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Life Analysis of an Electric Vehicle Battery

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ABSTRACT: Self-powered devices have become increasingly important to modern industries. One of the most significant components is the energy storage device, which is usually powered by lithium-ion batteries. There are secondary batteries used in nearly every aspect of our lives, from cell phones to laptops, medical devices, satellites, electric vehicles and renewable energy power stations. The life assessment is crucial tool for evaluation of battery performance. The battery performance is affected due to various factors including temperature, charge and discharge voltage, current, resistance, drive systems and the level at which the battery is charged or discharged. In this literature, battery life is analysed through various conditions using MATLAB/Simulink.

KEYWORDS: lithium-ion, life assessment, electric vehicles, MATLAB/Simulink.

I. INTRODUCTION

Rechargeable battery is an electrochemical device which converts electrical energy to chemical energy during charging and converts chemical energy to electrical energy during discharging [1]. Lithium-ion batteries, as one of the advanced batteries, are attracting much attention in the past few decades. Increasingly, lithium-ion batteries are being used in energy storage systems for hybrid electric vehicles (HEVs) and pure electric vehicles (EVs) due to their low self-discharge rate, high energy capacity, and high-power density compared to other batteries. Precise information about the battery such as state of charge (SOC), current, voltage is important for circuit designer to manage the energy consumption of battery powered system. Moreover, handling on battery is necessary to avoid inappropriate battery conditions like overcharging or over discharging. Therefore, an accurate battery model is vital as a guide in forecasting the characteristics of battery. Batteries deteriorate even when not in use and storage conditions, mainly the temperature and state of charge (SOC), rating of electric motor used, affect the rate of degradation and battery performance. Temperature is known to have a significant impact on the performance, safety and lifetime cycle of lithium-ion batteries.

MATLAB/Simulink is a powerful simulation tools for circuit and system designs. It provides a lot of simple, powerful and user-friendly toolboxes or simulation blocks [1]. A temperature dependent battery model is included in MATLAB/Simulink library as proposed in [2]. Further modifications are made and battery behaviour is observed in different conditions. In this paper, parameters of commercially available 3.7 V Li-ion cell are determined from simulation results. A lithium-ion model is simulated and modified to analyse the battery behaviour in various conditions.

II. METHODOLOGY

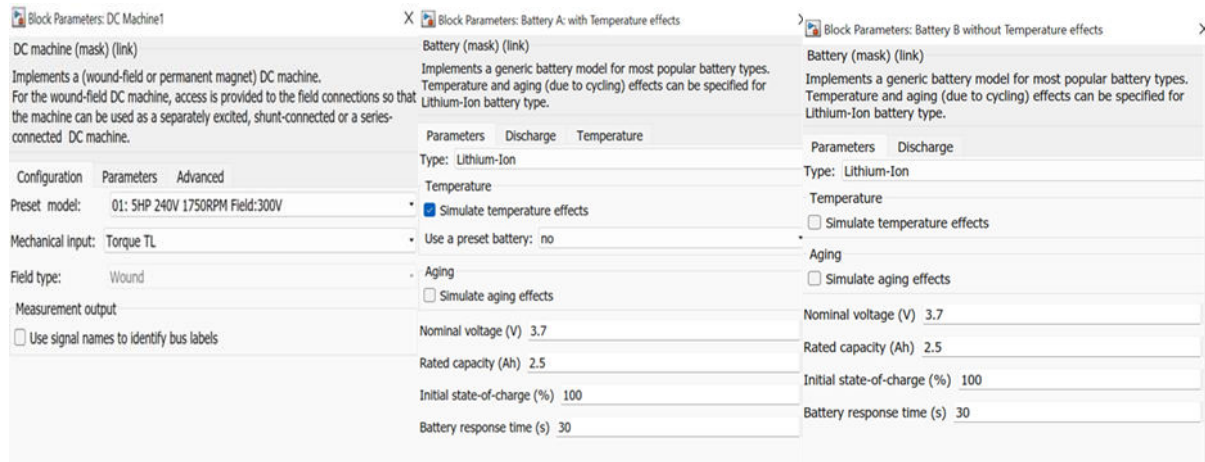
The purpose of this research is to apply the research method to solve problems resulting from fossil fuels used in automobiles and various industries. Global warming and greenhouse gas emissions are negatively affected by this practice. The battery has taken over the world or we can say that wide range of electrical equipment's, such as mobile phone, electric cars, are powered by batteries. In this project, MATLAB/ Simulink becomes the most used software for modelling and simulation of the dynamic systems.

