Heat Generation Characteristic of High Power Charging for BEV

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Abstract

With the increasing of the long range of electric vehicles, the high power charging technology over 250 kw is urgently needed to reduce the charging time and improve the convenience of using. However, high power charging is more obvious about generating heat than conventional power, which will affect the battery's charging efficiency, cycle life, and possibly even safety risks. Aiming at the above problems, two typical LiFePO₄ (LFP) and Li(NiCoMn)O₂ (NCM) batteries were selected to study the heat production characteristics of energy-based power cells with large power charging based on model and experiment. It is found that the maximum charging capacity of high power charging is greatly affected by the heat management system. Under the condition of forced-air cooling with over 4c-rate charging, the battery heat generation can make battery temperature over 55 degrees, but the water-cooled heat management system can make the battery work in the rated working temperature interval. Under the condition more than 3c-rate charging, the model's parameter mismatch is serious and the temperature difference between inside and outside is needed to be correction to applied to the high power charging strategy of electric vehicle on line.

Keywords: Battery electric car; High power charging; thermal generation; high charging rate; durability

1. Introduction

At present, the model of pure electric passenger vehicle is developing in the direction of high battery capacity and long range. In order to shorten the charging time and reduce the mileage anxiety of the users, the charging power of the whole vehicle must also be raised, and the development of super-fast charging over 350 kw has become the focus of research. With the charging power increasing, the charging voltage and the current are also increasing. Raising the voltage platform of the whole vehicle will bring challenges to the high-voltage system structure and charging system designing. The correlational research results show that increasing the charging rate will also increase the battery's heat production, accelerate the decline of the battery, affect the battery life[1], and may bring safety hidden danger.

Some researchers at home and abroad have studied the thermal behavior of high power charging. Joris[2] et al. have applied 4c-rate charge to NMC batteries and LTO batteries, at 25 °C when constant current constant pressure (CCCV) charging strategy was adopted, the temperature distribution of NMC batteries is uniform, but when the ambient temperature is 10 °C, the NCM battery quickly reaches the upper limit voltage and then the current slowly down meanwhile the charging performance is poor. Liubin Song[3] et Al. studied the effect of charge-discharge rate on the NCM thermal behavior of LiMn2O4 by electrochemical calorimetry. Panos D. PREZAS[4] et al. compared the effect of the two methods of constant current (CC) and USABC fast charge test (FC) on the resistance of the battery at different charging rates. The results show that the resistance is proportional to the charging rate; at the same charging rate, batteries that using a CC charging strategy have higher resistance than the FC. Matthew Keyser[5] et al. simulated the temperature rise of each cell during the 350kW high-power rapid charging (XFC). The results show that the power of the heat management system has a remarkable effect on charging and discharging efficiency.

2. Battery selection and experimental plan of high power charging test

At present, there is not a clear definition of fast charging at home and abroad. In Ref. [6] XFC is defined as charging to 80% capacity of the battery within 10 minutes. In this definition, there is no starting point for battery charging, nor does it take into account the
capacity of the battery. That is to say, for smaller cells that are also charged 80% battery capacity in 10 minutes, smaller battery packs have less charging power than larger battery packs, but may have a relatively short range; Another definition of XFC is charging at more than 20 miles per minute (average)[6]. In Ref. [7], rapid charging is defined as charging 80-90% of the battery capacity in 10 minutes with a minimum range of 95 miles. High Power Charging (HPC) is defined as a charging power of 350 kW[8]. According to the requirement of 500 km pure electric range estimation of high power charging for different capacity power battery, the corresponding charging rate is estimated to be about 4-5C.

The battery heat generation experiment uses a 30Ah LFP battery and a 24Ah NCM from two different manufacturers. The hybrid pulse power characteristic (HPPC) test results are shown in figures 1 and 2.

