Recent Trends in Electrical Machines and Drives
Volume 5, Issue 1, January- April 2020

Charge Status Estimation of a Lithium Ion Battery in an Electric Vehicle Using Modelling Techniques

***Rakshitha Ravi*[1]*, Dr Usha Surendra* [2]**
Assistant Professor[1]*, Professor*[2]
Department of Electrical and Electronics Engineering
Christ (Deemed To Be) University Bangalore, India
Corresponding Author's Email id: *rakshitha.r@res.christuniversity.in*

Abstract

In the Present scenario, Internal Combustion Engines [ICE] is overcome by Electric Vehicles [EV] due to advantages like reduction in carbon-di-oxide [CO2] emission, cost. Advancement in electric vehicles is extensively going on and one such concept is the Battery management system [BMS] in Battery Electric vehicle. In Battery Electric Vehicle, there are many types of batteries and from the literature survey, Lithium-Ion Battery can be concluded to be suitable as it is advantageous in weight, cost, energy density and many aspects. In Battery electric vehicle Battery plays an important role. The battery may be overcharged, or it may undergo faults. Hence a reliable management system is required to control the Electric vehicle [EV]. In this paper, two battery charge estimation models, namely, open-circuit voltage and Kalman filter, have been considered. From the simulation results obtained, it is found that data retrieval is difficult in open-circuit voltage method can be achieved using a Kalman filter and found out to be satisfactory.

Keywords*: - Battery management system, Open Circuit Voltage, Kalman filter, State of Charge.*

INTRODUCTION

Battery Electric Vehicle

Battery Electric Vehicles also called BEVs, and more frequently called EVs, are fully-electric vehicles with rechargeable batteries and no gasoline engine. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all onboard electronics. BEVs do not emit any harmful emissions and hazards caused by traditional gasoline-powered vehicles.

In this paper, Nissan leaf electric car has been considered since it has a DC charging feature and monitors the charge status of the battery consistently and detailed analysis is as follows:

The classifications are Level 1, Level 2, and Level 3 or DC fast charging. Level 1 EV charging uses a standard household (120v) outlet to plug into the electric vehicle and takes over 8 hours to charge an EV for approximately 75-80 miles [1]. Level one charging is typically done at home or at your workplace.

Level 2 charging requires a specialized station that provides power at 240v. Level 2 chargers are typically found at workplaces and public charging stations and will take about 4 hours to charge a battery to 75-80 miles of range.

Level 2 charging station for Nissan Leaf

Level 2 charging stations are considered an "upgrade" from the standard Level 1 chargers. A typical Level 2 charging station can fully charge the Nissan Leaf battery in 4 to 8 hours.[1]

DC Fast Charging for Nissan Leaf

DC Fast Chargers are commercial electric car charging stations that are accessible to EV owners to use across the country. Not every electric car can be charged with the use of DC Fast Chargers; however, the Nissan Leaf does have DC Fast Charging capabilities. Level 3 charging [1], DC fast charging, or simply fast charging, is currently the fastest charging solution in the EV market. DC fast chargers are found at dedicated EV charging stations and charge a battery up to 90 miles range in approximately 30 minutes.

Battery Management System: In Battery electric vehicle Battery plays an important role. The battery may be overcharged, or it may undergo faults. Hence a proper management system is required to control the Electric vehicle [EV], and it is called Battery Management System [BMS]. To design Battery Management System several concepts, have to be taken care of; the main function of the Battery Management System is to keep any single cell of the battery pack inside its safe operating area (SOA) by monitoring the following physical quantities: stack charge and discharge current, single-cell voltage, and battery pack temperature. Charge status has to be determined properly. If it is not determined and if the battery is overcharged, then the life of the battery may reduce. Hence to determine the state of charge, algorithms have been developed. Among the algorithms, a comparative charge status analysis in a Battery Electric Vehicle using Model-based Method Technique and Bookkeeping Method is carried out with suitable circuit model and simulation results are tabulated for the same.

Lithium-ion battery:

Lithium-ion batteries have higher energy densities than lead-acid batteries or nickel-metal hydride batteries, so it is possible to make the battery size smaller than others while retaining the same storage capacity. Nissan's Lithium-ion battery technology uses materials that allow a higher density of lithium ions to be stored. This results in an increase in travel distance.

From fig 1 importance of lithium-ion battery in an electric car is shown. In May 2020, recent development says a 62kwh battery with 80% charge can be achieved in 45 min and it can reach up to 680km and research is carried on the same[1][6].

From fig 1.1, Lithium-ion batteries have a high power-to-weight ratio, high energy efficiency and good high-temperature performance. In practice, this means that the batteries hold a lot of energy for their weight, which is vital for electric cars – less weight means the car can travel further on a single charge.