III. BATTERY AND MOTOR SPECIFICATIONS

The terms used to describe the battery conditions including C-rate, state of charge (SOC), depth of discharge (DOD), terminal voltage and open-circuit voltage; as well as the battery specifications, including cut-off voltage, capacity, cycle life, specific energy, energy density, internal resistance, charge voltage, and charge current.

- C-Rate: A C-rate is a measure of the normalization of the discharge current of a battery against its maximum capacity. One C rate means that the discharge current will discharge the entire battery in an hour.
- State of Charge (SOC): SOC (%) is the percentage of the present battery capacity over the maximum capacity.
- Depth of Discharge: DOD (%) is the percentage of battery capacity that has been discharged over the maximum capacity. 80% DOD or more is considered a deep discharge.
- Cut-off Voltage: Cut-off voltage is the lowest acceptable voltage, at which the battery is considered vacant.
- Capacity: The battery capacity, also known as the coulometric capacity, is the total Amp hours (Ah) available when the battery is discharged at a certain C-rate from 100 percent SOC (full) to the cut-off voltage (empty). Capacity can be calculated by multiplying the discharge current by the discharge time to estimate the battery's status.
- Specific energy (Wh/kg): Specific energy, also known as the gravimetric energy density, is the nominal battery energy per unit mass.
- Energy density (Wh/L): Energy density, also known as the volumetric energy density, is the nominal battery energy per unit volume.
- Internal resistance (IR) (Ω): The resistance within the battery. It is usually different when charging and discharging, and it depends on the battery SOC. The higher the internal resistance, the lower is the battery efficiency.
- Charge current (A): Battery charging that uses constant current to charge the battery and increases the voltage before switching to constant current charging.
- Charge voltage (V): The voltage the battery is charged to when full capacity is reached. The charge voltage is generally reached when the battery is charged to about 70% SOC by the charge current, and then becomes stable until the charge process ends.

The following battery and motor specifications are used in simulation for modelling of the system. The specifications of commercially available 3.2V, 2.5 Ah lithium-ion battery is used and according to that DC motor is used. Voltage and output current of the battery will be maintained to be consistent with the rating of the electric motor is used.



IV. SIMULATION MODEL

The simulation is performed on MATLAB 2022a (R2022a) version with Intel(R) Core(TM) i5-10210U CPU @ 1.60GHz 2.11 GHz 64-bit operating system. The model illustrates the effect of temperature on the performance of a 3.2V, 2.5Ah lithium-ion battery. The model (which includes the impact of cell/ambient temperature on the voltage, capacity and resistance) is submitted to a variable ambient temperature during a discharge and charge process. Its performance is compared to the case where the impact of temperature is neglected [2]. Reference model [2] is compared with other two modified model conditions and battery behaviour is analysed through simulation results.

