Battery Management System for Li-ion Chemistries

Nitesh Sharma, ShubhamRawat, EkanshiChandna, DikshaGoyal, ShilpiMazumdar

EEE Department,

ADGITM, GGSIPU, New Delhi, India

Abstract:A battery management system (BMS) is a critical component of every electrical system containing batteries, which are vulnerable to various conditions of operating conditions. The purpose of BMS is to guarantee safe and reliable battery operation. To maintain the safety and reliability of the battery, state monitoring and evaluation, charge control, and cell balancing are functionalities that have been implemented in BMS. As an electrochemical product, a battery acts differently under different operational and environmental conditions. The uncertainty of a battery's performance poses a challenge to the implementation of these functions. This paper addresses the hardware implementation of a BMS by state evaluation of a Li-ion 48V battery using 18650 cells, including state of charge and state of life which is a critical task for a BMS. Through reviewing the latest methodologies for the state evaluation of batteries, the future challenges for BMS are presented and possible solutions are proposed as well.

Index Terms **- BMS, 48V Li-ion batteries, PCB designing, MOSFETs, NTC, EV and HEV.**

I. INTRODUCTION

BMS systems are currently found in portable electronics, such as laptop computers and cellular phones, but they have not been fully deployed in EV and HEV. This is because the number of cells in a vehicle's battery is hundreds of times greater than that in portable electronics. Moreover, a vehicle's battery is designed not only to be a long-lasting energy system, but also to be a high power system. In other words, batteries for EV and HEV have to provide high voltage, high current and also have to be light in weight to reduce the load torque, since lithium ion compared to other batteries is considered more light in weight and are more efficient in storing energy than any other batteries present in application, therefore they are the first choice for many car manufacturing companies. These make BMS for EV much more essential and complex than those for portable electronics.The battery state determines the charge time, discharge strategy, cell equalization, and thermal management among the cells.

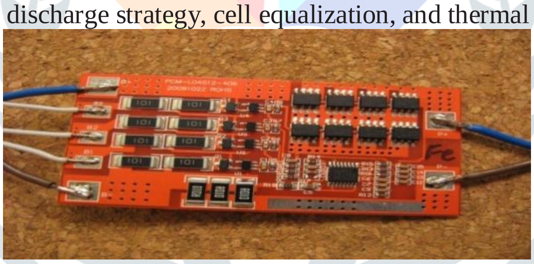

Fig1: BMS for 4s Li-ion cell

The system cannot be bypassed, by connecting batteries to the load in an electric and hybrid vehicle because the quantity of cell ranges in thousands and one mistake can lead to a huge explosion. A Li-ion cell have two conditions that need to be monitored throughout its operation while charging and discharging, that is the unbalancing and heating of cells i.e. above 45 degree Celsius temperature. Unbalancing can be caused various reasons which will be explained later in this paper.

A lithium ion battery is an arrangement of various small cells which are connected to each other in series and parallel. Cells connected in series increase the voltage and cells connected in parallel increases the capacity in Ah of the battery. Li-ion batteries are available in all shapes and sizes. And that renders them to be the perfect option for power needs irrespective of the size of the system. Along with that, lithium-ion batteries offer power solutions across the spectrum- from energy storage solutions to portable energy solutions.

If any situation like unbalance occurs in the battery, whole battery gets damaged. While manufacturing one should consider the battery life cycle in mind because a cell have a limited lifetime, usually it is considered 500 cycles of charge or 2-3years, degradation of cell over its continuous use or not in use happens and therefore it is often recommended to use cells which are manufactured at the same date, time and manufacturer.