Section I gives a detailed Introduction. Section II describes the description state of charge. Section III describes the Methodology and Results. Section IV describes the Conclusion and future Scope and Section V gives the References.

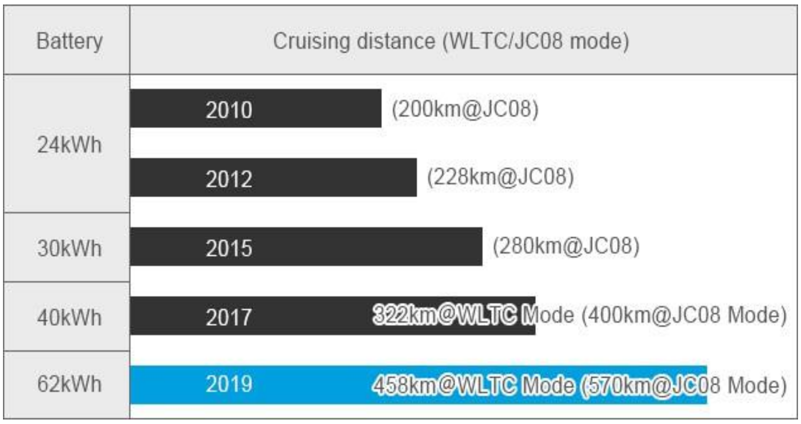


Fig 1: Lithium ion battery importance in Nissan Leaf Electric car

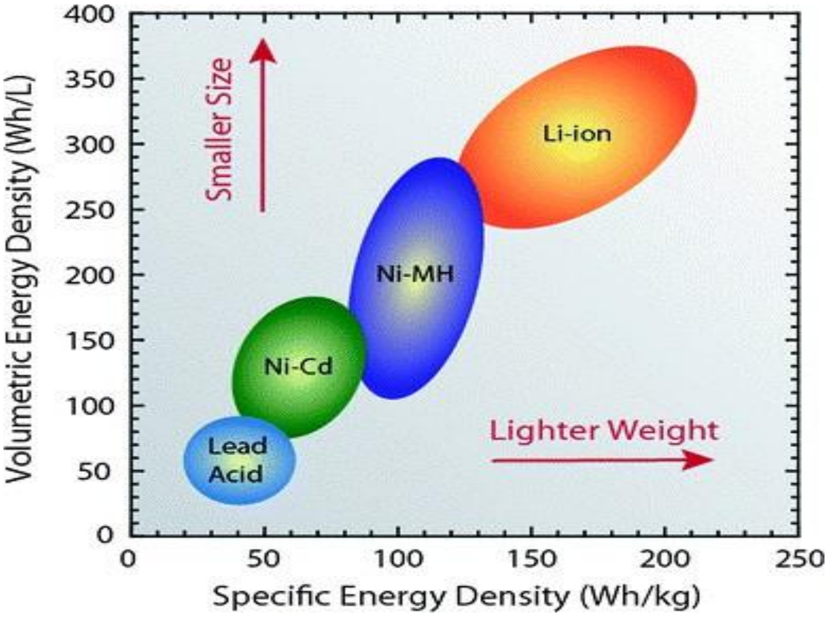


Fig 1.1: Characteristics of a Li-ion Battery

DESCRIPTION OF STATE OF CHARGE

State of Charge: State of Charge (SOC) is the level of charge of an electric battery relative to its capacity, as seen in fig 2. The units of SoC are percentage points (0% = empty; 100% = full). An alternative form of the same measure is the depth of discharge (DOD), the inverse of SoC (100% = empty; 0% = full). Fig 2.1 indicates the block diagram representation of various algorithms used to calculate the State of charge.

