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Research paper

Contribution of Heat Generation During Charging on Thermal Behaviour of Lithium-Ion Battery for HEVs Application

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Abstract

Lithium ion battery is a suitable choice in hybrid electric vehicles (HEVs) mainly because of its high energy density. Operating temperature is an important factor influencing the performance and safety of the batteries in HEVs. For this reason, the study on the battery thermal behavior during charging and discharging is necessary. The focus of this study is to develop a battery model using Matlab/Simulink software to predict the battery thermal behavior at different charge and discharge rates. A vehicle model incorporating aerodynamic drag force, rolling resistance, hill climbing force and acceleration force is used. The battery model and the vehicle model are combined to form a series hybrid electric vehicle model able to predict the battery performance in enduring the NEDC driving cycle. Result from this study is important for better understanding of the battery thermal behaviour, so a suitable battery management system can be developed ensuring an optimum use of lithium ion batteries in automotive applications.

Keywords: *numerical mode; lithium ion battery; thermal behaviour; hybrid electric vehicle*

1. Introduction

Lithium ion battery is one of the preferred power sources in hybrid electric vehicles (HEVs) application because of higher energy density, power density and less memory effect compared to other type of batteries. Lithium ion battery offers fast acceleration capability and long driving range that makes them suitable for HEVs applications [1].

Battery temperature is one of many parameters that have to be carefully controlled as the battery performance is much affected by this operating temperature, including the battery efficiency, cell degradation, and battery's life time [2]. Heat is generated during charging and discharging process. During rapid charge and discharge process, temperature increases significantly and may continue to increase to more than allowable temperature range [3, 4].

In this paper, the heat generation of lithium ion battery at different charge and discharge rate is investigated. First, electro-thermal model of the battery comprise of electrical model and thermal model is introduced. This battery model is combined with vehicle model to form a series HEV that able to predict the temperature behavior under the New European Driving Cycle (NEDC).

2. Materials and Methods

2.1 Vehicle Model

Tractive effort in the vehicle model is the force generated by the engine or motor in order to propel the vehicle. The tractive effort has to overcome the aerodynamic drag, rolling resistance, provide the force needed to overcome the component of vehicle's weight over a slope, and also accelerate the vehicle if the velocity is varying. The calculation of tractive force and tractive power are explained in detail by Larminie and Lowry [5].

2.2. Battery Electro-Thermal Model

The prediction of battery electrical performance including discharge current, voltage and state of charge is based on the model proposed by Erdinc et al. [6]. The battery output voltage can be calculated using Equation 1.

$$V_{bat} = V_{oc(SOC)} - I_{bat} \cdot R \quad (1)$$

where, $V_{oc(SOC)}$ is the battery open circuit voltage [V] in function of state of charge (SOC) and I_{bat} is the battery current [A]. SOC is predicted using equation 2.

$$\mathrm{SOC} = \mathrm{SOC}_{\mathrm{initial}} - \int \frac{\mathrm{I}_{\mathrm{bat}}}{\mathrm{C}_{\mathrm{usable}}}\,\mathrm{dt} \quad (2)$$

Where $\mathrm{SOC}_{\mathrm{initial}}$ is the battery initial SOC, and C_{usable} is battery usable capacity. Equation 3 is used to predict the battery current as proposed in [7]. Power required to propel the vehicle, P [Watt] is calculated from series of equations as explained in the section 2.1.

$$\mathrm{I}_{\mathrm{bat}} = \frac{\mathrm{P}}{\mathrm{V}_{\mathrm{bat}}} \quad (3)$$

The calculation of usable battery capacity, C_{usable} [Ah] is conducted by integrating the battery initial capacity, $C_{initial}$ and the capacity correction factor, CCF. The CCF is a factor that takes into accounts the capacity fading effect due to calendar life losses and cycle life losses. The source of heat generation in battery is mainly come from the effect of internal resistance and electrochemical reaction [8]. The process of modelling the effect of electrochemical reaction is complex while their impact is minimum compared to internal resistance power losses [9]. The power losses, P_{losses} and the heat energy generated from this power losses, Q is calculated from equation 4 and 5 respectively.

$$P_{losses} = I^2 . R \quad (4)$$

$$Q = \int P_{losses} . dt \quad (5)$$

This heat energy can be used to calculate the battery temperature using equation 6.

$$Q = m \cdot C_p \cdot \Delta T \quad (6)$$

where, ΔT is the temperature change in battery, m is the mass of battery cell [g] and C_p specific heat capacity [$jg^{-1}K^{-1}$].