Fig2: Li-ion battery 13s-1p

Therefore a common problem for the operation of the battery is the unbalancing of Li-ion cells in the battery which causes the operation of battery quite complex. To overcome the situation of unbalance and overheating while the battery is still in use, the battery is connected to a BMS which monitors and overcomes each situation to make the use of battery quite easy for the customers. Before moving on to the hardware of the BMS we should look at how unbalancing can affect the batteries. Some of the most common applications of lithium-ion batteries are:

- Power backups/UPS,
- Invertors and generator systems,
- Mobile, Laptops, and other commonly used consumer electronic goods
- Electric mobility

II. TYPES OF LITHIUM ION CELL UNBALANCE AFFECTING CHARGE/DISCHARGE VOLTAGE

A. State of Charge(SOC) Unbalance

A SOC unbalance is the term used when there is unbalance in the charge of each cell, for example a battery consisting for 3 cells connected in series and cell is 2000 mAh in capacity, now when in use somehow the, cell 1 got discharged 100 mAh, cell 2 got discharged by 200mAh and cell 3 got discharged by 150 mAh. If the cells continue to discharge there will be unbalance is the state of charge of the cell, which means cell 2 will discharge before other cells and now since other batteries have charge left in them, now further use of the cell 2 can damage the cell which can damage the working of the battery since each cell is connected in series.

B. Capacity Difference

This happens when different cells have different capacity in a battery, for eg, cell 1 is of 2000mah, cell 2 is 2200mah and cell 3 is of 4000mAh capacity. When in use it is obvious that the cell with less quantity will be drain first while there will still be some charge left in other batteries.

C. Impedance Difference

Different cells have different internal impedances, internal impedance makes a difference in voltage while charging and discharging. There is no circuitry solution to this problem, if there is it will complex the system more, therefore it is preferred to choose cells that have same internal impedance while manufacturing the battery, otherwise there always be a condition of imbalance.

III. HARDWARE IMPLEMENTATION

A. Interface

There are many ways to balance these cells and it is quite easier to balance these cells in portable electronics where there are three or four cells, but in applications where it requires higher voltages such as in HEV/EV vehicle or in storing solar power a lot of the complexities lies in how to monitor all cells as many cells are connected in series and parallel configuration, if we use separate circuit for each cell then it will not be economical and also will be quite complex to create an algorithm to sync the operation of each cell. So what we do is that we monitor each cell in series as shown in fig.

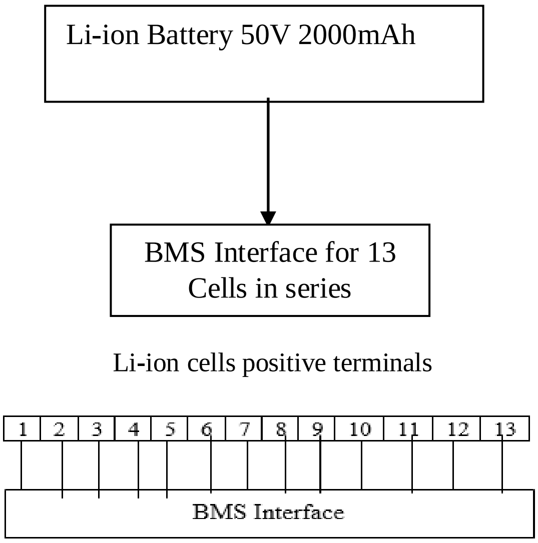

Fig3: BMS Interface

B. Hardware Implementation for Temperature Measurement

There is a separate connection for temperature measurement of each cell. A lithium ion has a working temperature of 0℃ to 50℃ when charging and -20℃ to 75℃ while discharging. NTC thermistors are found to be more accurate in measuring temperature as they vary their resistance according to the temperature that is easier and an economical way for temperature measurement. We have used 10D-9 NTC thermistor, which is connected in between each cell. These NTC are connected to a 5V source, whenever there is a change in temperature, voltage vary accordingly. This voltage is compared using comparators to generate a fault signal. MOSFETs are used to receive these fault signals and whenever there is a fault in a system these MOSFET performs the switching operation to disconnect the battery.

