# Performance Comparison of Conventional and Intelligent method of Charge Estimation

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***Abstract*— This paper focuses on the implementation and performance comparison of a conventional and an intelligent method for estimation of SoC of a battery. Two different methods of estimation have been selected after careful study and literature review. The first method is Linear Kalman Filter (LKF), which is a conventional method, widely in use. The second method selected is Neural network using Feed Forward. The final results of both the methods are compared and studied to draw a conclusion. Both the methods have been implemented in MATLAB software. For Kalman Filter implementation, Thevenin circuit is modelled to achieve the needed equations. These equations are used to calculate the predict the error which the updates the Kalman gain. In Neural networks, the implementation comprises of training and testing. Mini batches have been taken for the training of the network along with Adam optimizer.**

***Keywords*— State of Charge, Kalman Filter, Neural Network, Feedforward Neural Network.***

## I. Introduction

With the growing concern for global warming and depletion of fossil fuels, it has become the need of the hour to shift to more sustainable sources of energy. In order to address this requirement, it is important to replace the conventional vehicle with ecofriendly Battery Electric Vehicle (BEV). The battery is one of the main parts of an EV and hence needs to be monitored and controlled efficiently using Battery Management System (BMS) so that the battery has optimal working conditions. The BMS keeps a track of the State of Charge (SoC), State of Health (SOH), battery capacity, temperature, etc. SoC refers to the amount of charge available in a battery at any given instance. It is critical for managing batteries. The information provided by SoC can support the correct decision to initiate or stop the charge and discharge process in order to avoid battery failures. A good SoC estimation offers various advantages such as longer life, increased performance and reliability.

Batteries are becoming very popular because they can displace the consumption of fossil fuels and reduce the emission of greenhouse gases in vehicles. With increasing progress in the field of EV's and battery energy storage system, BMS is required to ensure a safe as well as efficient operation.

The Battery Management System continuously monitors the temperature, voltage and current. At the same time, the data acquisition sends this data for state calculation where parameters like SoC and SoH are computed. The acquired parameters are checked with their respective threshold values, based on which the electrical control system of the BMS manages charging or discharging of the battery. To limit the risk, the BMS can alter cooling and trigger various safety procedures. Fig. 1 below represents BMS for an Electric Vehicle.

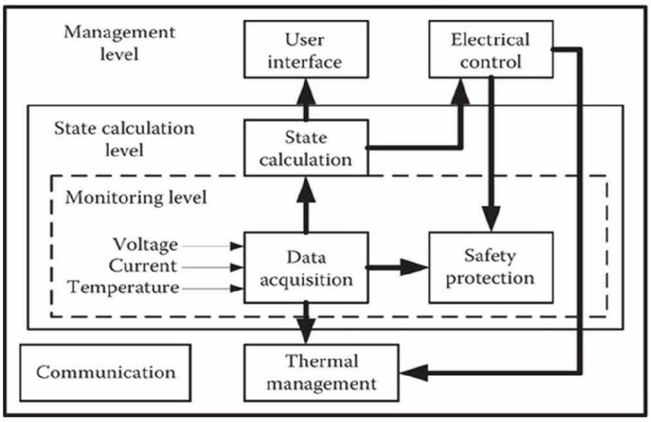


Fig. 1. BMS of an EV

Battery packs for lithium-ion electric vehicles have a higher energy density than other types of batteries [21]. It is possible that these batteries could ignite unexpectedly. Batteries must be operated within pre-defined safe limits in order to ensure the safety of both the user and vehicle at all times.

As long as the State of Charge (SoC) of lithium-ion batteries is kept between the minimum and maximum charge limitations, they will work optimally. Overcharging and severe draining both damage the battery's capacity, reducing its lifespan [26].

## II. Literature Survey

The SoC estimation methods can be categorized under Conventional, Adaptive, and Hybrid methods as shown in Fig. 2. The conventional methods include direct and indirect methods like Open Circuit Voltage (OCV), Impedance method and Coulomb Counting (CC), etc [16]. The direct methods are comparatively outdated as they require a complete access to the battery and standardized conditions for testing which makes them unsuitable for onsite or online determinations. The indirect method has a heavy dependence on the discharge current, making them highly dependent on the accuracy of the current sensor [17].