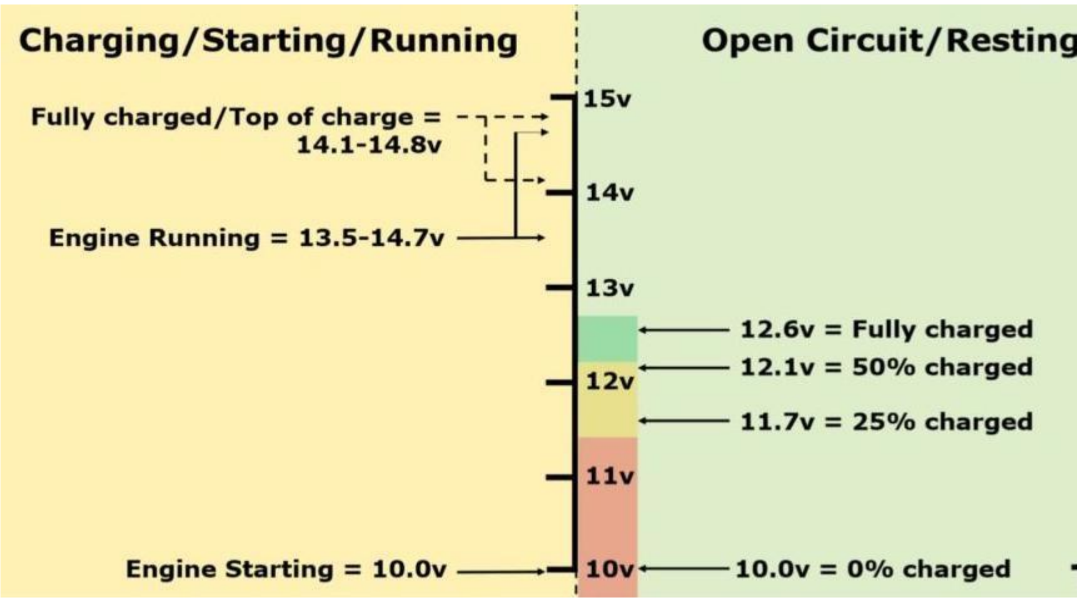


Fig 2: State of charge calculation in an electric car

METHODOLOGY AND RESULTS

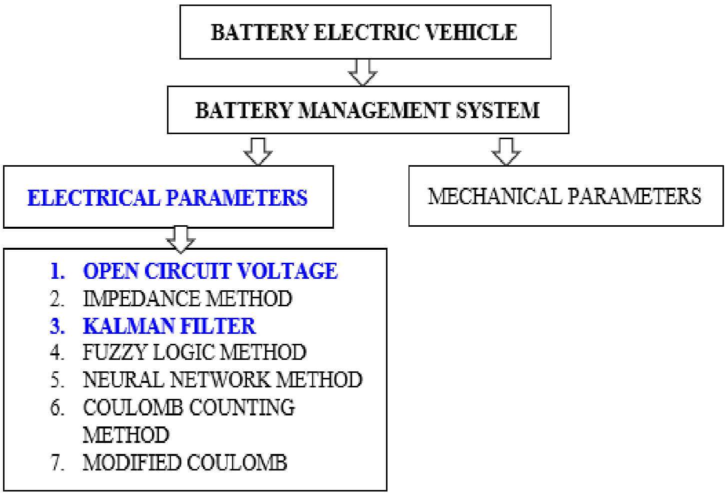


Fig 2.1: Block diagram of State of charge calculation in an electric car

Comparative charge status analysis in a Battery Electric Vehicle using Model-based Method has been carried out with suitable algorithms and simulation results. Among the various algorithms used to calculate state of charge, detailed analysis of Kalman filter and Open Circuit Voltageis explained below:

Case a) Open Circuit Voltage: In this method, the RC model has been built and simulated in Scilab. Simulation results are compared with experimental results [7] and it is found that it is the same and it is mapped with experimental results.

a) Open Circuit Voltage Method:

Open circuit voltage (OCV) has a considerable influence on the accuracy of the battery state of charge (SOC) estimation. The OCV curve can be locally reconstructed even when the accumulated data only cover a partial range of SOC, which is suitable for electric vehicle (EV) operation conditions. From the simulation model, consider the RC network in addition to the voltage source. The state of charge is measured at output [5]. Voltage is measured at terminal 2 and total resistance is measured at terminal 1. Voltage and Resistance of the RC Circuit model has been developed using Scilaband has been indicated in fig 3.1. Open circuit voltage, Voc, internal resistances during discharging, Redis, and charging, Rcha, are involved. The dependent variables considered for State of charge estimation includes:

Open circuit voltage (Voc),

Internal Resistance during discharge – Redis.

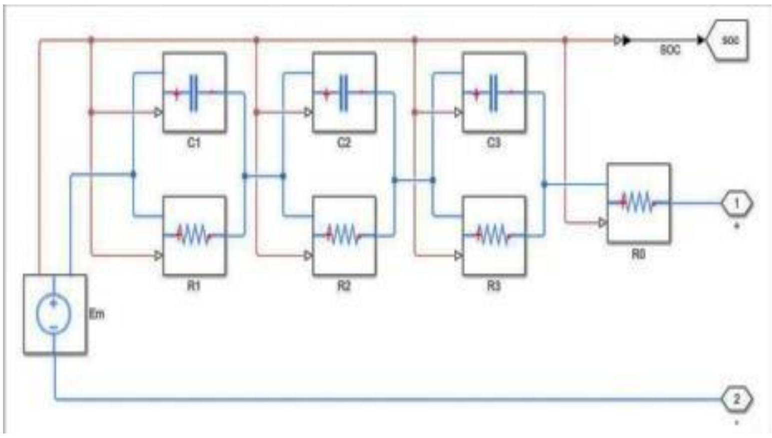


Fig 3.1: RC Circuit model of Open Circuit Voltage

The battery current and output voltage can be calculated as follows:

$$I = \frac{V_{oc} - V_b}{R_b}$$

$$V_b = \frac{P_{ele,m}}{I}$$

Where Rb is the internal resistance of the battery depending on discharge and charge mode, I is the circuit current, and Vb is the battery output voltage. SOC can be obtained by integrating the current. When the current is positive, it means that the battery is discharging. On the other hand, the battery is recharging if the current has a negative value.

$$SOC = SOC_{ini} - \int_0^t \frac{I}{Q_b} d\tau$$

Here, SOCini is the initial value of SOC, and Qb refers to the battery's storage capacity. The developed RC circuit model and simulation have been carried out and results have been compared with existing paper [6] and mapped all parameters and it is shown in fig 3.2. Hence the method is easy to implement. However, the initial value cannot be stored and hence data retrieval is found out to be difficult when the state of charge has to be calculated.

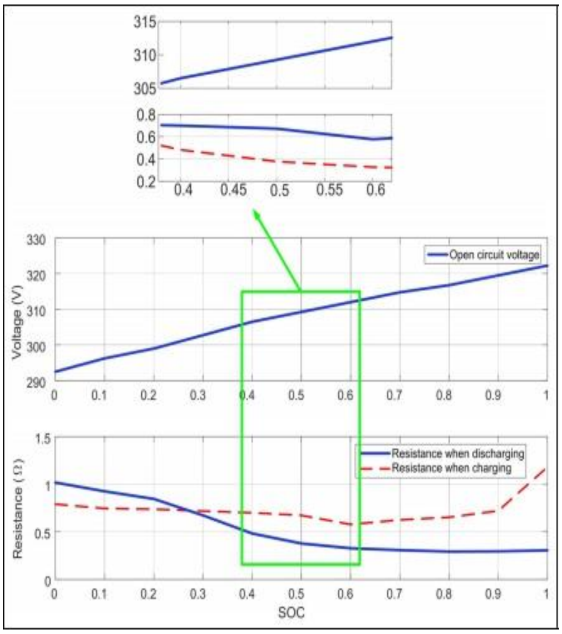
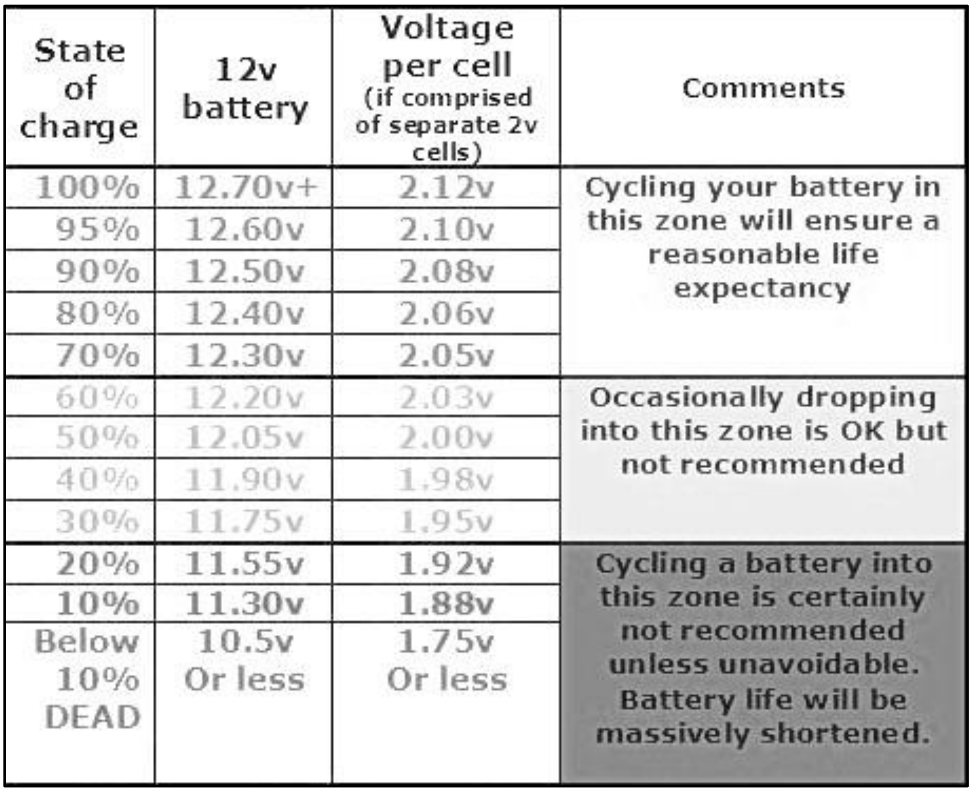


Fig 3.2. Battery open circuit voltage and internal resistance with respect to SOC.

