BMS application note

BMS ZE6000i-PCBT.xxxx / ver. 2

Programmable battery management system for Lithium Ion battery cells, for up to 32 round or prismatic cells, 10 to 400Ah

NOTE:

This application note provides guidance for selecting operating parameters for lithium ion battery management systems. The battery manufacturer's information always takes precedence, but it is hoped that this note will assist in identifying the issues that need to be taken into account.
Please refer to the disclaimer before acting on the contents of this note.

Overview

There is no such thing as an entirely safe battery system; this is true of all battery types, lead acid, nickel metal-hydride, as well as lithium based types. Battery management is one critical aspect of producing a safe lithium ion battery pack. Another aspect is the measures taken to deal with the consequences of a fault. In considering the relevant factors, the operating environment is one element in achieving the optimal balance of cost, performance & safety. For example, the risks associated with operation in, say, a helicopter are different from a telemetry system in the middle of a field.
The battery management system (BMS) is just one part of the protection arrangements.

The second important role of the BMS is to optimise battery life and delivered capacity. These two performance factors work in opposition. Maximum delivered capacity does not yield maximum battery life. The BMS provides the means to optimise the trade-off of these parameters to suit the application.

The third role of the BMS is to provide information; key information required by the user, along with much more detailed information for service & maintenance. In general, the needs of the user are simple & interpretation should not require technical knowledge. In contrast, battery service & maintenance demands comprehensive technical information for interpretation by qualified engineers & technicians. Various means may be used to communicate this data, including a text display, a wired connection to a PC, or a wireless connection via bluetooth.

A fourth role of a BMS is to provide some form of data-logging which may be useful where details of the battery's history are needed. This can be useful in pinpointing operational issues that may be reported by the user or for analysis of battery usage & operating conditions.

Battery safety

Lithium ion batteries are capable of both absorbing & delivering extremely high current. Excess current may cause overheating or burning of connected circuits, the battery itself can also suffer damage with fire & toxic emissions a possible outcome. Note that this is also a threat with conventional lead-acid batteries, although lithium-ion hazards are more severe. It is vital to guard against this type of fault; most, but not all BMS models include battery overcurrent detection but it is sensible, if not vital to provide additional fail-safe protection of last resort. A conventional fuse is one appropriate means of providing this protection. The fuse must be capable of breaking the fault current & the fault current must always be able to rupture the fuse. Information provided by both the battery & fuse manufacturer should enable the correct part selection to be made.

Short circuits internal to the cell is also a threat, with lithium dendrite growth puncturing the plate separator being one known cause. Good quality cells are designed to reduce the risk, although BMS settings also have a role to play in keeping the risk low. Overcharge, deep discharge and low temperature charging may lead to metallic lithium deposition and promote dendrite growth. Correctly setting BMS parameters will reduce these risks.
Should a cell internal short circuit occur, cell heating & rupture can occur extremely quickly and lead to thermal runaway in adjacent cells as heat is transferred to them. Different cell types differ in their susceptibility to this outcome, and advice from the battery manufacturer should be sought.
There is little that can be done by a BMS to deal with this; protection measures are mechanical in nature & include good thermal design to remove heat & limit heat flow to adjacent cells along with venting to dissipate any noxious fumes and the use of fire retardant containment materials.

Battery life

Battery cyclic life is improved if the battery is not cycled between the fully charged & completely discharged states. If the maximum possible delivered capacity[1] is demanded by the application, then battery life will be reduced as a result.
By limiting the range over which the battery is cycled, the life can be improved. Life reduction due to full cycling can be quite substantial; the battery manufacturer should be able to advise, or if in doubt look for the test conditions used to specify the cyclic life. As a generalisation, life will progressively improve if the cyclic range is limited to 10% to 90%, or better 20% to 80% or better still 30% to 70%. Further range limiting beyond this provides diminishing returns. As noted in the battery safety section, the risk of dendrite growth is also reduced if the operating range is confined in this way.
Avoiding operation close to the cell's specified upper & lower temperature limits will have a beneficial effect on battery life. Charging at low temperature can be particularly damaging and as a general rule, charging should be terminated if the cell temperature gets to within 5degC of the manufacturer's specified minimum. If the charging arrangement allows, it may be possible to continue charging below this 5degC recommendation, provided the charging current can be controlled & reduced to around C/10 to C/20. As always, consult the cell manufacturer for advice, since the chemistry specific to each cell type has a bearing on what is possible.