Eddaheck *et al.* [10] present the experimental result of the difference of the heat generated during charge and discharge at several current rates (C_{rate}). It shows that the heat generation during charging becomes more significant as the current rates increase. Based on these results, this article introduces coloration between heat generation during charge and discharge through different current rates (C_{rate}) as shown by equation 7 and 8.

$$a \cdot C_{rate} + b = \%_{Plosses} \quad (7)$$

$$\%P_{losses} \cdot P_{losses(disc)} = P_{losses(chrg)} \quad (8)$$

with, a and b are constant, $P_{losses(disc)}$ is the power losses during discharge, and $P_{losses(chrg)}$ is the power losses during charge.

3. Results and Discussion

3.1 Temperature Rise at Different Charge and Discharge Rates (Constant Current Rates)

Figure 1 shows the battery temperature for charge and discharge at C rate of 0.5C, 1C, 3C and 5C under initial temperature of 23°C. Result clearly indicates that the battery temperature is proportional to the amount of current discharged from the battery. Higher amount of current will generates more heat and thus increases the battery temperature.

Temperature during charging process is lower than the temperature during discharge at the same current rate. It should be noted that the higher the current rate, the higher the temperature difference. This indicates that temperature at high charging rate will have a significant effect on overall battery temperature.

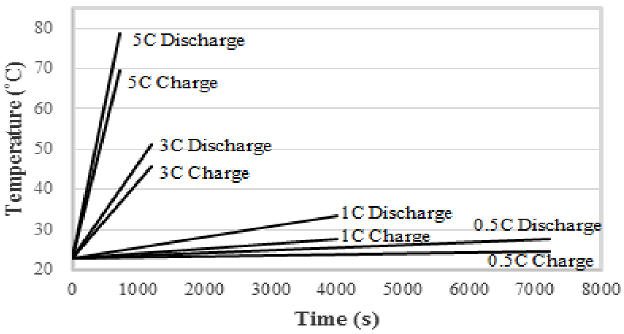

Fig. 1: Battery temperature during different charge and discharge rates.

3.2 Temperature Rise under Complete NEDC Driving Cycle

In series hybrid electric vehicle model, the power needed to propel the vehicle based on given driving cycle is calculated by the vehicle model. The electric motor transforms electrical power from battery into mechanical power to the wheel, while the regenerative braking system is used to charge the battery.

A standard driving cycle, NEDC- as shown in Figure 2 (a) is used to simulate the real driving condition. The HEV is required to complete 20 driving cycles that take 1220s to complete a cycle. During the entire driving period, it is considered that the road surface is dry, air temperature is constant at 23°C, the road is flat (no hill climbing), there is no headwind, and the air pressure remains constant.

Figure 2 (b) shows the total power required to complete a driving cycle. Positive power required indicates that power needs to be discharged from the battery, while negative power is used by generative breaking to charge the battery. Only 20% of braking power is transferred to regenerative braking.

