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Design of State of Charge Estimation Method for Battery Management System of Electric Vehicle

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Abstract: Environmental pollution and energy issues are becoming increasingly significant today. Due to its high energy density and extended cycle life, Li-ion batteries are frequently employed in electric cars. An essential indication for Li-ion batteries is their state of charge (SOC). The safe functioning of a Li-ion battery may be ensured by an accurate SOC estimation.

In a future where electric mobility is defining our way of life, electric storage is essential, especially in applications like electric automobiles. Although there are many other battery technologies, lithium-ion technology now dominates the market because of its superior performance. To maintain the security of these components, a battery management system (BMS) must be utilised to ensure safe and effective functioning. This system's fundamental function necessitates accurate state of charge (SOC) calculation. The state of charge (SoC), which reflects the capacity of the battery, is one of the most important states that must be monitored in order to improve performance and extend battery life.

In this study, a Kalman filter-based MATLAB programme for estimating state of charge (SOC) was presented.In order to concentrate on the impact of temperature on SOC, the temperature coefficient is suggested in this study. The battery can be represented in state space by adding a temperature coefficient to the current battery model. For state of charge estimation, an Extended Kalman Filter (EKF) is used to increase precision. The findings demonstrate the impact of temperature on the battery's open circuit voltage (OCV) and state of charge (SOC) after the suggested model has been applied in the MATLAB environment.

Keywords: state of charge

I. INTRODUCTION

A rising trend in the field of study is the electric vehicle (EV). The battery is one of the main sources of energy in an EV. How well a battery functions under varying load circumstances is determined by its internal chemical processes. The chemical inside the battery deteriorates over time, which has an effect on the functioning of the battery. Degradation may be brought on by extreme temperatures, quick charging or discharging, or other circumstances. Explosions could occur if such batteries are used in electric vehicles, which is dangerous and should be avoided. The Battery Management System (BMS) is now used in EVs to prevent this type of dangerous condition, such as battery explosions..

The battery of an EV serves as its primary form of storage. SOC is an important factor to take into account in order to make sure that batteries are charged and discharged safely. Evaluating State of Charge (SOC) in the context of electrical vehicles (EVs) is a crucial step in ensuring that this new technology is broadly embraced. Since state of charge cannot be detected directly, it is crucial to use a method that can precisely estimate SOC using variables that can be measured, such as battery terminal voltage and current. Extended Kalman Filter (EKF) may be used effectively for battery SOC prediction since Kalman Filters are frequently cited as the best estimator for linear systems and a decent one for non-linear ones. Consequently, this work provides an Extended Kalman.

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II. BACKGROUND

For the safe usage of batteries in various BMS tasks, SOC is a controllable option that regulates the charging and discharging limitations. To ease the driver's worry, SOC measures the battery's level of charge in a manner similar to an energy gauge. Therefore, precise SOC estimate is crucial for EVs. It is a challenging undertaking, nevertheless, because no sensor or measurement tool can directly assess it. Measured variables like current, voltage, and temperature must be used to estimate it.

It is observed battery used in Electric Vehicles is often Overcharged or Undercharged. This leads to deterioration in the efficiency of battery and causes early aging. Thus, it is important to have a BMS which can monitor the battery parameters continuously. State of Charge estimation in BMS of EVs is very crucial. Many methods are available for SOC estimation. But the reliability and accurate estimation is still a problem.

III. OVERVIEW

A. Battery Management System

A battery is a device which converts the chemical form of energy into electrical energy. In EVs commonly li-ion batteries are preferred, because it is a rechargeable battery. They are utilized in an electric cars and electronics device.

