and discharging cycles. By this system run time increases as total useable charge in the battery stack increases . It decreases charge time compared with passive balancing and decreases heat generated while balancing . It is used in communication like electric vehicles and appliances.

5.1 Why necessary

When charging the battery stack without balancing, the weak cells reach full capacity prior to the stronger batteries. Again it is the weak cells that are the limiting factor; in this case they limit how much total charge our system can hold. The diagram below illustrates charging with this limitation.

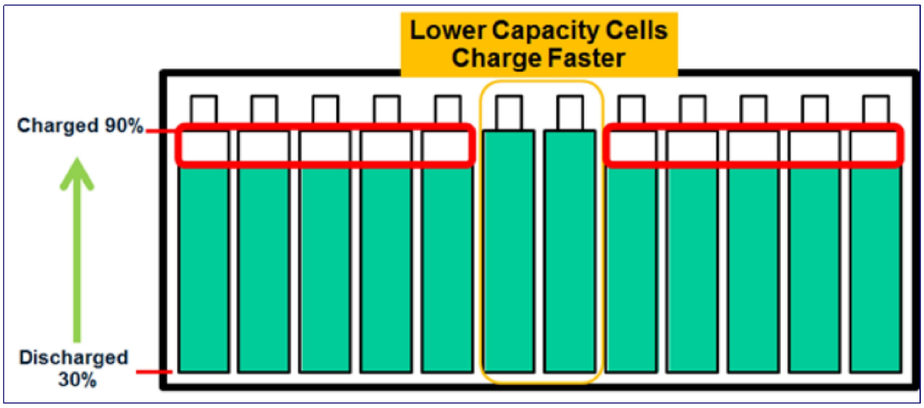

Figure 8: Charging without Balancing

With active balancing charge redistribution during the charging cycle, the stack can reach its full capacity. Note that factors such as the percentage of time allotted for balancing, and the effect of the selected balancing current on the balancing time are not discussed here, but are important considerations. Active cell balancing redistributes charge during the charging and discharging cycle, unlike passive cell balancing, which simply dissipates charge during the charge cycle. Thus active cell balancing increases system run-time and can increase the charging efficiency. Active balancing requires a more complex, larger footprint solution.

Requirements:-

1. Current Discharged
2. Voltage
3. Temperature
4. No. of cycles the cell has undergone
5. Internal Resistance and capacitance of the cell
6. State Of Charge

5.2 Implementation

Though battery monitoring IC's are present we would like to go without IC's to be cost-sensitive and to have deep-learning.We have used TP4056 single cell charging module to transfer charge from one battery to another i.e. the battery having lower voltage to the battery having higher voltage. It is done by using multiplexers and transistors as a switch also having arduino regulating and continuously measuring the voltage of each battery.

The code used for implementing active cell balancing, calculating SOC and monitoring of cell voltage is present in link below:
https://github.com/reithick/ABMS

6 References

- $https : //en.wikipedia.org/wiki/Batterymanagementsystem$
- $https : //www.eetimes.com/document.asp?docid = 1279404$
- $https : //pdfs.semanticscholar.org/6cfb/ef0876587ab8b5ca204d935eba0148ff0d47.pdf$
- $https : //www.youtube.com/watch?v = biY7FtLwE8$
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