Adaptative methods, as the name suggests, adapts itself to the operating conditions of the battery in order to predict the SoC with considerable accuracy. These methods take external as well as internal factors into consideration, since batteries are nonlinear in nature, hence SoC estimation using adaptive methods have a low error. This includes Kalman Filter, Neural networks, Fuzzy logic method, Deep learning methods [18], etc.

Hybrid methods are a mix of the aforementioned methods. The combination of two different methods results in higher efficiency as the potential is maximized. Some examples of hybrid methods are Kalman Filter implied with Neural Networks, Fuzzy logic or Genetic Algorithms. Kalman filter is also used with indirect methods like Coulomb Counting, Impedance method, etc., to improve accuracy.




Fig. 2. SoC estimation methods

Batteries are modelled as nonlinear systems in [6], where SOC is a system state. This method uses an extended Kalman filter to estimate the state of charge of a lithium battery pack. EKF is a nonlinear extension of KF. With linear time-varying system, it approximates a nonlinear system. On a power transmission line inspection robot, the method's effectiveness was tested. [7] addresses lead acid battery SOC estimate. A Kalman filter has been developed to determine the SOC using an RC equivalent circuit. Using a Kalman filter, it demonstrates how open circuit voltage may be derived from the RC equivalent circuit's parameter value. The simulation results are compared with experimental works applied to a lithium battery.

[9] proposed estimator estimates the SOC which converges quickly to the actual SOC for the actual state variables, independent of the charging conditions with 3% rms error. [12] This employs BP neural network method to estimate state-of-charge of a battery. The SOC can be determined by considering the changes in battery terminal voltage and current. The SOC estimation in this research proposes Back-Propagation Neural Network method, then the results are compared with feed-forward neural network method. [14] In this case, we used the second strategy to get the results we wanted. In order to precisely estimate a battery's SoC, an optimal feed forward neural network (FFNN) model was proposed. Training phases take into consideration different charging and discharging current profiles to improve the neural network model's robustness and estimation accuracy [21].

## III. Methodology

In this paper Kalman Filter and Neural Networks are used for the estimation of SoC. For Kalman Filter implementation, the equations are achieved by modelling of Thevenin circuit. These equations are used to calculate the error which then updates the Kalman gain. The code for Kalman Filter has been executed in MATLAB code editor. In Neural networks the data set of Li-On batter has been taken from LG battery testing directory which is available online on their official website. The code has been executed in MATLAB code editor.

The goal was to compare a conventional and widely used method with an adaptive method for the estimation of State of Charge of a battery. For the former, Kalman Filter was modelled to successively achieve the SoC, which was then compared with the SoC attained from Neural Networks.

### *A. Battery Model*

Kalman filter is known for estimating the battery SoC with good accuracy and robustness. Non-linear Kalman filter implementation is preferred because of nonlinearity of the ECM. Non-linear Kalman filter have much higher computation complexity than linear Kalman filter. The battery model parameters cannot be updated online effectively, thus dynamic SoC estimation with linear Kalman filter is shown with simplified structure.

Thevenin model is often used in battery modelling in calculation of battery State Charge Estimation (SoC). High order structure is not used as frequently, compared to first order or second order structure in Thevenin model parameters. Higher the order, lower the effect on enhancing the accuracy of the model, making the parameter identification more complex. Modelling of battery models at constant temperature requires estimation of operational parameters such as current (SoC). The Thevenin model of first order equivalent circuit is proposed and verified. According to Thevenin's model, load resistance is introduced. It is observed that the RC time constant is influenced by Thevenin model load resistance.

An experimental lithium-ion battery of 48V and 50Ah based on the Thevenin design is selected and studied. For example, the Thevenin model features a resistance capacitance (RC) circuit connected in series to an internal resistance with 'r' ohm. To determine the internal voltage of a battery, it is necessary to measure the battery's internal resistance r. An RC parallel circuit is used to measure the battery's polarization effect throughout the process. While working, the lithium-ion battery's dynamic characteristics can be