Table1: Simulation result for a Nissan leaf electric car lithium ion battery identified RC model



State of charge	12v battery	Voltage per cell (if comprised of separate 2v cells)	Comments
100%	12.70v+	2.12v	Cycling your battery in this zone will ensure a reasonable life expectancy
95%	12.60v	2.10v	
90%	12.50v	2.08v	
80%	12.40v	2.06v	
70%	12.30v	2.05v	
60%	12.20v	2.03v	Occasionally dropping into this zone is OK but not recommended
50%	12.05v	2.00v	
40%	11.90v	1.98v	
30%	11.75v	1.95v	
20%	11.55v	1.92v	Cycling a battery into this zone is certainly not recommended unless unavoidable. Battery life will be massively shortened.
10%	11.30v	1.88v	
Below 10% DEAD	10.5v Or less	1.75v Or less	

From Table 1, the Simulation result for a Nissan leaf electric car lithium-ion battery identified RC model is compared for a 12V battery. It is found that Nissan leaf electric car has used Level 2 charging and experimental and simulation results are the same and it is validated.

b) Kalman Filter Method:

To overcome the shortcomings of the open circuit voltage method, the Kalman filter method is used. The battery can be modeled with an electrical model, which the Kalman filter will use to predict the over-voltage due to the current. This method is complex, but data can be stored and data retrieval is also possible but has few errors like Integration of current sensor error: Integration of the current obtained by an erroneous sensor causes the results to drift.

1. Degradation of battery: Degradation of the battery results in a loss of battery capacity, which causes an estimation error.

2. Self-discharge: Self-discharge is the consumption of charge inside the battery. This cannot be observed by current measurement.

Battery Model and Parameter Identification of Kalman filter

While the demand for energy increases day by day, the amount of available fossil fuel reserves deplete. Relying on fossil fuel consumption causes damages to the environment and incremented greenhouse gas emissions as well. Consequently, renewable energy technologies have gained more attention and derived the use of more electric vehicles.

Lithium-ion batteries are getting popular in both renewable energy systems and electric vehicles thanks to their high power and energy density. Therefore, accurate battery models are vital to the design and simulation of hybrid/electric vehicle propulsion systems. Modeling and batteries are a toilsome task because of their complex electrochemical structure and nonlinear characteristics. [3]

Accurate real-time SOC estimation reporting to drivers is also difficult. This work addressed these challenges using an extended Kalman filter (EKF) algorithm and a two-RC-block equivalent circuit shown in figure 3.5. This battery equivalent circuit model is designed in Matlab Simulink using the Simscape language. Then, an algorithm with the EKF approach is developed to enhance the SOC estimation. In summary, to obtain a more accurate and robust SOC estimation, an improved Thevenin battery model was submitted, which is based on the analysis of the nonlinear characteristics of a lithium-ion battery module by experimental results and its parameters were identified by the EKF algorithm.

Li-Ion Battery Modeling using Kalman filter

The Thevenin model is widely used to model the Lithium-ion battery, but it is not accurate enough as all of its elements can change, depending on the state of the battery and its conditions.

To improve the model reliability, unlike the general equivalent Thevenin model, an extra RC branch is added, as shown in Fig. 3.5.1. These blocks shown in the figure were created in Simulink Simscape Language to define the custom components as text files.

The texts include complete parameterization, physical connections, and equations represented as a couple of causal implicit differential-algebraic equations. The mathematical relation has been obtained as a result of experimental work, as explained in [1].

