Battery Management System for SOC Estimation of Lithium-Ion Battery in Electric Vehicle: A Review

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Abstract- Battery Management system is still very difficult task for the electric vehicle (EV). Lithium-ion (Li-ion) batteries have proved to be the battery of electric vehicle manufactures because of its high charge density and low weight. In EVs, essential thing is a smart battery management system (BMS). The Li-ion battery is highly unstable in nature so it is challenging task to estimate accurate state of charge (SOC) of a Li-ion battery. This paper present comprehensively reviews its SOC estimation methods for a Li-ion battery. This paper is provided merits, demerits, critical explanation and their estimation errors.

Keywords— Battery Management System, Lithium-ion Battery, Electric Vehicle, State of Charge.

V. Introduction

All over the world are facing many problems such as fast reduction of crude oil reserves, day by day increasing the prices of crude oil, high atmospheric and noise pollution, Electric vehicle is the only option to overcome these problems.

The battery-operated Electric Vehicles are beginning to play a big role in today's automotive industry. Electric Vehicle performance is mainly depending on two major parts controller and Battery management system (BMS). BMS provides the power and the controller that controls the application of this power. An improved selective harmonic elimination technology is used in the controller to control the magnitude of the input DC link [1-3]. In recent years, there is high demand of rechargeable batteries (RBs) in EVs, HEVs, and PHEVs [4–7]. There are many sorts of batteries which are widely accepted for transportation such as Sodium Nickel chloride (NaNiCl), Vanadium Redox Flow Battery (VRFB), lead-acid, Lithium Ion (Li-ion), Nickel Cadmium (NiCd), Zinc Bromine Flow Battery (ZBFB), and Sodium Sulphur (NaS) [8]. On the bases of important characteristics such as battery efficiency, cost, safety and operation cycle it is difficult to think positive for Electric Vehicle. Four different types of lithium sulfur (Li-S), molten salt (Na-NiCl2), nickel metal hydride (Ni-MH), and lithium ion (Li-Ion) batteries all have the same electrical energy storage capacity [9]. In addition, Lead-acid, Nickel-Cadmium and nickel-metal hydride it gives a digest description of those batteries and comparison between the various sorts of batteries are presented [10]. The Li-ion battery offers high efficiency, high energy density, high reliability, high power density, long lifespan and low discharge rate [11].

In EVs an efficient battery management system is first important component to assure the safety, reliability, and ongoing operation of a Li-ion battery while working on challenging conditions with the electric grid. The BMS protect the battery from overcharge and over discharge conditions by monitoring the battery voltage, current, and temperature and it also utilized to estimate the SOC of Lithium-Ion battery [12-14]. A serious and central concern within the design of BMS is accurate SOC estimations in EVs. The remaining energy and/or remaining useable time this information is very important with accurate and precise estimations [15].

VI. Battery Storage System

Battery storage system, mechanical transfer, motor, and power inverter are main parts of EVs [16]. Many batteries are available in market such as Lead-acid, Sodium Sulphur, Sodium-Nickel-Chloride, Nickel cadmium and Lithium-Ion.

Table1 lists the properties of the above-mentioned batteries. For safe and reliable operation in EVs the ambient temperature has been considered of batteries.

TABLE I. Properties of Different Types of Battery [17]

Battery Type	Energy Density (Wh/L)	Power Density (W/L)	Nominal Voltage (V)	Life Cycle	Depth of Discharge	Efficiency	Estimated Cost (USD/kWh)
Lead-acid	50-80	100-400	2.0	1500	50%	82%	105-475
Sodium Sulphu	140-300	140-180	2.08	5000	100%	80%	263-735
Sodium Nickel chloride	160-275	150-270	-	3000	100%	84%	315-488
Nickel Cadmium	60-150	80-600	1.3	2500	85%	83%	-
Li-ion	200-400	1500-10000	4.3	10000	95%	96%	200-1260

VII. Battery Management System (BMS)

Battery monitoring plays a vital role in electric vehicles (EV) because life, performance, and safety depend on the battery system. This parameter is to check the most important characteristics of the battery management system (BMS) under its specified safe operating conditions, such as storage efficiency, structural characteristics, price, safety and service life. The safety unit is employed to provide safety to the battery packs. The system avoid damage from overcharge and over-discharge. Accurate SOC estimation is a difficult task because of non-linear and changeable behaviour of a battery

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As discussed earlier, SOC acts as the fuel indicator of the Electric Vehicle which helps us to show the battery capacity in percentage. Similar to cellular phones. But it is not as easy as it sounds. In EV, SOC estimation is that the most important part of the BMS design. Therefore, the SOC estimation has an major role towards performance of EV, So estimate the SOC accurately and precisely different methods are there

TABLE II. PROPERTIES OF DIFFERENT TYPES OF LI-ION BATTERY [18]

Battery Chemistry	Safety	Powe Density	Energy Density	Cycle	Cost
lithium ferro phosphate	Very good	Very good	Moderate	Very good	Medium
Lithium Nickel Manganese Cobalt oxide	Moderate	Moderate	Moderate	Low	Low
lithium ion manganese oxide	Moderate	Moderate	Moderate	Low	Low
lithium-titanate-oxide	Very good	Very good	Low	Very good	Medium
Cobalt Oxide	Low	Low	High	Low	Low

The estimation methods are classified as shown in fig.1. presents the SOC estimation methods. In direct measurement method the physical properties are used to estimates the SOC. Input charging and discharging current is used in book keeping estimation methods for SOC estimation. The model-based methods are used adaptive filters and observers for the battery parameters and SOC are estimated.