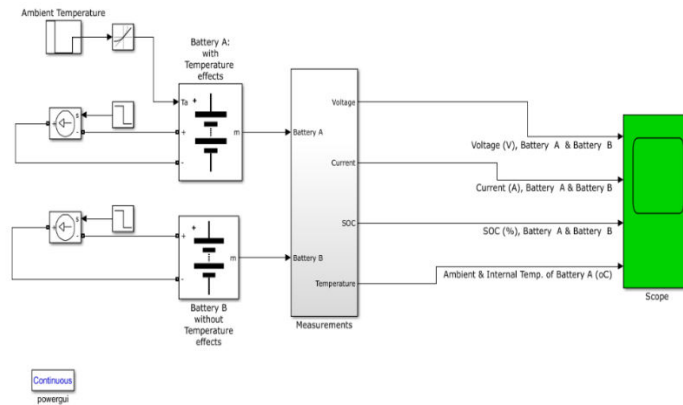


Fig 1: Lithium-ion temperature dependant model [2]

Condition I: The effect of temperature on the battery parameters when connected in series with each other

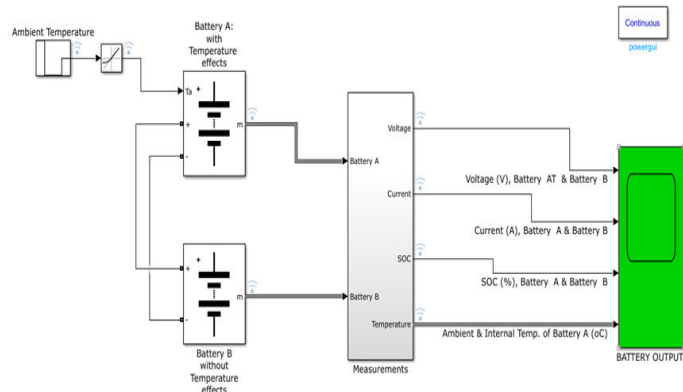


Fig 2: Lithium-ion battery temperature dependant model (batteries connected to each other)

Condition II: The effect of temperature on battery parameters when electric dc motor is connected to the battery

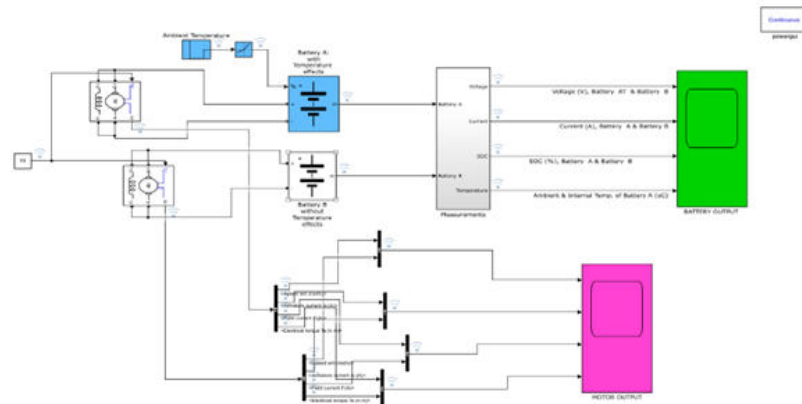


Fig 3: Lithium-ion temperature dependant model (with dc motor)

V. RESULTS AND DISCUSSION

MATLAB/Simulink is used for modelling and simulation of systems. It is used in automatic control and digital signal processing for multidomain simulation and model-based design. After simulation, the lithium-ion temperature dependant model in different conditions, the battery output parameters are obtained and represented with the graphs mentioned below:

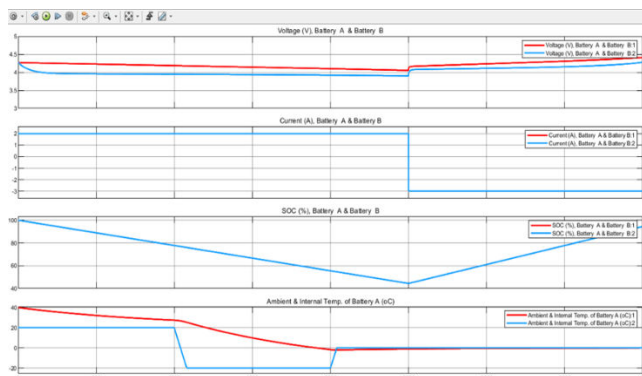


Fig 4: Output parameters of battery A and B (fig.1 model)