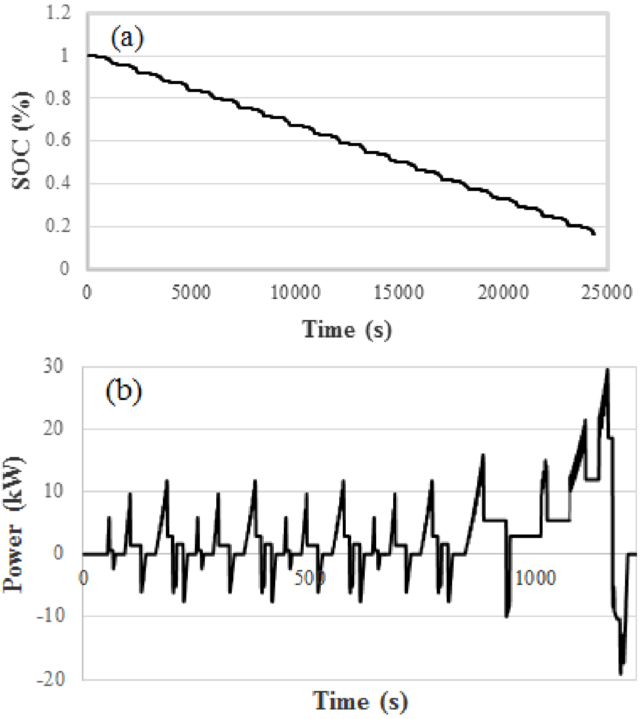

Fig. 2: (a) New European Driving Cycle (NEDC), (b) Power to complete a driving cycle.

After each cycle, battery voltage decreases due to the drop of battery SOC as shown in Figure 3 (a) and (b). SOC initial is set to be at 100 % as the battery is at fully charged and it drops to 25 % after 20 cycles of NEDC driving cycle. The SOC increases slightly during each cycle when power is supplied to charge the battery by energy recovery from regenerative braking. However, for overall condition the SOC continues to decrease because at each repeated cycle the power discharge from the battery is bigger than recovered.

Figure 4 shows battery temperature to complete 20 NEDC driving cycle. The result is divided into two parts; temperature with and without regenerative braking. Without regenerative braking, temperature rises from 23°C up to approximately 30˚C. By considering temperature during charge 2°C of temperature increase is recorded, or 22% of overall temperature increase. This shows that it is important to consider heat generation during charging in the battery thermal model

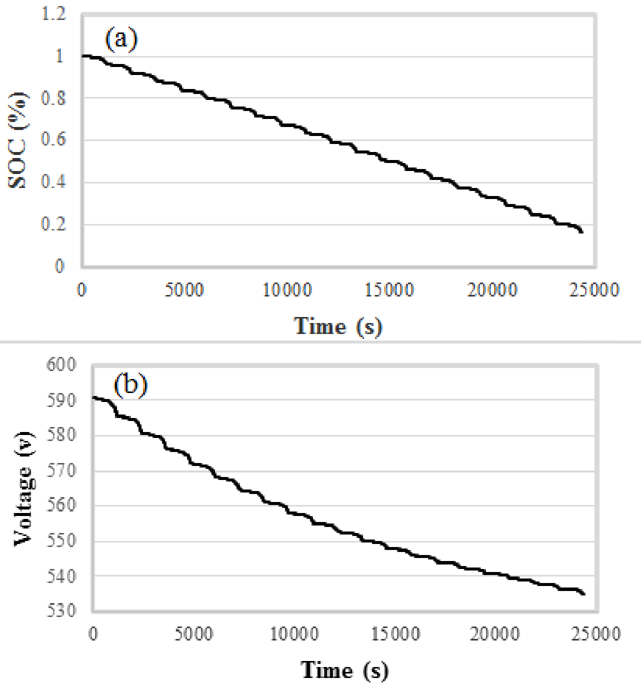

Fig. 3: (a) Battery SOC, (b) Battery output voltage to complete 20 NEDC cycles.

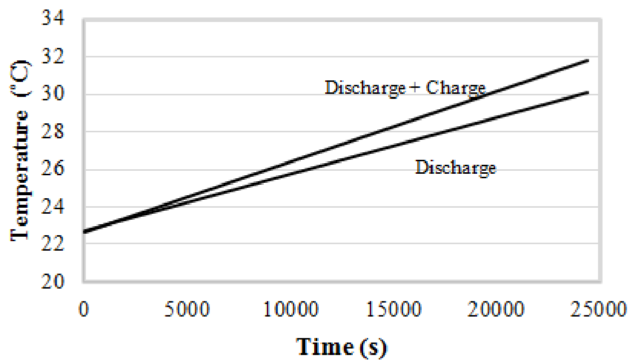

Fig. 4: Battery temperature with consideration heat generation during charge and discharge.

4. Conclusion

In this study, an electro-thermal battery model is used to predict the temperature at different charge and discharge rates. The series HEV model used is capable to predict battery performances such as power required during driving cycles, battery SOC, battery voltage and the battery temperature at various discharge and charge rates. It is shown that the heat generation during charging process is important and need to be considered in battery thermal model.

Acknowledgement

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