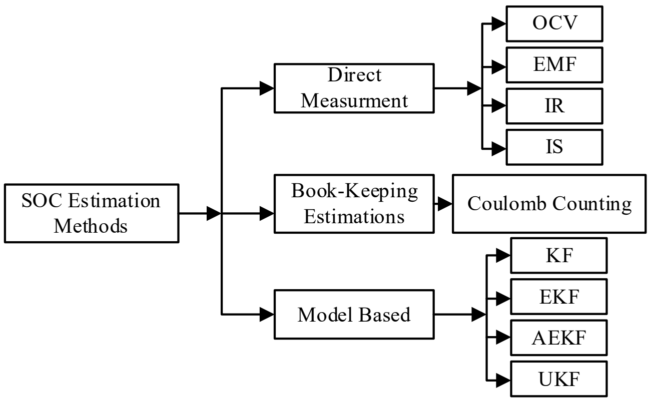


Fig.1 Estimation methods

A. Direct Measurements

open circuit voltage (OCV), electromotive force (EMF), internal resistance (IR), impedance spectroscopy (IS) methods. These are four methods under direct measurement for SOC estimation.

The battery state of charge (SOC) can be estimated in lithium-ion batteries by calculating the open circuit voltage (OCV). It also helps to analyzed the changes of electronic energy in electrode materials for battery pack. Therefore, in lithium-ion battery management accurate OCV modeling is a great implication . The experimental results show that the OCV-SOC characteristic significantly affected by temperature of the battery. Therefore, in order to increase the accuracy of battery SOC estimation and accuracy of the model these factors need to be considered [19].The SOC and OCV relation are depends on type of battery. Its relations are varying from battery to battery [20].

The electromotive force (EMF) voltage is projected based on the estimated EMF voltage when the battery is in a charged state. This is a method that has nothing to do with time. The EMF estimation method uses terminal voltage, current, impedance and c-rate [21] to solve the impedance distortion problem. In this method, the influence of temperature and aging is not considered

For SOC in internal resistance (IR) estimation method, the resistance of the lithium-ion battery is calculated. For resistance calculation charging/discharging current of battery used. Resistance is called as DC resistance. Terminal voltage with change in current was measured for short duration [22]. The resistance value is very small which is challenging to measure [23]. So, this method isn't reliable and honest choice for SOC estimation.

In impedance spectroscopy (IS) technology, internal impedance is used to describe lithium ion batteries under different conditions. Impedance spectroscopy is performed on the lithium particles step by step for charging and releasing. In IS technology, the impedance is calculated by applying currents of various frequencies through the lithium particle battery. The internal impedance is drawn based on the impedance that is not actually set. SI technology can also be used for online SOC evaluation [24].

B. Book-Keeping Estimations

In the Coulomb (CC) counting method, the charging or discharging current of the battery is considered by integrating the time to find the SOC. The initial SOC value is the main concern because it will cause errors in the accuracy of the SOC estimation. When the initial SOC value is known, this method is only effective in a short time [25].

C. Model-Based Methods

In direct measurement and book keeping estimation methods have some limitation in actual time data. To overcome the disadvantage of conventional methods Model-based SOC estimation methods is used. Model-based methods uses Li-ion battery model with some advanced algorithms. Fig.2 presents a general schematic of the model-based SOC estimation methods. Parameter of Li-ion battery is measured like voltage, current, temperature and compare with true value. The error signal is generated by comparing the difference of the true value and estimated value to estimate the SOC.

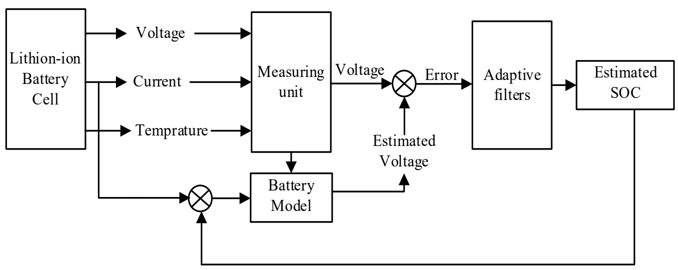


Fig. .2 General schematic of model-based SOC estimation methods.

Lithium-Ion batteries with the adaptive filtering is used in model based estimation method. To estimate accurate SOC of Li-ion batteries Adaptive Filter algorithm is best choice. It provides robustness and exact accuracy. The SOC estimation has been implemented using Kalman Filter with coulomb counting method [26].Kalman filter works efficiently with liner system.

