Technologies In Battery Management System-A Review

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Abstract: The battery consists of one or more electrochemical cell and it transforms stored energy into electricity. Batteries are widely used in flash lights, smart phones and electric cars. Battery Management System (BMS) plays a prominent role in monitoring and controlling of rechargeable batteries. The key terminologies in BMS are as follows, the prime selection of battery chemistry is essential for meticulous applications followed by technologies in battery management systems it includes battery monitoring, diagnostics ,control of charging and discharging cycle, state estimate, protection, equalization of charge, heat control and management, early failure detection and assessment to improve overall system performance. An effective BMS protects the battery from damage, forecasts lifetime and maintains battery efficiency. BMS can optimize downtime and battery lifespan per discharge cycle. Finally the outcome of this paper is to identify the best battery chemistry, charging methods, battery model, cell balancing and SOC estimation techniques.

Index Terms: Battery charging, Battery discharging, Battery modeling, Battery types, Cell balancing and Parameter estimation.

1 INTRODUCTION

The worldwide energy consumption is growing rapidly, as the world's population is growing and energy consumption per cap ita has been increasing. So the next big challenge is how to store the energy. Quite a few energy storage technologies are using globally. Among the different technologies at present, batteries have the greatest potential to reduce cost s. Hence battery can be used as energy storage devices. Recent research trend concentrated on certain attributes of battery it include Recycling , Energy and Power density, Temperature ,Retention charge, Cell potential, Charge and Discharge cycles, Price per kW,kWh and safety. None of the technologies satisfied all the criteria mentioned above each battery have its own advantages and disadvantages. So choosing a battery suitable for their application will be effective. Batteries have high energy density, portability, low standby loss, long life cycle, but batteries require periodical maintenance [1].

Some batteries are extremely dangerous because they can ex plode, cause fire and chemical contamination. Safe operation of battery without affecting its performance is important because it will affect the temperature and process of aging. So a battery management system is essential [2]. Effective charging methods will protect the battery from damage, charging should not be too slow or too fast. Slow charging is safer and puts less stress on the battery which can make it last longer, fast charging reduces battery lifetime. Efficient battery model is essential in predicting the behavior of battery, state estimation of battery, controller design, thermal effects and fault detection. Equivalent circuit model parameters are helpful to capture the performance of the battery. The internal resistance of the battery will affect the temperatur e directly and is useful for determining the cell power, the ener gy and heat losses, the internal state of the battery and cannot be directly measured but it need to be monitored using state estimation. Batteries are discharged based on C rate. Battery has to discharge safely not below end discharge voltage [2].

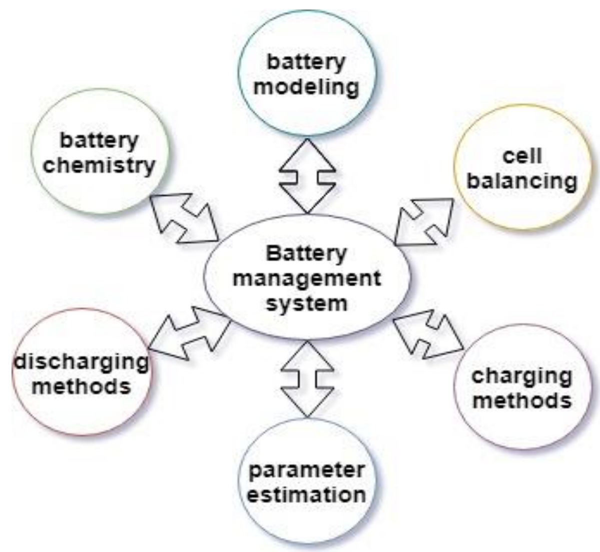

Fig. 1. *Key terminologies in Battery management System*

Cells balancing techniques ensure safety, longevity, incomplete pack charging and energy utilization. This paper focus on key terminologies in battery management system which is referred in figure.1.The paper is structured as follows section 2 describes battery types, section 3 presents the traditional charging methods, section 4 deals with battery modeling, section 5 highlights parameter estimation, Section 6 discusses different discharging methods, section 7 deals with cell balancing and finally section 8 gives the concluding remarks