The following BMS parameters provide the means to optimise life against delivered capacity and also constrain operation to within specified limits:

- Cell under voltage threshold
- Cell overvoltage threshold
- Charge low temperature (limit)
- SOC[2] for charger on

<u>Cell under voltage threshold:</u>

This is the cell voltage at which loads are disconnected by the BMS in order to limit the depth of discharge.

1. If maximum battery delivered capacity is required, set this to the cell manufacturer's specified discharge termination voltage. Nothing is gained by setting the threshold any lower & hazardous battery damage may occur.
2. Consult the manufacturer's discharge data to determine the 10% to 30% voltage limits, or if this is not provided then try setting between 200mV & 300mV above the cell manufacturer's specified minimum discharge voltage. Data provided by the BMS can be used to find where this point lies and adjust the settings accordingly.

<u>Cell overvoltage threshold:</u>

This is the cell voltage at which the charger is disconnected by the BMS in order to limit the upper SOC.

3. If maximum battery delivered capacity is required, set this to the cell manufacturer's specified maximum recharge voltage. Nothing is gained by setting the threshold any higher & hazardous battery damage may occur.
4. Consult the manufacturer's recharge data to determine the 70% to 100% voltage limits, or if this is not provided then try setting between 50mV & 100mV below the cell manufacturer's specified maximum recharge voltage. Data provided by the BMS can be used to find where this point lies and adjust the settings accordingly.

[1] *I.e. charged to 1200% and discharged to 0% of rated capacity*
[2] *SOC is the acronym for state-of-charge*

Charge low temperature:

This is the cell temperature below which recharge is inhibited by the BMS.

5. Ideally, this is best set 5degC higher than the cell manufacturer's specified minimum recharge temperature.
6. However, if the option is selected & if the charger has the capability, the BMS can output a signal to the charger to reduce its output current & will allow charging at the reduced rate to either commence or continue down to 5degC below the set limit.

SOC for charger on:

Once a lithium ion cell has been recharged, charging must be terminated. There is no equivalent to lead acid's float voltage. The "state of charge for charger on" setting is the point at which charging is re-enabled, having previously been terminated by reaching the cell overvoltage threshold. Setting this to a low value has the benefit of improving battery life, although this has to be traded-off against the anticipated usage pattern in the final application. The set value is expressed as a percentage of the useable capacity, & this in turn is determined by the under & over voltage limits set as described above. So for example, if a battery with 100Ahr rated capacity is operated between the 10% & 90% SOC limits, the useable capacity is 80Ahr. The "SOC for charger on" setting is a percentage of the 80Ahr useable rather than the 100Ahr rated capacity.
Explanatory note: the BMS tracks battery usage & re-calibrates the SOC as a percentage of the useable capacity. All reported data relates to this useable capacity, not the rated capacity. The last measured capacity is reported in the service & maintenance data stream.

Battery balancing

Balancing has the objective of bringing all cells to the 100% state of charge condition at the end of a charge cycle.

Battery balancing is an important part of maintaining a lithium ion battery in good condition. Part of a lithium ion management strategy involves ensuring that no single cell in a stack is subjected to overcharge, or deep discharge. Should any one cell reach the point of overcharge or onset of deep discharge before others, the BMS would be expected to terminate charge or discharge in order to prevent irreversible cell damage.

If all cells in a stack were absolutely identical is all respects, then it could be argued that balancing is not necessary as all cells will remain in an identical state of charge as the pack is cycled. Unfortunately, as of today, manufacturing is not sufficiently consistent for that to be the case, & may never be so. Other battery technologies, such as Lead Acid and Nickel Metal Hydride are tolerant to overcharge so all cells in a stack can be brought to 100% capacity by controlled overcharge. This is not the case with lithium ion, which cannot recover from overcharge; damage is irreversible.