An electronic device called a battery management system is used to maximize efficiency. It also protects the battery by keeping track of its condition, calculating secondary data, reporting that data, controlling its environment, authenticating it, and/or balancing it. Electric vehicles do not need to be charged externally at charging points for the autonomous car. Electric cars are those that use electricity as their main fuel source. .[7]

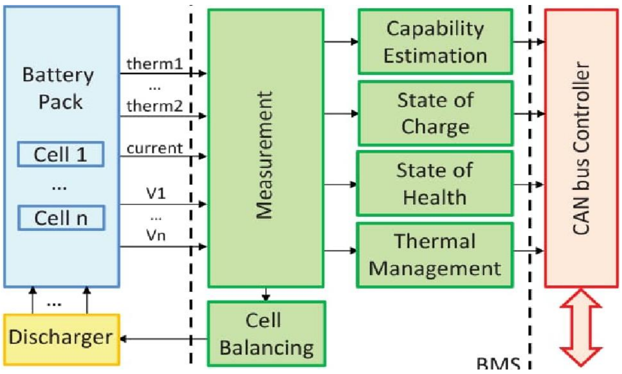

Fig 1. Block Diagram Of BMS

B. Characteristics of Li-ionbattery:-

- High energy density
- Extended lifespan
- Negligible self-discharge
- Minimal maintenance expenses
- Environmentally friendly
- Excellent responsiveness

C. Features of Battery Management System

- Cell under-voltage and -voltage protection
- Estimation of State of charge
- Intelligent battery balancing
- Pack temperature monitoring
- Battery charger control
- Monitors health of the battery

D. State of Charge

Overcharging and overdischarging a lithium-ion battery will always result in damage; to avoid this, the battery's inner charge must be properly assessed.

phenomenon and assure safe operation.Li-ion battery condition is SOC. The battery's available energy is indicated by SOC. As a result, SOC information serves as the foundation for BMS's control and monitoring of Li-ion batteries. BMS should offer accurate SOC estimate.

$$SOC = 1 - \frac{\int idt}{Cn}$$

The percentage of the battery's actual capacity to its remaining capacity is known as SOC. It displays the storage charge of the battery. SOC's equation and definition are provided by

Initial SOC of battery is represented by SOC(t0), its nominal capacity is represented by Cn, and the battery current is specified as positive for draining and negative for charging..

A proper SOC calculation has various benefits for EVs, including greater battery performance, longer battery life, and battery pack failure warning. The density of the battery's chemical components can be measured to calculate capacity, however this is not a workable approach. As a result, several techniques based on the measuring of battery current and voltage have been presented. The majority of these approaches calculate battery SOC without taking temperature into account. To precisely anticipate the journey / remaining distance of the vehicle, especially for electrical vehicle applications, the SOC should be computed.

Why Estimation of SOC Is Important

- Estimation of Energy consumption
- To make the cell work in best operating regions
- To analyze parameters battery performance and reliability
- To increase the sustainability of the battery
- Cell parameters are a direct function of SOC
- Cell balancing strategies are dependent on the cell SOC

Embedded System

An embedded system is a combination of computer hardware and software that serves a specific function. Furthermore, embedded systems may function as a component of a larger system. The systems may be programmable or limited in their capabilities. Applications for embedded systems are numerous. This work includes an embedded system model for EKF's state of charge estimation.

IV. KALMAN FILTERING

Extended Kalman Filter

The extended kalman filter is a extended version of kalman filter which works efficiently on non linear systems. The EKF approach may be used to estimate nonlinear systems with weak nonlinearity and is frequently used to a variety of nonlinear systems. A wide variety of nonlinear systems may be used with the EKF method, and it can provide favourable estimate states.

Advantages of Extended kalman Filter:

- Applicable for all battery system
- Exact estimation of SOC
- No primary SOC needed
- It can filter the noice easily
- It can handle non linear dependencies
- High precision

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V. MATLAB MODEL OVERVIEW

1. Algorithm for SOC estimation

A. Battery Modelling

The second RC ECM (Fig. 2) is often utilized battery models observed in the various literature. It consists of the battery's internal resistance, open circuit voltage, etc. The extended Kalman filter technique utilizes the discrete-time state-space version of the battery model once these parameters have been optimized.