2 BATTERY TYPES

Batteries are classified into primary as well as secondary, primary batteries can not be recharged while secondary ones can be recharged [1]. Secondary batteries are mostly preferred because of prolonged life cycle, high energy density, and small energy loss. The commonly used battery technologies are discussed below in Table.1 [1], [2], [3]

TABLE 1

POPULAR BATTERY STORAGE TECHNOLOGIES

Battery chemistry	Service life/ cycle	Nominal voltage/ (V)	Energy density/ (W.h.kg -1)	Power density/ (W.kg - 1)	Charge efficiency / (%)	Self discharge rate/ (%.month- 1)	Charging temperature/°C	Discharging temperature/°C	Round Trip efficiency (RTE) (%)
Li-Ion battery	600-3000	3.2-3.7	100-270	250	80-90	3-10	0-45	-20 to 60	100%
Lead acid battery	200-300	2	30-50	180	50-95	5	-20 to 50	-20 to 50	70-90%
NiCd battery	1000	1.2	50-80	150	70-95	20	0 to 45	-20 to 65	70-72%
NiMH battery	300-600	1.2	60-120	250-1000	65	30	0 to 45	-20 to 65	70-74%

Compared with all other storage technologies, lithium ion battery storage technology is best suited for energy storage because it has high density of energy with very less self discharge, high charge and round trip efficiency, improved service life/cycle.

3 TRADITIONAL CHARGING METHODS

Battery has to be charged fully within short span of time. In case of any fault in battery it will degrade the performance and life cycle [2]. Charging process in the battery is non linear so different traditional charging control strategy is presented below.

3.1 Constant current [2, 6] - For the entire charging process constant current is required for charging and the process gets terminated when the charging current reaches the threshold value. Constant current method has to select a appropriate charging current rate which is enough to counterbalance between the speed of charging and utilization capacity of the battery

3.2 Constant voltage [2, 6] - Predetermined constant voltage is required to charge the battery and this method avoids overvoltage's .Process get terminated when the charging voltage reaches the threshold value. In this method current gradually decreases when constant voltage is applied. So this approach needs high rate of current in the initial stage of charging in order to keep terminal voltage constant.

3.3 Constant Current Constant Voltage/ Two step Charging (CCCV) [2, 6] - Initially the battery charges with the predetermined current in constant current mode. Until the voltage charge up to preset voltage, later it is switched to constant voltage mode and it gets end up when it reaches the necessary terminal value of charging current

3.4 Multi-stage constant-current (MCC) charging [2]- Constant current is given to battery at each stage when the charging current reaches the threshold voltage level of first stage, then charging process is switched over to next stage. This process of decreasing charging current is carried out till it reaches the last threshold voltage with minimum current

3.5 Pulse Charging [4, 5, 6] - In this method current in the form of pulse is injected into battery and a relax time is given in each charging cycle of a battery. Pulse charging method will improve the life of the battery

3.6 Burp charging/reflex /negative pulse charging [5, 6] - A positive going pulse, relax time and a negative going pulse is applied to charge the battery. But this method decreases the charge efficiency

3.7 Trickle Charge/Taper-Current (TC) [6] - Charging is done by providing a small charging current at very low C rate

3.8 Boost charging [4] - High current is given to charge the battery within a short span of time and it is also called as fast charging

3.9 Divide and conquer pulse charging method [5] - The divide and conquer pulse charging method. This method is used for charging the high capacity batteries with pulse charging and battery pack is divided into a smaller sections and it is charged separately with a smart charger

4.0 Float charge [6] - Constant voltage is used to charge the battery fully. After fully charged constant voltage is maintained

4.1 Galvanostatic Charging [5] - By applying high voltage at the terminal battery and the battery can be charged

Real challenge is to choose an efficient technique to charge the battery faster and to reach the SOC with best charging efficiency and delay aging effects [4]. Concurrently, the charging approaches can also safeguard the battery and to extend the lifecycle and capacity utilization of battery [2]. Hence all the above mentioned charging methods are not applicable to all types of batteries because battery charging techniques are application specific. Most commonly used charging technique is pulse charging method because it has increases battery charge, energy efficiencies and also reduces charge time.