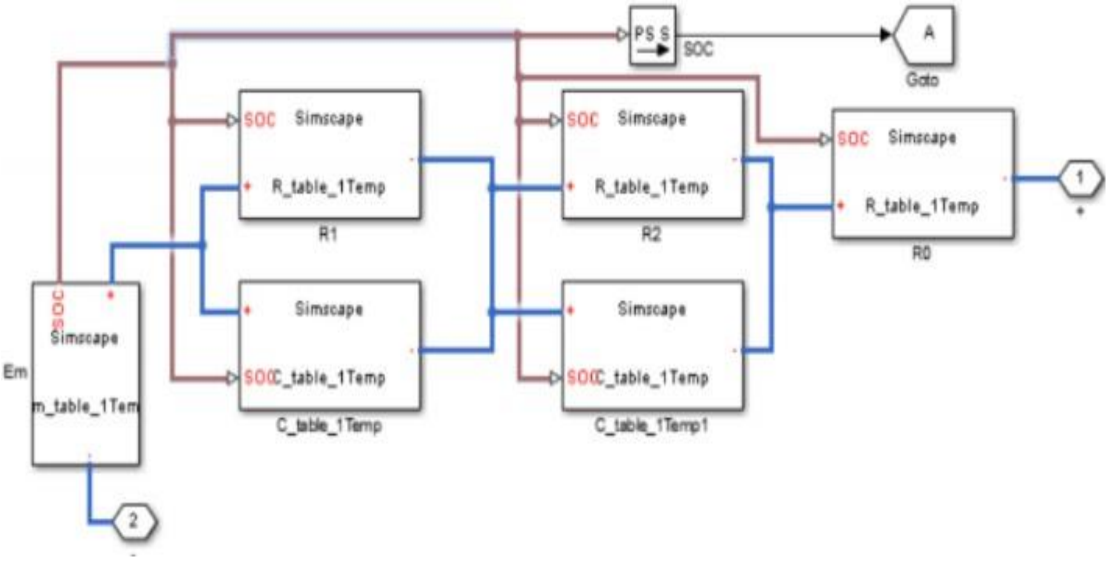


Fig 3.5 2RC Li-ion battery improved physical model design and its Simscape library elements.

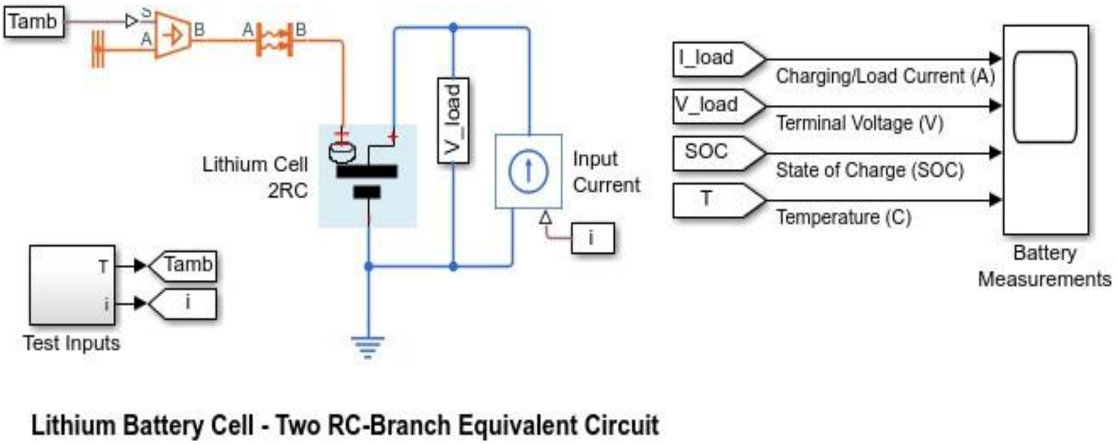


Fig 3.5.1.Two RC Branch Equivalent circuit model

The Thevenin model shown in fig 3.5.2 includes three parts as open-circuit voltage-Voc, internal resistances, and equivalent capacitances. The internal resistances include ohmic resistance-Ro, electrochemical polarization resistance-Rpa, and concentration polarization resistance-Rpc. The equivalent capacitances [4], which include electrochemical polarization capacitance-Cpa and concentration polarization capacitance-Cpc, Charging current iL and UL are the charging/discharging current and the terminal voltage, respectively. The soc output voltage is explained in fig 3.5.3