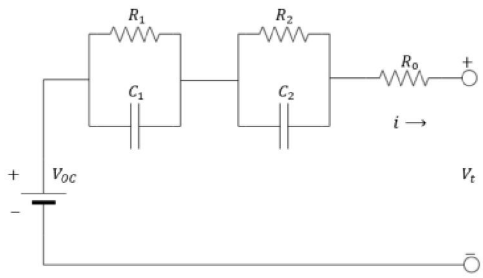

Fig. 2. 2nd order RC ECM Diagram

The state and measurement equations can be calculated as follows

$$X_{k+1} = A_k x_k + B_k u_k$$

$$Z_k = C_k x_k + D_k u_k$$

Where the state variables are x = [SOC, V1, V2] , X_{k+1} is the system state vector at time k+1, ,system input is *uk* = *ik*, and system output is *zk* = *Vt*. The A, B, C, and D matrices as follows

$$A=\begin{bmatrix} 1 & 0 & 0 \\ 0 & exp^{\frac{-\Delta t}{R1C1}} & 0 \\ 0 & 0 & exp^{\frac{-\Delta t}{R2C2}} \end{bmatrix}$$

$$B=\begin{bmatrix} -\frac{\Delta t}{Q}\, n[k] \\ R1(1-exp^{\frac{-\Delta t}{R1C1}}) \\ R2(1-exp^{\frac{-\Delta t}{R2C2}}) \end{bmatrix}$$

$$C=\begin{bmatrix} \frac{\partial Voc}{\partial soc} & \frac{\partial V}{\partial V1} & \frac{\partial V}{\partial V2} \end{bmatrix} = \begin{bmatrix} \frac{\partial Voc}{\partial soc} & -1 & -1 \end{bmatrix}$$

D = - R0

B. Extended Kalman Filter

The extended kalman filter are described in following equations. It has two steps first is prediction and other is correction.

The Extended Kalman Filter algorithm are described as follows :

Prediction (Time Update)

1. Project the states ahead:

$$\hat{x}_{k+1|k} = A\hat{x}_{k|k} + B_{u_k}$$

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2. Project error covariance ahead:
   $P_{k+1|k} = AP_{k|k}A^T + Q_k$

Correction (Measurement Update)

1. Computing Kalman gain:

$$K_{k+1} = P_{k+1|k}C^T\left(CP_{k+1|k}C^T + R_{k+1}\right)^{-1}$$

2. Update estimate with measurement zk

$$\hat{x}_{k+1|k+1} = \hat{x}_{k+1|k} + K_{k+1}(z_{k+1} - C\hat{x}_{k+1|k})$$

3. Update the error covariance:

$$P_{k+1|k+1} = (1 - K_{k+1}C)P_{k+1|k}$$

$Q_k = k_k * Error_k * k_k$

This are EKF algorithm which are taken into consideration[9]

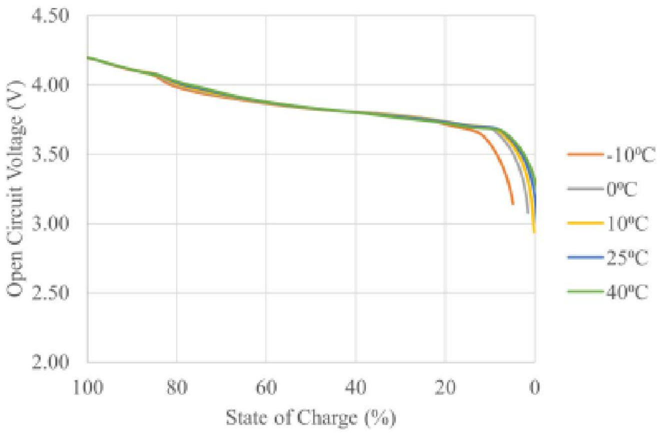

Fig. 3. OCV vs. SOC of a Turnigy Graphene 5000mAh Li-ion Battery at different temperatures.

2. Output Graphs

Output at 40°C

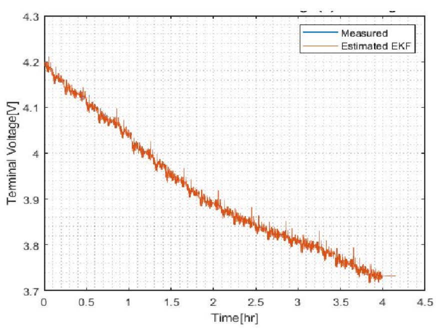

Fig. 4. Terminal Voltage (V) Vs Time(Hr)