4 BATTERY MODELING

An effective battery model is crucial. Different battery models are electrochemical model, reduced order model, thermal model, electrical equivalent circuit model, Empirical and bio inspired black box model [8] and Electrical-thermal model [2]. The dynamics of the battery can be modeled mathematically as an OCV along with the internal resistance in electrical equivalent circuit model.
The subsystem will consist of charging and discharge characterstics, SOC forecasts, evolutionary algorithms, syste m optimisation, and simulation in real time for battery management system [10]. Modeling of electrical equivalent circuit can also be done by using suitable software [7, 33]. The different types of battery models are explained below in Table.2 [8, 9].

TABLE 2
COMPARISON OF DIFFERENT TYPES OF BATTERY MODELS

Model type	Accuracy	Complexity	Effort	Interpret-ability	Applications
Electro Chemical[8]	Very high	Very high	High	Low	Battery design
Reduced-order[2,8]	High	High	Medium	Medium	Control, SOC estimation
EECMs[8,9]	Medium	Low	Medium	High	Real-time Control, SOC estimation
Empirical[8]	Low	Very Low	Low	Medium	Only for constant operation conditions
Bio inspired black-box[8]	Medium	Medium	Medium to High	Low	Off-line analysis
Thermal[2]	High	High	High	High	Battery thermal management
Electro Thermal[2]	Very high	high	high	moderate	Battery management system

An accurate battery model which completely characterizes both the electric and thermal behavior is needed .Hence the combined model (Electro-thermal) is the most efficient battery model because it captures both electric and thermal behavior of the battery simultaneously.

5 PARAMETER ESTIMATION

Battery parameters will vary with time and usage and are difficult to estimate. For accurate estimation of parameters an accurate battery model is needed. An accurate dynamic battery model should take into account multiple parameters, such as open-circuit voltage, current, charging control methods, discharge rate, state of charge [11].

5.1 Open Circuit Voltage (OCV): Open circuit voltage is an essential parameter in the battery. OCV is used to assess electronic energy shifts in electrodes and to measure the battery pack's SOC. Hence, proper OCV modeling will have a good impact in battery management system. The different open circuit voltage techniques are discussed below as a flow diagram in figure.2

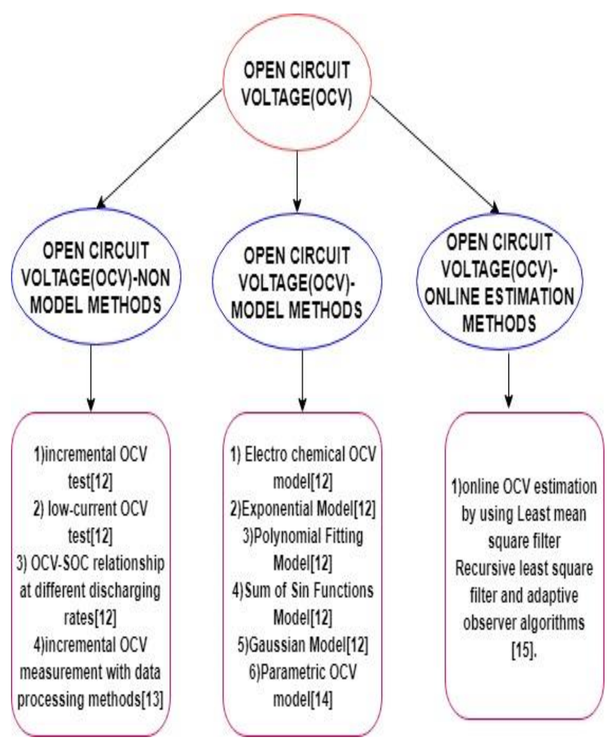

Fig. 2 *open circuit voltage methods*

Hence for OCV measurement the incremental OCV test holds good for non model based measurement because of more robustandaccurate tracking against various conditions of loading. The incremental OCV test is therefore recommended for the OCV-SOC relationship predetermination. Gaussian model (n = 4) gives minimum RMSE error in model based method, in online measurement, adaptive observer gives accurate OCV estimation

5.2 Current: Current information is of great importance for BMS, especially for the estimation of SOC. In a variety of applications, current measurements are useful, i ncluding power monitoring and fault detection. The various methods for measuring the Current are listed below.

