Design of Battery Management System

Sayak Pal1, Partha Chakraborty 2

1,2Department of Electrical Engineering, 1Technique Polytechnic Institute, 2Elitte Institute of Engg & Management

***Abstract*: This paper gives a brief idea about how to design a battery management system for a large amount of charge storing purpose. Various types of batteries which are very useful for BMS design with necessary specifications have been discussed in this paper. BMS algorithm also has been discussed here with required steps.**

Keywords: Algorithm, Battery, BMS, SOC, SOH

1. Introduction

At present day energy crisis is looming large throughout the world. Rapid industrialization and increasing populations are the main cause of energy crisis. Energy demand rises to the sky day by day. At present worlds' maximum countries depend on fossil fuels which create a huge environmental pollution. Now many countries are shifting their energy production from fossil fuel to renewable energy sources. In renewable energy sources, there is no pollution and no fuel cost at all. The circuits which are set up for non conventional energy generation, batteries are used in most of the cases to store the electrical energy. Battery plays an important role for energy storing purpose. In today's world electric vehicles are also growing very popular. Many countries including India have been adopted a special scheme for mass production of electric vehicle. Government of India aims to reduce the quantity of petrol/diesel cars to 70% of total cars in the country. So battery manufacturing industries have a crucial role in this scenario. To make a battery some important procedures are included. In this paper we have tried to focus on the above mentioned steps. This total system is called Battery Management System (BMS).

2. Over View of Battery Usefulness

Currently Lead-acid, sodium-sulfur, Nickel, Lithium-ion etc batteries have became mainstream technologies in various worldwide applications. Energy storage system has become an essential unit that stores unstable electric energy during wind and photovoltaic power generation. This storage takes an important part in the electrical systems households, industrial, commercial and power plants. To compensate wind and solar variability, energy storage provides stored electrical energy to the grid & stable power output from renewable energy sources.

3. Types of Battery

Battery has two types mainly viz. a) primary battery b) secondary battery. The basic details of the batteries are as follows:

a) Primary Battery: A primary cell which is not rechargeable. Only one time use. It is due to the chemical reaction within the battery is always unidirectional i.e. irreversible. Example alkaline battery, carbon zinc dry battery etc.
b) Secondary Battery: It is rechargeable i.e. internal chemical reaction is bi-directional. It is also called reversible reaction. Example Lead Acid battery, Nickel Cadmium battery.

- **Alkaline Battery**: The alkaline battery is another popular type also used four types A, AA, C, D, etc. It has 1.5V output voltage as carbon-zinc cells, but they are longer-lasting .It consists of a zinc anode and manganese dioxide cathode. Alkaline potassium hydroxide is used as electrolyte in this battery. It works with high efficiency even with continuous use, due to low internal resistance.

- **Carbon Zinc Battery:** This is the most popular primary batteries (often used for type AAA, AA, C, D). The negative and positive electrodes are made of zinc and carbon respectively**.** The output voltage of a single battery is about 1.5 V. Performance of the battery is better with intermittent operation.
- **Lead Acid Battery:** This battery is a widely used secondary type of battery. The uses of the battery are extensively in vehicles and other applications requiring high values of load current. The positive electrode is made of lead peroxide. The negative electrode is made of spongy lead metal. The electrolyte is sulfuric acid. The output is about 2.1 volts per battery. The batteries are typically used in series combinations of 3 (6-Vbattery) or 6 (12-V battery). The secondary batteries used in vehicles have a reversible chemical process.

$$Pb + PbO2 + 2H2SO4 = 2PbSO4 + 2H2O$$

- **Nickel-Cadmium Battery:** This type of cell delivers high current. It can be recharged many times. It can be stored for long periods of time. Applications include Portable power tools. alarm systems, portable radio and TV equipment.