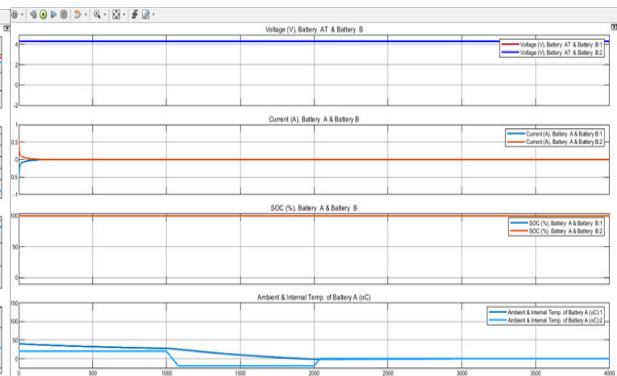


Fig 5: Output parameters of battery A and battery B (fig.2 model)

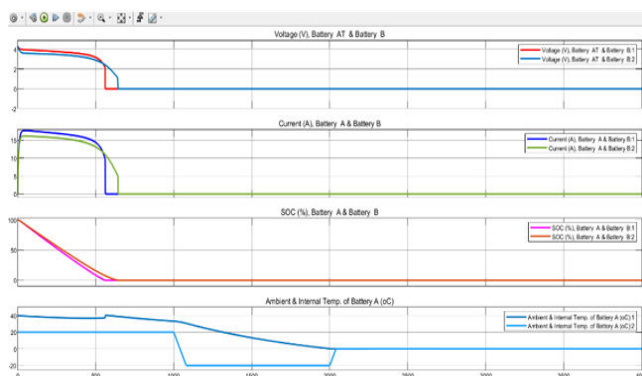


Fig 6: Battery output of battery A and B (fig 3 model)

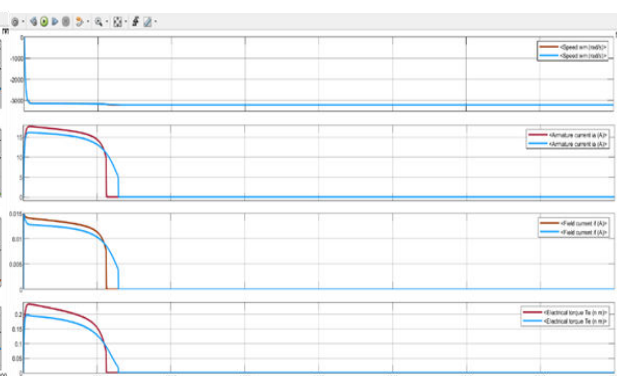


Fig 7: Motor output (fig 3 model)