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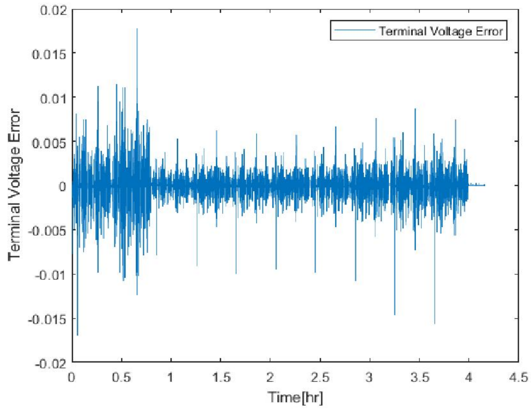

Fig 5. Terminal Voltage Error Vs Time(Hr)

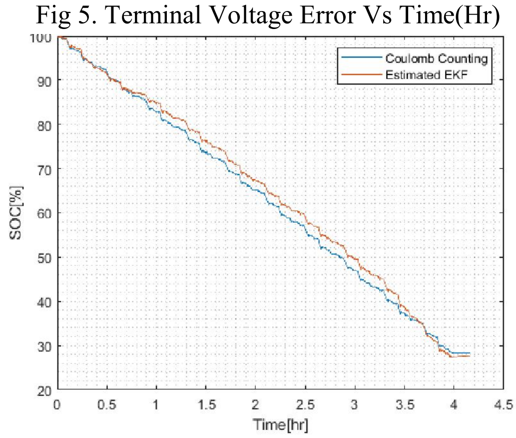

Fig 6. Coulomb Counting Vs SOC Estimated by EKF

This results are also obtained at various temperatures like 40°C, 25°C, 10°C, 0°C using extended kalman filter and the battery data available using MATLAB .

V. METHODOLOGY

Block diagram & description

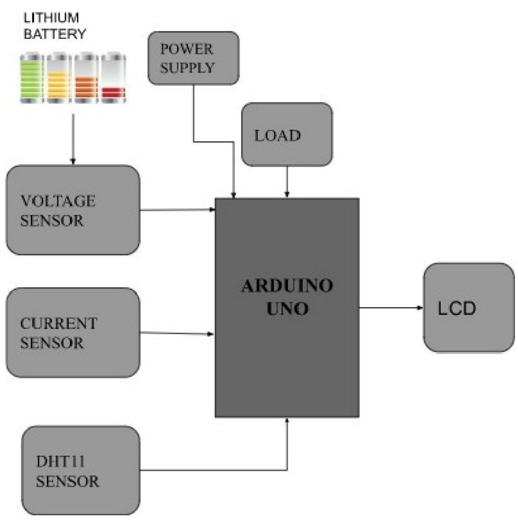

Fig 7. Block Diagram

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In this work, we measured the SOC of lithium-ion batteries. For implementing the system, we used Arduino UNO as a microcontroller, the voltage sensor, current sensor, and DHT11 sensor, for detecting the current of load and temperature and voltage of batteries. The LCD is connected to display all parameters likevoltage and the temperature and current and SOC. for the load we used the LED as a light source

In this project, we use Arduino as a microcontroller. The voltage sensor, current sensor, and DHT11 sensor are connected as input devices to the microcontroller. The LCD is connected as an output device to the microcontroller

Flowchart

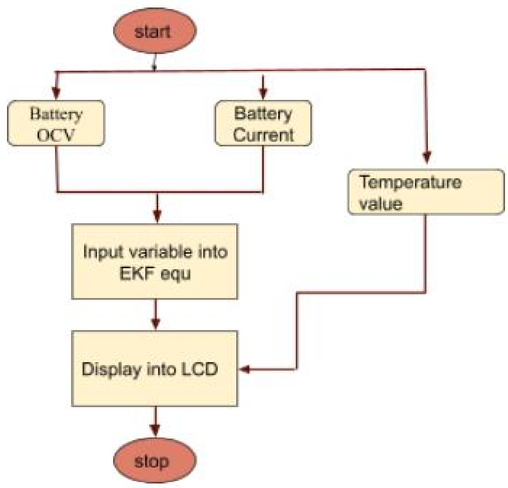

Fig 8. Flowchart

VI. SYSTEM REQUIREMENT

HARDWARE REQUIREMENT

- Arduino UNO
- Voltage sensor
- Current Sensor
- DHT11 Sensor
- LCD
- Lithium-ion battery
- LED

SOFTWARE REQUIREMENT

- Arduino IDE
- Proteus

VII. RESULT & DISCUSSION

EXPERIMENTAL SETUP

This is proposed hardware model. In this model Li-ion batteries of 3.7V/2.6Ah rating are used which are connected in parallel combination .