$$2 \quad Ni(OH)3 + Cd = 2\ Ni(OH)2 + Cd(OH)2$$

4. Specification of Battery

Sl no	Type of battery	Energy density (Wh/kg)	Charging & discharging efficiency	Self discharge rate	Advantages	Disadvantages	Life cycle	Power density (W/kg)	Application	Remarks
1.	Lead -acid	35-40	50%-85%	Low	Low cost, surge capacity	Capacity loss due to large amount of power discharge	1500	180	Backup system	inexpensive
2	Ni-Cd	40-60	70%-90%	Low	Deliver high current output	Low energy density	2000	150	Portable power tools	Longer lifetime
3.	Li-ion	100-250	90%-95%	Mode rate	Low maintenance, high energy density	Expensive, high risk of damage	2000	340	Electric vehicle, micro grid	Requires protection circuit
4.	Na-S	120	70%	-------	No self discharge	Requires heat sources for operating conditions	2000	230	Standalone renewable energy system	Environmental friendly
5.	Redox flow batteries	10-20	75%-80%	Low	Unlimited energy capacity	Poor energy to volume ratio	14000	100	Large power storage applications	Energy scalong

Table no: 1 specification of battery

Sl no	Type	Average project power capacity(MW)	Initial cost	Average discharge duration (hour)	Average round trip efficiency	Estimated cycle life
1.	Lead -acid	1-25MW	$260/kWh	1	50%-85%	3000-4500
2.	Na-S	1-100MW	$660/kWh	6	75%-90%	2000-6000
3.	Li-ion	1-100MW	$270/kWh	0.5-5	85%-95%	500-10000
4.	Flow battery	0.5-100MW	$550/kWh	3-10	65%-85%	500-15000

Table 2: initial cost of batteries

5. Battery Energy Storage System (BESS)

Battery Energy Storage Systems (BESS) are considered as an essential tool to decrease the power and energy imbalance between the scheduled generation and the actual sources output. In grid connected standalone systems, battery storage energy system are used for peak shaving when there is a critical load. In standalone systems batteries are used to store the energy but in grid connected system, we use them as a backup. When surplus power is available it stores in it and used for peak shaving. Batteries particularly Li-ion based are mostly used for BESS. The combination of hybrid systems and batteries are commercially used to improve the self consumption and self sufficiency. Battery energy systems consist of basic storage cells connected in series or parallel combination to meet the application specification. There may be chance of different state of charge (SOC) levels in different cell at any given time. This leads to difference in SOC level which impacts the battery characteristics and performance.

6. Types of Battery Energy Storage System:

There are mainly four types of battery energy system available in electrical system. They are a. Residential b. Commercial c. Industrial d. Utility. The properties of each system are given below.

a. **Residential:**
- Storage energy 1 to 10kWh
- Grid voltage 230V/440v, 1 or 3 phase AC
- Back up of power failure (UPS)
- Grid integration of decentralized low power renewable

b. **Commercial:**
- Storage energy 10 to 100kWh
- Grid voltage 400V, 3 phase AC
- Located in factories and commercial buildings
- Short term support during grid faults and production deficit

c. **Industrial:**
- Storage energy 100 to 1MWh
- Grid voltage 690V,3 phase AC
- Connected to MV grid via grid frequency transformer
- Grid integration of decentralized medium power renewable

d. **Utility:**
- Storage energy 10 to 100kWh
- Direct or via MV transformer connected the MV grid
- Combinable with high power renewable energy sources

7. Battery Management System (BMS):

Battery management system (BMS) is essential tool for battery module or pack for safe, reliable and efficient operation. BMS are real time systems used to monitor, protect, estimate and maximize battery performance by controlling many functions vital to correct and safe operation of the battery energy storage system EV, PHEV's micro grid etc. BMS mainly measures the battery voltage, current and temperature to estimate the state of charge (SOC) and state of health (SOH) condition of the battery. These estimations are used in BMS functions for optimal charging, cell balancing and safe operation.