5.2.1 Shunt resistor [16]-The current flow is calculated by using Ohm's law

5.2.2 Hall effect current sensor [16] – Sensor is used to measure the magnitude of a magnetic field for a given current flow

5.2.3Unknown Input Observer [(UIO) [16] - It is used to estimate cell current when one or more input signal are unavailable.

Hence UIO method is more accurate than rest of the methods for current estimation.

5.3Internal resistance: The internal battery resistance is used to measure the battery system performance, cooling system, select and compare cells and to calculate power an d energy of cell [17].Real-time internal resistance estimation will be helpful to reveals the characteristics single cell of the same type of battery model and also to improve SOC estimation accuracy. Hence the list below provides different methods for measuring internal resistance.

Internal resistance measurement methods are VDA current step method [17], Optimized VDA Step Method [17], Reducing Time, Advanced Method [17], and Current-Off Method [17], Current Switch Method [17], Energy Loss [17], Quasi-Adiabatic Battery Calorimeter [17], AC Internal Resistance [17], Impedance Spectroscopy [17], online measurement of internal resistance using DCSP current source [18]. Current steps and energy loss methods provides similar results and thus recommended for internal resistance calculation

5.4 State of Charge (SOC): SOC is defined as current capacity (Q(t)) to the nominal capacity (Q_n). The maximum amount of charge that can be stored in the battery is called as nominal capacity [23]. The mathematical formula for SOC is given below:

$$soc(t) = \frac{Q(t)}{Q_n} \quad (1)$$

$$soc(k) = soc(k_0) + \int_{k_0}^{k} \frac{\eta I(t)dt}{cn} \quad (2)$$

Where S (k0) is the SOC (initial), η is the battery charging or discharging efficiency, Cn is the nominal capacity, I (t) value will be positive and negative for charging and discharging [2].SOC is similar to a fuel gauge in a fuel tank of vehicle. The accurate SOC estimation does not only indicate the remaining useful capacity, but also the performance of the battery [24].It also improves the lifetime of a battery. The various SOC estimation methods are listed below as a flow tree in figure.3