Fig4: NTC 10D-9

C. Hardware Implementation of Overcharge/ Undercharge and Balancing of Li-Ion cells

There are many way to solve the unbalancing problem in lithium ion cell but each process have their own set of complexities and disadvantages and advantages. Current Bypass technique uses microcontrollers, MOSFETs, resistive load bank and comparators to balance the cell by draining the cells from high to bottom, this is a simple way of balancing cells in a battery but there's a significant loss in the form of heat while using this technique, but this is not a very big problem since the loss of energy is happening while charging the batteries, it would have been a problem if there were losses when the circuit was in operation. A different approach can be a Charge Redistribution method in which a capacitor is used instead of a resistive load bank which can store the energy, than dissipating it in the form of heat. This approach is quite complex and increases the size of circuit board. The main problem with this method is that there are significant energy losses in capacitors during charging, maximal efficiency of this process is 50%. Another problem is that high voltage differences between the unbalanced cells exist only in highly discharged state. Because this method transfer rate is proportional to voltage differences, it only becomes efficient near the end of discharge so total amount of unbalance that can be removed during one cycle is low. This can be overcome by using a transformer to provide the balance charge to which cell that requires an additional charge but with an added transformer the price of circuitry also increases therefore we have used the Current Bypass method to balance our cells, by the application of MOSFET IRLZ24N and UA741CN op amps as our comparators.

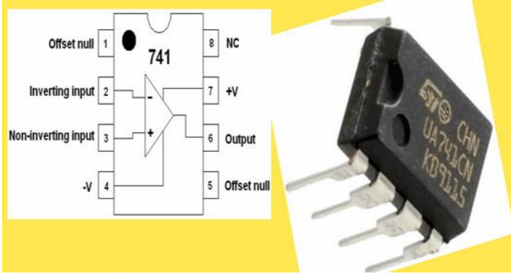

Fig5: UA 741 CN

Fig6: IRLZ 24N

IV. Balancing Algorithm Used

To balance the cell we first let the cells charge to the maximum limit and one a particular cell in series reached 4.1V, it is subjected to bypass and drain to keep the energy in limits by this way each cell in series reaches to 4.1V and hence we can easily balance the cells by charging them all to a same potential. This algorithm is suitable for balancing cells with different capacities and cells which are of different impedance.

If the temperature of the cells reaches an undesirable limit for in our case we have set it to 45° C a fault signal is send to the MOSFETS (in high current applications a contactor or a high voltage relay suitable for the application is used) to disconnect the batteries for the main circuit and then they are subjected to cool down process by using fan. In case of undercharge condition of any cell the battery is disconnected from the main circuit so as to protect the cell from further degradation by undercharge condition.

V. CONCLUSION

In this work, we have used balancing of state of charge (SOC) of Li-ion cells by using current bypass method to design a PCB for BMS. A BMS which monitors and protect cells from unbalancing conditions during charging cycles, protection against getting cells over heated and getting under charged.

REFERENCES

[1] Electric Power Research Institute (EPRI), *"Electric Transportation: Industry Terms,"* 2013. [Online]. Available: http://et.epri.com/ResearchAreas_IndustryTerms.h

[2] M. Kane, *"Battery Capacity Comparison: Plug-ins Vs Hybrid Car Sold From 2011 To 2015,"* Inside EV, October 2016. [Online]. Available: http://insideevs.com/battery-capacity-comparison-of-plug-ins-hybrid-car-sold-in2011-2015/.

[3] http://www.uscar.org/guest/view_team.php?teams_id=12.

[4] P. Wolfs, *"An Economic Assessment of "Second Use" Lithium Ion Batteries for Grid Support,"* in Universities Power Engineering Conference (AUPEC), 2010.

[5] R. C. Kroeze and P. T. Krein, *"Electrical battery model for use in dynamic electric vehicle simulations,"* in Power Electronics Specialists Conference, 2008.

[6] D. Yang, C. Lu and G. Qi, *"An Improved Electric Model with Online Parameters"* International Journal of Computer and Electrical

Engineering, vol. 5, no. 3, pp. 330-333, 2013.