The extended Kalman filter (EKF) and the adaptive extended Kalman filter (AEKF) operate on a non-liner system. Using EKF and AEKF, two model-based estimation methods have been developed. SOC estimation is based on the comparison between the model and the actual measured value of the system. AEKF gives better results than EKF based on noise covariance [27].

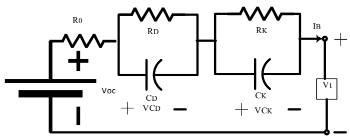
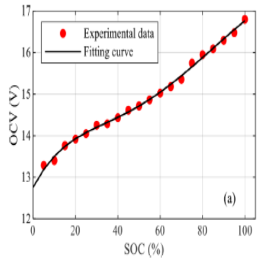
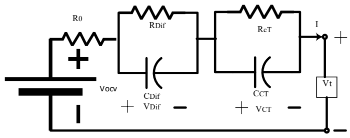
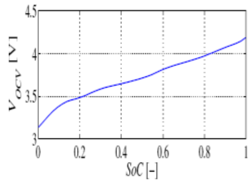
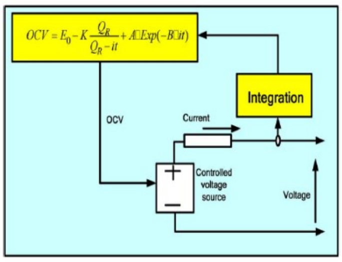
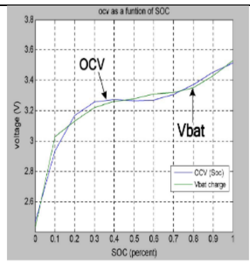
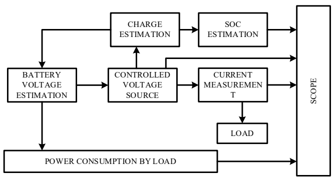
EKF estimate more accurately in the discharging phase. The working of BMS is controlled and monitors by using EKF and it analyzed by using MATLAB/Simulink [9] When the precise characteristics of static noise in the SOC estimation of lithium-ion battery packs are unknown or change with time, the enhanced AEKF algorithm is used to improve the accuracy of the estimation. [28].

The Unscented Kalman filter, unlike the EKF, doesn't really linearize state-space equations. Instead, it uses a nonlinear Unscented Transformation (UT). In UT to produce sigma points for states, the mean and error covariance are computed and updated repeatedly [29].

TABLE III. SUMMERY OF DIFFERENT SOC METHOD [30]

Method	Advantages	Disadvantages	Suitable for EV
OCV	Simple and easily to implement with high accuracy	Suitable for elevator and calibration	No
IR	It is simple and easy	Low accuracy, Challenging task to measure a small value of resistance	No
IS	Reasonable accuracy of SOC	Good for identical charging and discharging currents.	No
EMF	Less costly and simple	After current disruption It requires significant time	No
CC	Low computation cost, simple and easy	Its accuracy changes with unknown initial SOC, aging, self-discharging & temperature	Yes
HF	Reasonable accuracy, less cost	Accuracy of model affected by temperature, aging and hysteresis of Li ion battery	Yes
KF	System affected by external perturbations in real time then also estimate the state with high accuracy	It cannot apply directly to estimates the state of nonlinear system	Yes
EKF	Under noisy and inaccurate initial condition, system State predict accurately	It has low robustness, system is appliable for linearization	Yes
UKF	For any higher order nonlinear system's state estimate easily.	It has low robustness	Yes

TABLE IV. COMPARISION OF DIFFERENT ADAPTIVE FILTERS

Battery Model	OCV -OSC Characteristics
 Improved Adaptive Extended Kalman Filter [29]	
 AEKF and EKF [27]	
 Kalman Filter [26]	
 MATLAB/Simulink with EKF[9]	MATLAB/Simulink model with EKF used for four different batteries namely Nickel metal hydride, Nickel cadmium, Lithium-Ion and Lead acid.

This is the observation of model based methods using the different adpative filters. In the IAEKF algorithm, when the statistical noise characteristics deviate from the actual value, the SOC is accurately estimated. Shows less than 2% errors and is better than EKF [29]. AKF and EKF is developed for e-bikes. AEKF is shows better result than EKF. Estimation Error is reduced to 1 % [27]. Kalman filtering technique is used to improve the SOC estimation with coulomb counting OCV method [26]. It is used for four different batteries namely NiMH, NiCd, Li-Ion and Lead acid [9]. It observed that Lithium-Ion battery performance is better than other batteries.

IV. CONCLUSION

For safe and reliable Battery Management System Lithium-Ion battery is best choice for Electric Vehicle on the basics of its life cycle, high-power/energy density and low cost. This paper conclude that the direct measurements and Coulomb counting methods are easy and simple to implement but their performance is affected by temperature, age, drift current and external perturbation of battery. These factors overcome in model-based estimation methods. It provides good results with high accuracy. Extended Kalman filter, adaptive Kalman filter are best option for SOC estimation. This paper present review of different methods with their advantages and disadvantages using for Lithium-Ion battery-based SOC estimation in Electric vehicle. It also provides information to manufacturers and researchers.

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