8. BMS Operating Modes:

There are mainly five operating modes viz. a) performance b) protection c) application d) Diagnose e) Interface.

a. Performance:
- Voltage, current and temperature monitoring
- Balancing cell voltages
- Power saving modes

b. Protection:
- Short circuit
- Over loads
- Over charging
- Over discharging
- Over heating/temperature rise
- Too deep charging

c. Application:
- Pre-charge control
- Charge control
- Inverter control
- Cooling control

d. Diagnose:
- State of charge estimation
- State of health estimation

e. Interface:
- Status of battery
- Isolating
- Communication
- Data logging

9. Objective & Constraints of Battery Management System (BMS)

To maintain equal amount of voltage level of all cells in the battery pack or module for optimal utilization. To design BMS some constrains come. At design level the constraints must be considered. This consideration approaches not only optimal operation of the battery but also battery degradation avoidance. The constraints are as follows:

i. Safe operational SOC range:

$$SOC_{min}^{i} \leq SOC^{i} \leq SOC_{max}^{i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

ii. Limitations of charge/discharge:

$$P_{\max\_dis}^{i} \leq P_{B}^{i}(t) \leq P_{\max\_ch}^{i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

10. BMS algorithm

BMS is responsible for charge-discharge, performance, battery ageing and safe operation. The BMS algorithm state machine consists of four modules viz. a. battery state & charge/discharge circuit b. fault monitoring circuit c. charge contactors and controller d. inverter contactors & controllers. All the four modules are operated parallel at same time interval of time with its own functionality to maintain equal voltage level of all cell in the battery module/pack. Steps of BMS algorithm are as follows:

Step 1: Monitors cell voltage and temperature
Step 2: Estimates state of charge and state of health
Step3: Limits power input and output for overcharge protection
Step 4: Controls charging profile
Step 5: Balances the state of charge of individual cells
Step 6: Isolates the battery module/pack from the load when necessary

The BMS algorithm is implemented is implemented with the help of state flow tool box. These states machines have four main functions which are operated in parallel. The figure of machine tool box is given below.