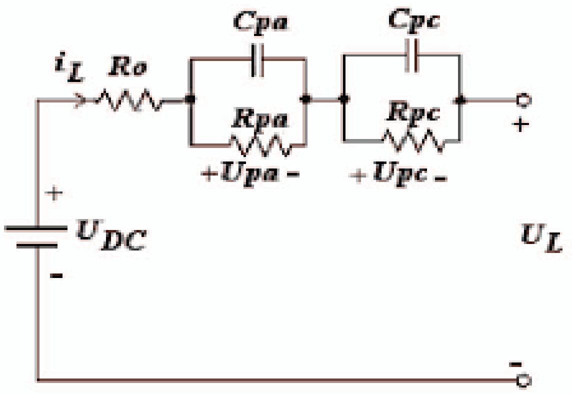


Fig 3.5.2: RC Thevenin Model

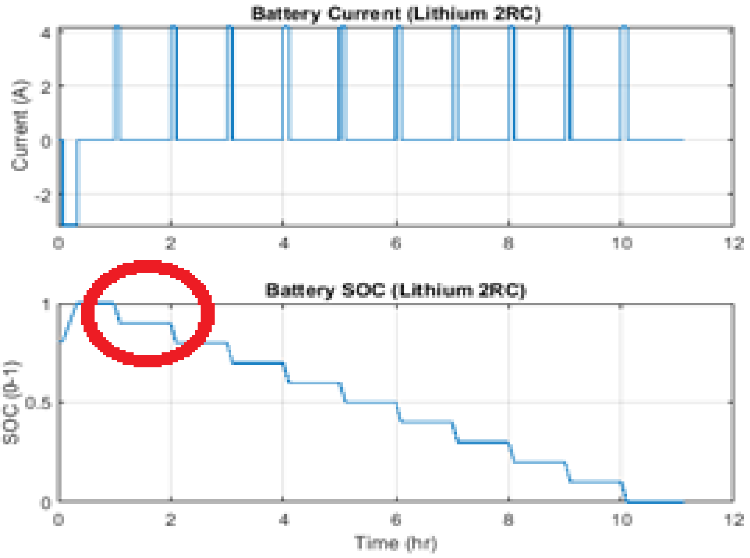


Fig 3.5.3: RC Thevenin Model

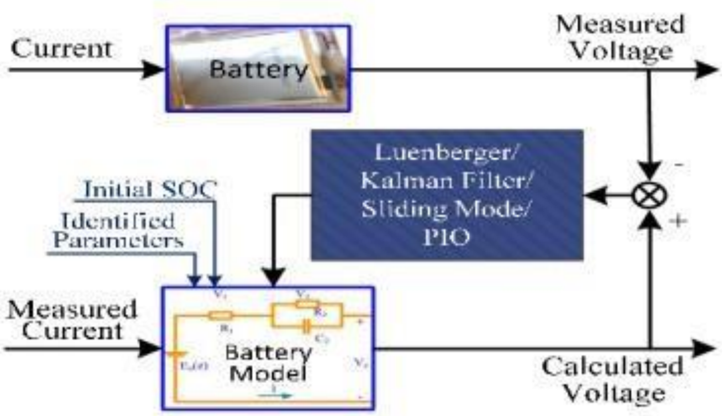


Fig3.6. Equivalent battery model based SOC Kalman filter method [6].

The state of charge estimation using the Kalman filter method and its equivalent battery model has been shown fig 3.6. The Extended Kalman filter is a method for predicting a system's future state based on the previous ones and a convenient form for online real time processing. It consists of two equations. The equations include A, B, C and D matrices that can be constituted using Ro, Rpa, Rpc, Cpa and CPC. The expressions of matrices and vectors are the same as [1]. Xk is the system state matrix and one of the matrix values represents SoC. Therefore,xk captures system dynamics. The system's input is the UK, which is a control variable matrix and known or can be measured. However, the measurement could result in errors, assumed to be stochastic process noise, wk, which cannot be measured and affects the state of the system

$$xk + 1 = A \times xk + B \times uk + wk$$
$$yk = C \times xk + D \times uk + vk$$

The second equation is the measurement equation and models the output voltage of the system yk, in terms of the input, the state vector and the noise in the measurement of the output, vk, which is called measurement noise. For the Lithium-ion battery module, some parameters for the Extended Kalman Filter code are specified as follows:

$$Q= \begin{bmatrix} 0.1 & 0 & 0 \\ 0.000001 & 0 & 0 \\ 0 & 0 & 10 \end{bmatrix}$$

$$R= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0.1 \end{bmatrix}$$

$$P= \quad [10]$$

State of Charge Estimation

Using the Matlab Optimization Tool Box, parameters of the battery such as Cpa, Cpc, R0, Rpa, Rpc, Uoc were determined. The Charge and discharge input current signals, as well as the real and estimated SOC curves, are shown in Fig 3.7. The results are compared and found out to be mapped in all aspects [7].