The capacity that a battery pack provides is limited to that of the lowest capacity cell in the stack. If all cells can be brought to 100% state of charge, then the charge that can be withdrawn on discharge is that of the lowest capacity cell. However, if it happens that the lowest capacity cell is already partially depleted for whatever reason, then it cannot be brought to 100% state of charge without overcharging the other cells in the stack. If this happens, then the capacity provided is still that of the lowest capacity cell, except that the starting condition is already partially depleted, so even less is available.

This is where balancing comes into play. The objective is to ensure that all cells in the stack can reach 100% state of charge without any cells being overcharged. If this can be achieved, then the battery will be able to deliver the maximum possible charge to the load. Without balancing, there is the threat that any out-of-balance cell can drift so far away from the others that the battery eventually becomes unusable.

Balancing involves trimming the current[3] flowing through each cell by providing a bypass path across each individual cell. By controlling each bypass, the cells can be kept in balance such that all reach the 100% state of charge condition at the same time. Many simple BMS systems function by turning on a fixed bypass

[3] *The balancing current in ZE6000i-PCBT BMS system is up to 1A, but can be extended to 5A max.*

current for each cell when its voltage on charge reaches a predetermined level, typically just below the charge termination voltage. This common approach presumes that the cell voltage on charge reflects the cell state of charge. This may be true if all cells are identical, but this is not the case. There's an element of irony in claiming that cell differences drive the need for balancing, and then implementing a balancing strategy that presumes that the cells are virtually identical.

The *ZE6000i-PCBT BMS* is more sophisticated than these simple systems, responding to cell differences at all times during both charge & discharge. It does not presume that the cells are virtually identical.

Glossary & acronyms

BMS : battery management system
C: the battery rated capacity, usually expressed in amp-hours
C/x : this is used to express battery current as a proportion of the rated capacity; example - for a 100amp-hour battery C/10 would be 100/10 = 10 amps.
OCV : open circuit voltage, in this case the open circuit voltage of a battery, usually after a rest period of 1 to 2 hours.
OVP : overvoltage protection
UVLO : under voltage lock-out
SOC : state of charge, where 0% indicates battery depleted & 100% is battery charged
NTC : negative temperature coefficient. In the context of this note, this would normally relate to a type of sensor used for temperature measurement.
OLED: organic light-emitting diode

<u>Lithium-ion battery:</u>
This is a general term used to describe a rechargeable battery based around transporting lithium ions held in solution between a porous anode & cathode. Unlike lead-acid or nickel metal-hydride batteries, there is no chemical reaction involved in the usual sense. The ions are merely transferred between & absorbed into the positive & negative plates. Think of the plates as porous, with lithium ions occupying the pores.
There are many different plate materials used for these batteries, the more common including lithium iron phosphate & lithium cobalt oxide. This description refers to the material used for the positive plates. Graphite is commonly used for the negative plates.

<u>Lithium battery:</u>
There are batteries that do use lithium as part of a chemical reaction. These are not lithium ion batteries and the information in this note does not apply.

<u>Anode, Cathode:</u>
These are the technical terms for what are more commonly referred to as the positive & negative plates of a battery.
Confusion can arise here because the chemist's anode can be the electrical engineer's cathode, & vice versa. To avoid confusion, this note avoids these terms & uses the unambiguous terms positive terminal & negative terminal, or plates.

<u>Ions :</u>
Put simply, lithium does not exist in metallic form in a lithium-ion battery, but is always dissolved in a solvent; the electrolyte. If the battery is abused, lithium can be deposited is a metal, & as such is potentially hazardous because of lithium's highly reactive nature.

<u>Rated capacity :</u>
The absolute maximum amp-hour capacity that a battery is capable of delivering, as stated by the manufacturer.

<u>Useable capacity :</u>
the is the actual capacity that the battery will deliver, given that the BMS is constraining it for the reasons given in the “battery life” section of this note.

<u>Deep discharge:</u>
This term is used to define the point where any further discharge will cause irreversible damage to the cell.

<u>Balancing:</u>
A system that tracks cell state of charge with the objective of bringing all cells to the 100% state of charge condition at the end of a charge cycle.