[7] M. R. Jongerden and B. R. Haverkort, *"Which battery model to use?,"* IET Softw, vol. 3, no. 6, pp. 445-457, 2009.

[8] M. Chen and G. A. Rincon-Mora, *"Accurate electrical battery model capable of predicting runtime and I-V performance,"* IEEE Transactions on Energy Conversion, vol. 21, no. 2, pp. 504-511, 2006.

[9] S. Peck, T. Olszanski, S. Zanardelli and M. Pierce, *"Validation of a Thermal Electric Li-Ion Battery Model,"* SAE International, vol. 5, no. 1, pp. 154-163, 2012. 98

[10] J. Li and M. S. Mazzola, *"Accurate battery pack modeling for automotive applications,"* Journal of Power Sources, vol. 237, pp. 215-228, 2013.

[11] C. Sen and N. C. Kar, *"Battery pack modeling for the analysis of battery management system of a hybrid electric vehicle,"* in Vehicle Power and Propulsion Conference, 2009.

[12] B. J. Yurkovich, *"Electrothermal Battery Pack Modeling and Simulation,"* 2010. [Online]. Available: https://etd.ohiolink.edu/rws_etd/document/get/osu1281632214/inline.

[13] University of Colorado, Boulder, *"Today: Battery pack modeling and BMS,"* 2014. [Online]. Available: http://ecee.colorado.edu/~ecen5017/lectures/CU/L15_slides.pdf.

[14] A. Cordoba-Arenas, S. Onori and G. Rizzoni, *"A control-oriented lithium-ion battery pack model for*

[15] C. Lin, A. Tang and W. Wang, *"A review of SOH estimation methods in Lithiumion batteries for electric vehicle applications,"* in International Conference on Applied Energy, 2015.

[16] Y. Zou, X. Hu, H. Ma and S. E. Li, *"Combined State of Charge and State of Health estimation over lithium-ion battery cell cycle lifespan for electric vehicles,"* Journal of Power Sources, pp. 793-803, 2015.

[17] M. Daowd, N. Omar, P. V. D. Bossche and J. V. Mierlo, *"A Review of Passive and Active Battery Balancing based on MATLAB/Simulink,"* International Review of Electrical Engineering, vol. xx, no. x, 2011.

[18] J. H. Pikul, H. G. Zhang, J. Cho, P. V. Braun and W. P. King, "*High-power lithium ion microbatteries from interdigitated three-dimensional bicontinuousnanoporous electrodes*," natureresearch journal, 16 April 2013.

[19] BatteryUniversity, *"The High-power Lithium-ion,"* 2017. [Online]. Available: http://batteryuniversity.com/learn/archive/the_high_power_lithium_ion.

[20] MathWorks, *"Model batteries when designing battery-powered systems,"* 2017. [Online]. Available: https://www.mathworks.com/discovery/battery-models.html.

[21] A. Li, S. Pelissier, P. Venet and P. Gyan, *"Fast Characterization Method for Modeling Battery Relaxation Voltage,"* Batteries, vol. 2, no. 7, 6 April 2016.

[22] Woodback Communications Ltd, *"Battery Chargers and Charging Methods,"* 2005. [Online]. Available: http://www.mpoweruk.com/images/bat_hysteresis.gif.

[23] R. Ahmed, J. Gazzarri, S. Onori, S. Habibi, R. Jackey, K. Rzemien, J. Tjong and J. LeSage, *"Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications,"* SAE International, 2015.

[24] R. Jackey, M. Saginaw, P. Sanghvi, J. Gazzarri, T. Huria and M. Ceraolo, *"Battery Model Parameter Estimation Using a Layered Technique: An Example Using a Lithium Iorn Phosphate Cell,"* in SAE World Congress, 2013.

[25] P. Keil, S. F. Schuster, J. Wilhelm, J. Travi, A. Hauser, R. C. Karl and A. Jossen, *"Calendar Aging of Lithium-Ion Batteries,"* Journal of the Electrochemical Society, vol. 163, no. 9, 2016.