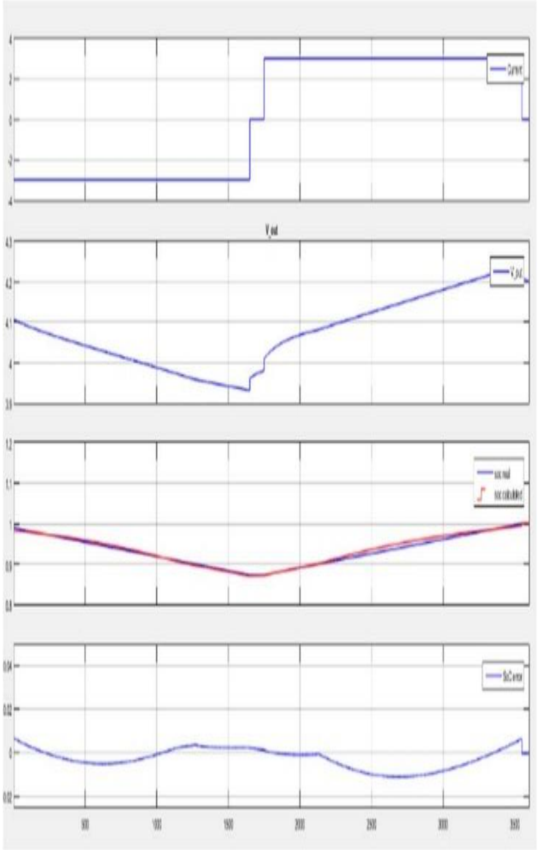


Fig 3.7 Experimental data results for Kalman filter

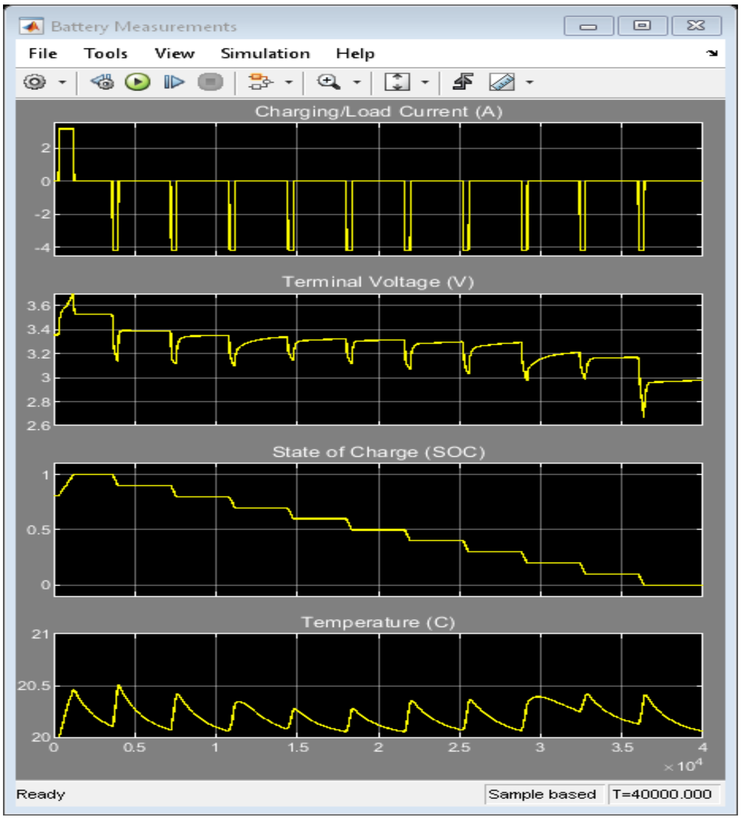


Fig 3.7.1Theoretical results of Kalman filter

Fig 3.7 and 3.7.1 indicate the Compare the simulation results with research paper results and found out to be the same [7]. Maximum SOC error is found out to be 1% from the simulation results as per fig 3.7.1 And it proved to be a successful implementation of the Kalman filter technique.

CONCLUSION AND FUTURE SCOPE

For monitoring the charge status, suitable algorithms have to be implemented. In this paper, a Comparison between the Kalman filter and Open circuit voltage has been calculated mathematically with a suitable battery model. In Open circuit voltage data, retrieval is found out to be difficult. Hence retrieve data Kalman filter has been implemented. In the Kalman filter method for a Lithium-ion battery model, the proposed improved Thevenin model has been implemented, and its parameter identification has been performed using the Extended Kalman Filter algorithm. Maximum SOC error is found out to be 1% from the simulation results.

FUTURE SCOPE

Kalman filter is applicable only for nonlinear systems and it is hard to implement in linear systems as there is no feedback compensation mechanism.

Hence, to overcome this Kalman filter issue, other suitable algorithms like coulomb counting, fuzzy logic, and modified coulomb counting methods may be considered for the reliable operation of a battery in a battery electric vehicle.

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VII. Li-ion Battery Modeling and SOC Estimation Using Extended Kalman Filter,Fatma Nur Dişçi(1), Yasser El-Kahlout(2), AbdülkadirBalıkçı (1,2)(1) Department of Electronics Engineering, Gebze Technical University, Kocaeli, Turkey (2) Energy Institute, TUBITAK Marmara Research Center, Kocaeli, Turkey .