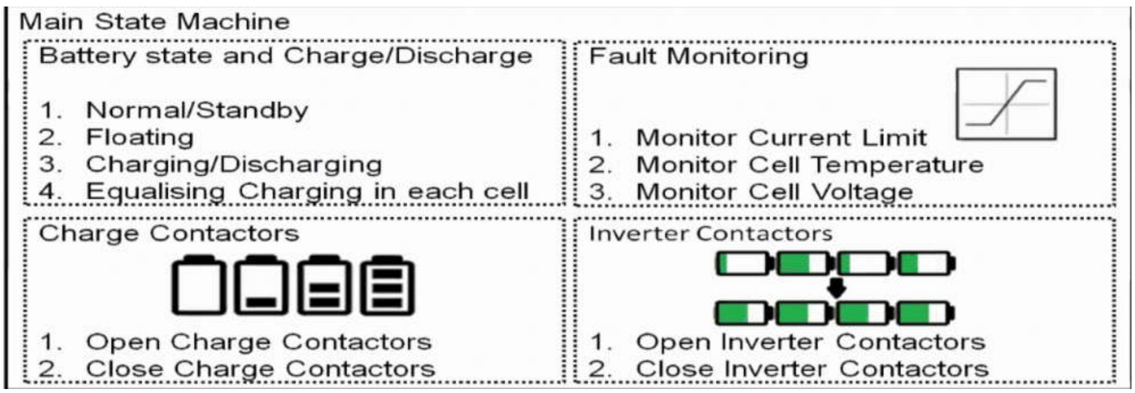

Fig 1: Main machine tool box for BMS

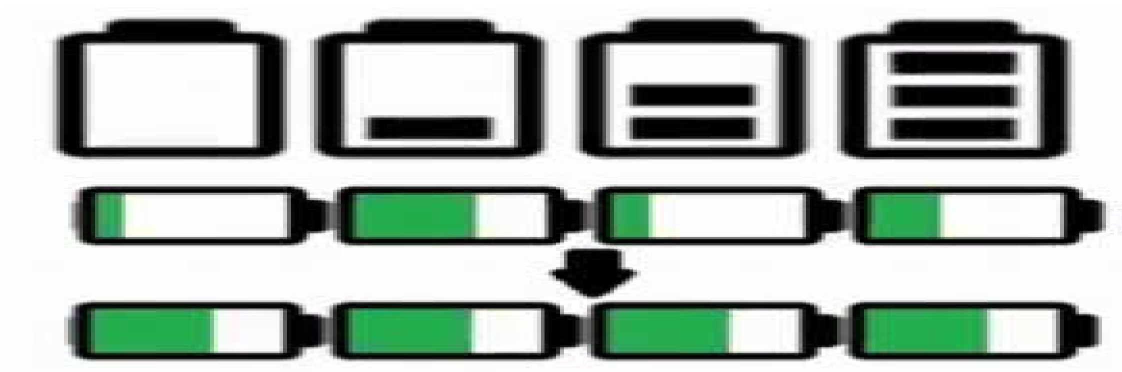

Fig 2: Equalizing of battery cells voltages

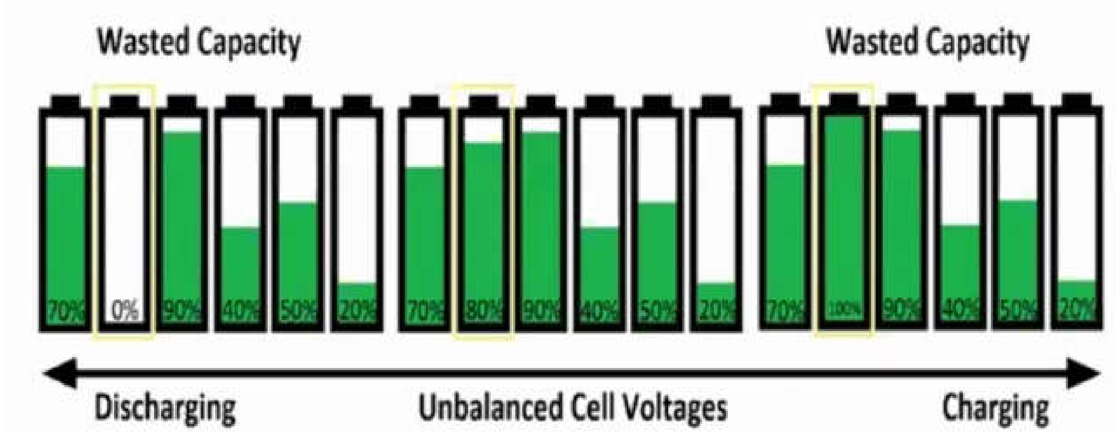

Fig 3: Capacity loss of battery cells

11. Conclusion

BMS is very essential tool in electrical system in today's world. A battery management system is designed by the above algorithm. It is very easy algorithm for easy implementation. BMS is now growing more attentions of electric vehicles companies throughout the world. Tesla etc companies are investing a large amount if money on researching of BMS. So in near future the BMS technology will be more developed with ultra modern technical specifications.

