Lithium 10 cell balancer/protector.

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Author: Loopy Byteloose from the Parallax Forums at www.parallax.com
Email: hwanghetw_at_yahoo_dot_com
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The information herein is intended to help others start with building an improved DIY 10 cell (or more) Lithium battery Battery Management System intended for ebikes. For my own consideration, I elect to consider using the Parallax Propeller micro-controller as a first attempt (www.parallax.com). No build details are yet included as one needs as overview of what requires control before drawing schematics and making physical boards.

These observations are intended to appeal to electric bike users and dealers that want to have a more nuanced approach to managing the charge of battery packs, discharge, and replacement of their battery packs. Goals are enable the end user or dealer service to extend the overall life of the battery pack, to enable replacement of individual cells as required, and to be able to monitor performance in a way that choices are intelligently made.

Generally, protection is resolved in two ways - voltage limit control (under and over voltage situations) and monitor of overheating. But terms of active and passive balancing have entered in sales literature. One must be educated and informed because not all balancing is good. In some cases it can shorten the life of the battery by trying to impose an idealized method on the real problem.

Thermal management.

Overheating likely requires a complete shut down of the charging (and maybe discharging) in order to allow the individual cell and those adjacent to adequately cool. Choice of battery chemistry can influence the management of temperature. And one can elect only to manage charge temperature if denied operation is considered a hazard.

It seems that one could get away with just one thermal sensor, but one per cell is ideal and if the BMS has data recording to an SDcard - hot cells can be identified for further examination of their performance in real context.

Voltage Limit control

Both over-voltage and under-voltage are managed by shut off or shunting the individual cell until it has been allowed to recover with in a certain period of time. But a digital approach might additionally recognize multiple consecutive events for further investigation and maybe resetting the limits to avoid frequent consecutive events.

The major issue with voltage limit controls is if one cell won't take a charge, remains below the appropriate limit, and locks out the entire battery in a refusal to charge unless added features are included. The second issue is excessively charging the battery.

Since the user/customer is paying hundreds of dollars for the battery, such an approach tends to imply that they suddenly must buy yet another battery pack. Since battery packs often represent 50% to 66.7% of their ebike's units total cost; NOT HAVING a more reasonable battery service policy is simply bad for business. Such a low cell would require remedial charge or replacement before the unit would be up and running again. But it might be possible to create a scheme that completely bypasses the defective cell until repair or replacement is resolved.

Under-voltage

Generally under-voltage is a product of a fast discharge over an extended period of time and the cell will recover if not used. But as cells age, there is always one that is first to permanently fail. In some cases, the whole unit can be salvaged by replacing the defective cell; in other cases, multiple cells are showing age and it is time for wholesale replacement. The worst case for the dealer is when a battery pack is provided new with one cell that goes quickly bad. The dealer often is in a position of loosing all his profit from swapping out a battery pack if he doesn't have the means to repair the defective new unit. And often, the BMS board is making his situation worse.

So if the BMS not only did protection and balancing, but also offered a mode to provide a remedial recovery charge to such cells, everyone would be much happier.

Over-voltage

Over-voltage usually occurs during the charging of the battery. At the end of the charge cycle, the battery dramatically climbs to the peak voltage offered by the charge. Since a 10 cell charger is really 10 times 4.25 volts, an unbalance charge might exceed the 4.25volt limit and create battery damage via excessive heat. It is important to realize that all batteries are chemical devices and have optimal operating temperatures inclusive of optimal charging temperatures. It they get too hot, the chemistry of the battery evolves into a destructive phase that may not be recoverable. The best approach is to monitor cell temperature at all times AND in conjunction with identification of charging or discharging mode. If a battery runs hot during the charging mode at the tail end, it is possible to set lower peak voltage and longer recovery cycle before additional attempts to charge.

Some people have mentioned that wholesale lowering of the 4.25 volt limit to 4.10 volts will substantially increase the useful life of the battery while delivering 90% of the capacity. Having such a choice would likely appeal to many users that only use their ebikes for short range or infrequent use.

Lithium batteries overheat when left on a trickle charge. It is better to leave them in a partially charged state when no in use that to repeatedly top off the battery. If you are needing maximum range with your existing battery, it may be best to buy a larger replacement than to try continually top off. The replacement can be charged to 4.10 volts maximum and survive better.

Balancing

All batteries have three phases, but these phases tend to be more pronounced Lithium batteries. Low battery, interim battery, and Full battery. The interim phase is relatively flat for lithium batteries. At this point, all cells tend to have about the same voltage output by nature of the chemistry. Not much is to be gained by trying to actively manage the individual cells within tight limits.

On the other hand, the extremes of Full and Low are important to extending the useful life of individual cells, and yet the wrong balancing method can do real harm to individual cells. It would be optimal to be able to set limits individually for each cell according to what appears as optimal management. It also seems that one can specify a mid-band of use where not management is really required.

Some have presented concepts of charge and discharge balancing. Since the charger injects a much smaller current that the battery's actual discharge, the components to manage balanced charging are far less costly than managed discharge. It might be more optimal to have discharge effectively bypass a cell when it has been adequately identified in a discharge algorithm. Temperature monitoring would be one criteria, so bring all voltages down in lock step may not be needed or productive.

There is discussion of 'active' and 'passive' balancing. I have yet to gain clarity on these terms and consider them more likely in the realm of marketing appeal than of engineering importance at this time. With further reading I may change this opinion.