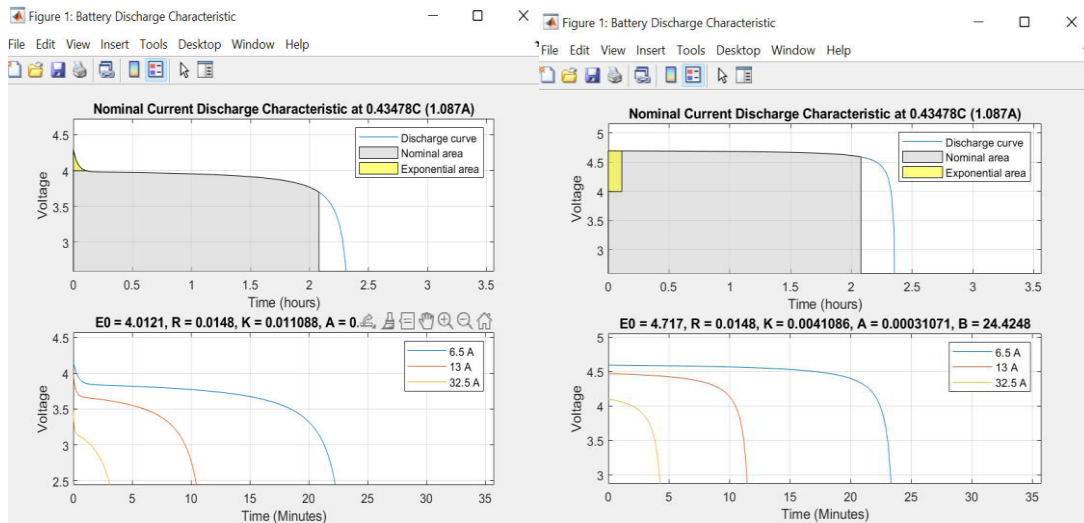


Fig 8 (a) and (b): Discharge Characteristics of battery A & B

Figure (4) indicates the output voltage(V) of battery A increases due to temp and heat losses whereas of battery B decreases. The current(A) in both batteries remain same, at the initial point current is 2A, but at 2500 seconds the current decreases suddenly to -3A. At $t = 1000$ s, the ambient temperature is decreased to -20 degrees C. This causes the output voltage of Battery A to greatly decrease as the internal temperature decreases rapidly. Also, the SOC of Battery A decreases due to the reduction of battery capacity. The battery B output voltage continues to decrease slowly to its steady state voltage. At $t = 2000$ s, the ambient temperature is increased from -20 degrees C to 0 degrees C. As the internal temperature increases, the output voltage of Battery A increases. Also, as the capacity increases, the SOC of Battery A increases. The Battery B output voltage remains constant to its steady state value. At $t = 2500$ s, the Battery A and B are charged with 3 A at ambient temperature of 0 degrees C. This causes the internal temperature to increase due to heat losses during the charge process, which increases the charging voltage of Battery A. Afterwards, Battery A and B continue to charge up until fully charged.

Figure (5) shows the voltage(V) remains the same throughout in both batteries. The current(A) in battery A decreases gradually to constant whereas the current in battery B increases slightly then becomes constant. When batteries are connected in parallel to each other, the number of electrons they push out each second and energy supplied is added, hence the total current in the circuit is increased. The SOC (%) remains the same as initial value.

Figure (6) shows the voltage(V) decreases predominantly in battery B after $t = 500$ seconds then remains constant as compared to battery A. The starting current(A) of both the batteries are different and gradually decreases after $t = 600$ seconds. The SOC (%) of battery A decreases initially after $t = 500$ seconds due to temperature and heat losses compared SOC (%) of battery B where temperature effect is neglected. At the beginning, the ambient temperature is 20°C, after temperature effect heat losses are obtained so the temperature decreases up to -25°C at $t = 1000$ seconds.

Figure (7) shows different output parameters of the DC motor used in the simulation model. The speed of the motor (rad/s) in both the conditions remains same. The armature current(A) in the dc motor connected to battery A increases due to heat losses whereas in case of battery B it decreases slowly due to no head losses. The field current(A) in the dc motor in both battery A and B remains the same as in case of armature current. The electric torque (Te) in battery B increases.

VI. CONCLUSION AND FUTURE SCOPE

This paper shows the battery behaviour in different given conditions using MATLAB/Simulink and this report helped to study the dynamic characteristics of lithium-ion battery. The temperature dependent model in condition 3(with electric motor) performs close to reality. Electric motor coupled with lithium-ion battery without the temperature effects is more reliable in electric vehicles (EV).When temperature increases this affects the chemical reactions that occur inside the battery. At higher temperatures one of the effects on lithium-ion batteries is greater performance. However, there is a drawback to this increased performance, the lifecycle of the battery is decreased over



time. Based on higher degradation at higher temperatures, the battery lifecycle can severely diminished due to exposure to extreme heat. While heat exposure does temporarily increase battery capacity the damage that it does to the life cycle can cause long terms effects and prolonged heat exposure should be avoided. Modern energy storage devices, such as ultra-capacitor and even fuel cells, can be integrated as power sources.

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