12. References

1. Hosseini, S.E.; Andwari, A.M.; Wahid, M.A.; Bagheri, G. A review on green energy potentials in Iran. *Renew. Sustain. Energy Rev.* 2013, *27*, 533–545.
2. Granovskii, M.; Dincer, I.; Rosen, M.A. Greenhouse gas emissions reduction by use of wind and solar energies for hydrogen and electricity production: Economic factors. *Int. J. Hydrogen Energy* 2007, *32*, 927–931.
3. Derbeli, M.; Barambones, O.; Sbita, L.; Derbeli, M.; Barambones, O.; Sbita, L. A Robust Maximum Power Point Tracking Control Method for a PEM Fuel Cell Power System. *Appl. Sci.* 2018, *8*, 2449.
4. Hosseini, S.E.; Wahid, M.A.; Aghili, N. The scenario of greenhouse gases reduction in Malaysia. *Renew. Sustain. Energy Rev.* 2013, *28*, 400–409.
5. Manoharan, Yogesh, et al. "Hydrogen fuel cell vehicles; current status and future prospect."*Applied Sciences* 9.11 (2019): 2296.
6. Heywood, J.B. *Internal Combustion Engine Fundamentals*; McGraw-Hill Education: New York, NY, USA, 1988.
7. O'hayre R, Cha SW, Colella W, Prinz FB. Fuel cell fundamentals. John Wiley & Sons; 2016 May 2.
8. https://www.energy.gov/eere/fuelcells/fuel-cells.
9. Reschiotto, D. Effffects of Anode Fuel Recirculation on SOFCs Fuelled with Biogas. Master's Thesis,
Politecnico di Torino, Torino, Italy, 2018.
10. Yang, G.; Jung, W.; Ahn, S.-J.; Lee, D.; Yang, G.; Jung, W.; Ahn, S.-J.; Lee, D. Controlling the Oxygen Electrocatalysis on Perovskite and Layered Oxide Thin Films for Solid Oxide Fuel Cell Cathodes. *Appl. Sci.*
2019, *9*, 1030.
11.O'Hayre, R.P.; Cha, S.-W.; Colella, W.G.; Prinz, F.B. *Fuel Cell Fundamentals*; John Wiley & Sons: Hoboken, NJ, USA, 2016; ISBN 9781119113805.
12. NFCRC Tutorial: Solid Oxide Fuel Cell (SOFC). Available online:
http://www.nfcrc.uci.edu/3/TUTORIALS/ EnergyTutorial/sofc.html.

13. Barbir, F. *PEM Fuel Cells: Theory and Practice*, 2nd ed.; Academic Press: Cambridge, MA, USA, 2013; ISBN 9780123877109.
14. Srinivasan, S. Fuel cells: From fundamentals to applications. In *Fuel Cells*; Springer Science &Business Media: Boston, MA, USA, 2006; pp. 3–25.
15. Briguglio, N.; Andaloro, L.; Ferraro, M.; Antonucci, V. Fuel Cell Hybrid Electric Vehicles. In *Electric Vehicles, The Benefifits and Barriers*; InTech: London, UK, 2011.
16. Shukla, A.K.; Jackson, C.L.; Scott, K. The Promise of Fuel Cell-Based Automobiles. *Bull. Mater. Sci.* 2003, *26*, 207–214.
17. Stefan, J.; Minott, S.J.; Norman, R.; Scott, N.R. Feasibility of Fuel Cells for Energy Conversion on Dairy Farms. In Proceedings of the ASABE Annual Meeting, Sacramento, CA, USA, July 29–August 1 2001.
18. Ehsani, M.; Gao, Y.; Longo, S.; Ebrahimi, K. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, Third Edition*; CRC Press: Boca Raton, FL, USA, 2018; ISBN 9780429504884.
19. Liu, Y.-L.; Tong, C.-C.; Jwo, W.-S.; Lin, S.-J. Design an Intelligent Neural-Fuzzy Controller for Hybrid Motorcycle. In *NAFIPS 2007. 2007 Annual Meeting of the North American Fuzzy Information Processing Society*; IEEE: San Diego, CA, USA, 24–27 June 2007; pp. 283–288.
20. Arora, A.; Medora, N.K.; Livernois, T.; Swart, J. Safety of Lithium-Ion Batteries for Hybrid Electric Vehicles. *Electr. Hybrid Veh.* 2010, 463–491.
21. Walters, J.; Husted, H.; Rajashekara, K. Comparative Study of Hybrid Powertrain Strategies. *SAE Trans.* 2001, *110*, 1944–1953.