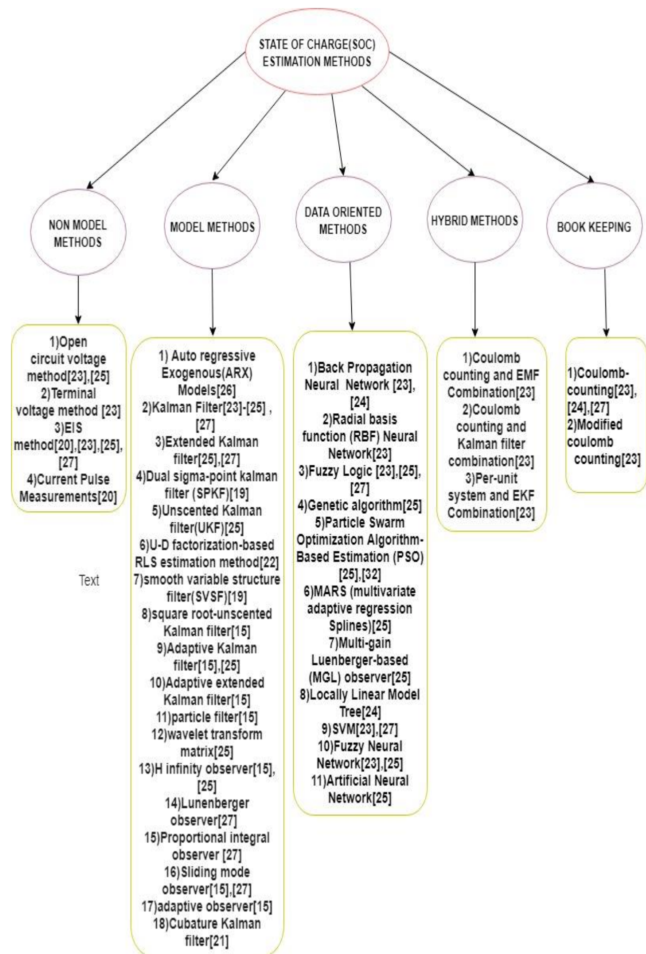

Fig. 3. *State of charge estimation methods*

Model based methods are more effective to measure the SOC.

6 DISCHARGING METHODS

Battery needs store energy and release the energy whenever it is needed. Battery needs to store a huge amount of energy and it needs to satisfy the load demand and also it has to deliver energy in case when the equipment is cutoff. The different methods of discharging are discussed in Table 3.

TABLE 3
DIFFERENT DISCHARGING STRATEGIES

Discharging Methods	Description
C rate[28]	It is the amount of current which is charged or discharged per unit ampere hour capacity
Depth of discharge[28]	The battery is discharged from a fully charged capacity to a nominal capacity of the battery; it refers to deep discharge of a battery
Pulse discharge[28]	To assess the battery characteristics by observing voltage change in pulse duration
Load modes[29]	Battery behavior is analyzed at different load modes and it behaves differently from one mode to another mode
Self discharging[30]	when there is no contact between two batteryelectrodes the stored charge in the gets reduced due to chemical reactions inside the battery [35].

Batteries are most commonly pulse discharged based on their C rate.

7 CELL BALANCING TECHNIQUES

Balancing the battery system is essential to increase the shell life by maintaining the cell voltage and capacity during battery operation. The state of battery is even worse during frequent regenerative braking and the battery pack consists of long string of cells. Balancing methods were employed to increase available capacity and durability of cell. Cell balancing is needed because not all cells are equal, in terms of system and environmental condition, reduce exposure to cell over voltage and under voltage stress, enables greater energy to be used from total pack, cell balancing reduce hazard, improve safety and extends battery life[36].Balancing algorithms are categorized as active and passive. Balancing techniques will differ in cost, size, control and implementation. Here some of the commonly used balancing techniques are discussed below in Table 4

TABLE 4
VARIOUS CELL BALANCING TECHNIQUES

Techniques	Description
Passive (Cell-to-Heat) [31].	A discharge resistor and switch per cell is used to drain a small amount of energy from high state of charge cells during the charging cycle so that all cells charge to their maximum SOC
Active (Module-to-Cell) [31].	By using galvanic isolated DC/DC converter the charge can be transferred to a single cell from battery module
Active (Cell-to-Cell) Distributed[31]	Transfer of charge from neighboring cells
Active (Cell-to-Cell): Shared [31].	Transfer of charge from cell A to tank and then from tank to cell B
Active (Cell/Module Bypass)[31]	The battery segment can be disconnected from the current path when it reaches the fully charged condition .Hence the remaining cells in the string can continue to charge

The active balancing technique offers a good balance between complexity and efficiency so it is preferred mostly for charge equalization

8 CONCLUSION

Major battery management system technologies are comprehensively discussed in this paper. The key focus of the paper is to identify the best technologies for battery management system. Such as lithium ion is preferred as best cell chemistry, pulse charging is more powerful for battery charging, electro thermal model is the most efficient battery model. Model based methods are more specific in order to estimate SOC; Active balancing technique gives good balance between the cells. So exploring the different technologies will be helpful for the researchers to identify the suitable technologies for their applications. However it is hard to ensure that the real life application would be different from test circumstances. Hence tackling all the challenges and developing a smart battery management system is predominant to meet the industry needs and commercial standards

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