Bypassing

Bypassing a cell that has reached its limit of charging or discharging certainly is an important topic and is often not examined separately from balancing. I feel that the two concepts should be looked at as separate because balancing is a rather dynamic function that attempts to provide optimal power while preserving the useful life of the battery. And bypassing, is a protective mode that removes the individual cell charging or discharges until the battery is either presented to a charger or removed from a charger.

Bypassing during charging is quite different from bypassing during discharge. This is due to the amount of current in the circuit. It may be that the FETs that are appropriate for monitoring cells are also appropriate for bypassing charge, but that the same FETs are inadequate for handling bypass of heavy current discharge.

In some cases, it would seem that no discharge bypassing would be the easiest option. On it might be that another device - such as relay or a SRC is better suited for discharge bypassing. This is a topic that requires further investigation. It may be that merely using larger power FET is the simplest design.

Given that a 10 cell charger provides a constant voltage 10 times the optimal individual cell voltage, if bypass during the charge cycle occurs, the remaining cells might be subjected to excessive individual charge voltage (0ver the usual 4.25v limit) and suffer heat damage. So it would seem that if one bypasses cells, one needs a means to reduce the available overall voltage. I suppose that PWM of the input voltage could progressively knock down the input available to the individual cells.

Choice of circuit design

I have seen one IC chip (no longer available from Dallas Systems) that is used in conjunction with a schematic that has a two terminal scheme (effectively presenting just a + and - terminal for connection to the outside world). Personally, I would prefer having a three terminal scheme of a common ground, a charger input, and a power output.

To me, this three wire approach seems to avoid a lot of hazards and to eliminate the need to disconnect the motor during charge so that it doesn't turn. The fact that a charger may provide 2amps and the motor may require 30 amps implies different component size for overall control. The output requires a wholesale shutoff when the battery requires charging.

Indicators

Everyone that has ever ridden a Vespa or old motorcycle knows what it is like to not have a gas gauge. Since Lithium batteries have a flat curve, it is difficult to provide a good indication of remaining life, but something needs to be provided. One alternative is to do like a Vespa and have a reserve option. The bike will stop and demand the user switch over to reserve when the power drops below a certain level. In that way, the user has time to make ones way to a recharge station or to switch to pedaling. In night driving, the reserve might be switched only to provide warning lights and not to power the motor.

Battery Chemistry and its implications
There are a lot of Lithium battery choices, but the choices narrow rapidly if you exclude primary batteries and hazardous. Primary batteries are not rechargeable, so they are not considered in this essay. Attempt to recharge them may cause one great harm. Secondary batteries are the industrial term for rechargeable. Your everyday Alkaline batteries are primary cells, and your NiMH are secondary cells. It is that simple. Many of the so-called hazardous chemistries used in small batteries and primary cells as both small size and not being rechargeable eliminates the hazard.

In Lithium technology, it seem that Lithium Manganese Ion cells were one of the first chemistries that was stable enough to not create big explosions and fireballs. Regular Lithium Manganese cells are primary cells, not secondary. But some websites haven't learned the difference in nomenclature, so if it is rechargeable you can presume it is the 'ion cell', not the other.

Since these were the earliest, they are not the best - but they are pretty good and many ebikes are being still sold with them. If you already have them, it is just a matter of 'loving what you got' and not worrying too much about not having the best. You can latter replace them when you need a new battery pack. In the meantime, nurture them as best you can.

So what is 'the best'? LiPO4 is the latest and some claim it is far better. But you will see a raging debate on the Internet as dealers tend to have only one or the other. And of course, if you can't sell the best, you lie and say yours is the best.

What is the difference? It seems the critical difference is that LiPO4 can tolerate higher temperatures - from 45 degrees to 70 degrees Centigrade; whereas the Lithium Manganese Ion survives better at 50 degrees Centigrade an less. So this is where it becomes critical to have temperature sensing of your cells. We can talk all day about specified maximum charge voltage and specified maximum discharge rate, but damage to the cell is directly reflected in the actual temperature of the cell. It is indirectly reflected in the applied voltage or drained current.

So having a smart board that keeps watching the temperature puts you way ahead. I guess if you are living in Iceland, this think this may not matter. But you just might be charging your battery next to a roaring fire while you take a long winter's nap.

The beginnings of circuitry
If you have looked at other boards, you pretty much know if you need a 15amp board or a 30amp board. But it you look closely at a board that provides 10 or 15 amps to your ebike, you begin to notice it has 3 or 4 power MOSfets in parallel that imply switching a total of 85 amps or more. What is going on here?

It is all about spikes and surges in demand. Your board may be designed to provide 10 to 15 amps of steady power, but when you first turn on your cold motor, there is a momentary spike in demand that would ordinary blow up a 10 or 15 amp MOSfet. So one has to provide for that momentary condition. Please don't think your board expects to run at 90amps all the time on the puny 14 gauge wire connecting to the motor controller. And if you do design a board and have your main power MOSfets blow, add another one in parallel until the performance is stable. It really is that simple. Many boards also include heat sinks for these, but that too may be a bit of overkill. It is up to you to figure it out.

References
Frankly, providing reference and their links is a bit tedious. Try to find the thread that discusses this

topic on the Parallax Forums (Google works) and you will find ample to read.