[26] F. Todeschini, S. Onori and G. Rizzoni, *"An experimentally validated capacity degradation model for Li-ion batteries in PHEVs applications,"* in IFAC Symposium on Fault Detection, Mexico City, Mexico, 2012.

[27] A. Cordoba-Arenas, S. Onori, G. Rizzoni and G. Fan, *"Aging propagation in advanced battery systems: Preliminary results,"* in IFAC, 2013.

[28] Woodback Communications Ltd, *"Traction Batteries for EV and HEV Applications,"* 2005. [Online]. Available:

http://www.mpoweruk.com/traction.htm.

[29] R. E. Araujo, R. d. Castro, C. Pinto, P. Melo and D. Freitas, *"Combined Sizing and Energy Management in EVs With Batteries and Supercapacitors,"* IEEE Transactions on Vehicular Technology, vol. 63, no. 7, pp. 3062-3076, 2014.

[30] Iowa State University, *"Palmgren-Miner Rule,"* 2009.[Online]. Available: http://www.public.iastate.edu/~e_m.424/Palmgren-Miner.pdf.

[31] M. Todinov, *"Necessary and sufficient condition for additivity in the sense of the Palmgren–Miner rule,"* Computational Materials Science, vol. 21, no. 1, pp. 101- 110, 2001. 100 [44] C. Pinto, J. V. Barreras, E. Schaltz and R. E. Araujo, *"Evaluation of Advanced Control for Li-ion Battery Balancing Systems Using Convex Optimization,"* IEEE Transactions on Sustainable Energy, vol. 7, no. 4, pp. 1703-1717, 2016.

[32] L. Lu, X. Han, J. Li, J. Hua and M. Ouyang, *"A review on the key issues for lithium-ion battery management in electric vehicles,"* Journal of Power Sources, vol. 226, pp. 272-288, 2013.

[33] L. Yarris, *"Roots of the Lithium Battery Problem: Berkeley Lab Researchers Find Dendrites Start Below the Surface,"* Berkeley Lab, 22 May 2014. [Online]. Available: http://newscenter.lbl.gov/2013/12/17/roots-of-the-lithium-battery/.

[34] M. Daowd, M. Antoine, N. Omar, P. Lataire, P. V. D. Bossche and J. V. Mierlo, "Battery Management System—Balancing Modularization Based on a Single Switched Capacitor and Bi-Directional DC/DC Converter with the Auxiliary Battery," Energies, pp. 2897-2937, 2014.

[35] M. Brandl, H. Gall, M. Wenger, V. Lorentz, M. Giegerich, F. Baronti, G. Fantechi, L. Fanucci, R. Roncella, R. Saletti, S. Saponara, A. Thaler, M. Cifrain and W. Prochazka, "Batteries and Battery Management Systems," in Design, Automation & Test in Europe Conference & Exhibition (DATE), 2012. [

[36] Zen Energy Systems, "System Overview," 7 April 2016. [Online]. Available: http://www.zenenergy.co.nz/home-energy/energy-storage/system-overview/.

i. S. Collings, "Understanding Two MOSFET with sources connected," 15 August 2013. [Online]. Available: https://electronics.stackexchange.com/questions/79028/understanding-two-mosfetwith-sources-connected.

[37] Vishay, "IRF510, SiHF510 Power MOSFET," 13 June 2016. [Online]. Available: http://www.vishay.com/docs/91015/sihf510.pdf. [53] M. Mets, "Ask MAKE: Using an optocoupler," 6 October 2009. [Online]. Available: http://makezine.com/2009/10/06/ask-make-using-an-optocoupler/.

[38] Intersil, "Battery Management System Tutorial,"

a. Available: https://www.mouser.com/pdfdocs/isl94203wpbatterymanagementsystemtutorial.PDF.

[39] "Multi-Cell Li-Ion Battery Management System Using MSP430F5529 and bq76PL536"

a. Published on- *SLAA478–December 2010.*

b. *By- Daniel Torres (Texas Instruments)*