The result of the input is obtained that we get the reading of parameters like the current, voltage and temperature, and State of charge in two conditions first when the lithium battery is not connected and the second one is lithium battery is connected.

Following is the hardware model which is developed in embedded system for estimation of state of charge.

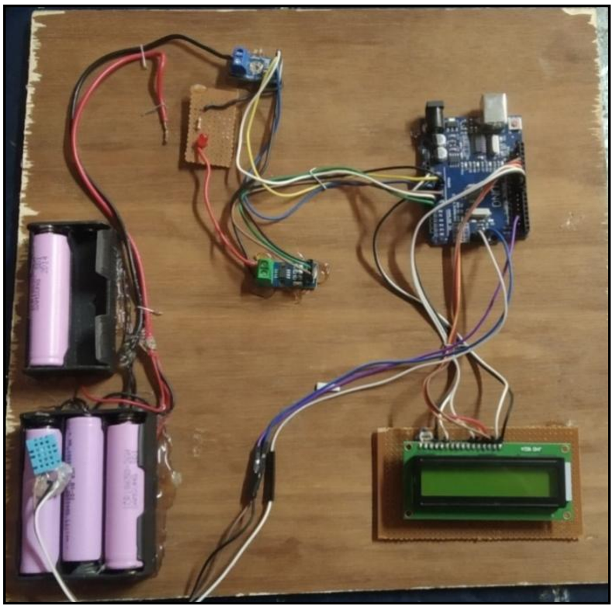

Fig 9. Hardware Model

Here to detect the SOC of the lithium battery which we used in a recent Electric vehicle by using the Extended Kalman Filter. This work is divided into two parts where we used the detect the current of load and another where we want to detect the temperature and voltage and The SOC of Li-ion batteries.Modelling the battery might provide vital details on its internal status. The battery's state of charge (SOC), which denotes how much energy is still available inside, serves as a proxy for the internal state. Monitoring the internal battery parameters, such as the voltage, current, and SOC, is the major goal of modelling. To power the system, we must turn on the power supply. For sensing the other battery parameter and SOC, we employed lithium-ion rechargeable batteries that were placed in parallel. Following power supply, the LCD displays the SOC, battery voltage, and load current.

RESULT

In this paper, the extended Kalman filter is presented for estimation of SOC of li-ion battery, which is an important in proper management of battery power and energy. The implementation led to the conclusion that Extended Kalman Filter method provides precise SOC estimation and rejection of the error, and because its diversity against the unreliability of initial state of charge, it can be concluded that Extended Kalman Filter is well chosen for SOC estimation of an electric vehicle lithium-ion battery.

After implementing the proposed system we get the output as a result that, when the lithium battery is not connected and when the li-ion battery is connected and it shows that the parameter like Temperature is the battery where the voltage 3 because we used 3.7-volt batteries and current is 9.65 ampere and the temperature is 34.70 Degree Celsius and SOC is 100 percent.

VIII. CONCLUSION

This study suggests a hardware model and MATLAB function for SOC estimate based on Kalman filters.

The battery management system of an electric vehicle's level of charge is correctly and with very minimum error calculated in this study. Therefore, it can be said that this approach is one of the most effective ones for estimating the condition state of charge of BMS.

In this paper, we proposed the extended Kalman filter for li-ion battery SOC estimation, which is a crucial part of efficient energy and battery power management. The implementation's outcomes showed that EKF provides accurate SOC estimate and mistakes rejection. to the first SOC's unpredictability. And this study concludes that accurate estimation of state of charge of BMS is one of the most important part in an electric vehicle.

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