![Figure 1](image1.png)

**Figure 1** The open-circuit voltage varies with the state of charge (SOC) change curve

![Figure 2](image2.png)

**Figure 2** Internal Resistance of charging 30s varies with the SOC change curve

Put the battery in the temperature chamber under 25°C, with the thermocouple sticked to the battery center; then Do the following experiment on the battery:

1. Discharge the battery at constant discharge current 1C to the discharge cutoff voltage
2. Rest 1 h
3. Charge the battery at constant charge current 0.5C to the charge cutoff voltage
4. Rest 1 h
5. Discharge the battery at constant discharge current 1C to the discharge cutoff voltage
6. Rest 1 h
7. Repeat step 3-6 twice, then replace the charge current 0.5C with 1C/2C/3C/4C/5C and Re-run the experiment separately till the 6 kinds of charge current condition have been finished.

3. Study on the influence of large-power charging on the thermal characteristics of batteries

3.1 Model for estimation of heat production

The battery can satisfy the energy conservation in the process of producing heat:

\[ C_p M \frac{dT}{dt} = -q_n + q \]  \hspace{1cm} (1)

There are three main modes of heat transfer in the battery: Heat Conduction, thermal radiation and convective heat transfer[9]. Considering that in the incubator, the heat transfer between the battery and the external environment is mainly natural convection heat transfer, heat transfer and thermal radiation heat transfer is relatively small, negligible. As a result,

\[ q_n = hA(T - T_i) \]  \hspace{1cm} (2)

So, after substituting formula (1) for formula (2), it is available:
\[ C_p M \frac{\partial T}{\partial t} = -hA(T - T_f) + q \]  

(3)

In this formula, \( h \) is convective heat transfer coefficient, \( A \) is the surface area of the battery, and \( T_f \) is the ambient temperature around the battery. \( C_p \) is the specific heat capacity of a single cell, \( M \) is the mass of a single cell, \( T \) is the surface temperature of the battery, \( q_n \) is the heat transfer power of the battery, and \( q \) is the heat producing power of the cell. In this heat generation relationship formula, the inconsistency of the internal temperature of the battery is ignored.

State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

3.2 Calculation of heat production in battery

The method of extracting the parameters of the Bernardi equation is more direct than that of other heat production models, so Bernardi heat production model is one of the most common formulas[10], the study is based on the Bernardi model. The model assumes that the material inside the battery is uniformly heated. According to the heat production model[11], established by Bernardi et al., it is available,

\[ q = I(U - U_0) + IT \frac{\partial U}{\partial T} \]  

(4)

In this formula, \( I \) is the current, \( U_0 \) is the Open Circuit Voltage, and \( U \) is the battery working voltage.

After formual (3) has been deformed, it is available,

\[ q = I(U - U_0) + IT \frac{\partial U}{\partial T} = I^2R + IT \frac{\partial U}{\partial T} \]  

(5)

In this formual, \( R \) is the total resistance of the battery (including ohmic resistance and polarization resistance), as known as potential impedance; the first item on the right of the equation indicates the heat produced by the internal resistance of the battery during charging and discharging, which includes the joule heat generated by the internal resistance of the battery and the polarization heat due to the loss of the mass transfer. Since this heat is irreversible, it is as known as irreversible resistance; the second represents reversible reaction heat due to the reversible entropy heat generated by the electrochemical reaction of the cell[12].

3.3 Measurement of entropy heat coefficient

Since the entropy heat coefficient \( \partial U/\partial T \) is considered to be constant under a fixed SOC, but it changes with the changing of SOC, it is necessary to test the values of \( \partial U/\partial T \) under different SOC. The variation of \( \partial U/\partial T \) with SOC is shown in Fig. 3.

According to the formula (3), due to the positive current \( I \) in the charging process, when \( \partial U/\partial T > 0 \), the reversible reheat of the battery is positive, that is to say, the reversible reaction of the battery is exothermic;
When $\partial U/\partial T > 0$, the reversible heat yield of the battery is negative, it appears to be heat-absorbing. As can be seen in Fig. 4, for the LFP battery charging process, when the charge state is 10%-20% and 70%-80%, the reversible reaction of the battery is characterized by heat absorption, while the other charge states as heat release. For the NCM battery charging process, the battery absorbs heat up to 30% SOC and releases heats at 40%-60% SOC, then continuously absorbs heat up to 100% SOC.

4. Result analysis

4.1 Heat production model analysis

Fig. 5 is a view showing the total heat generation power of the battery predicted by the heat generation model. It can be seen that the larger the charging rate, the greater the heat generating power of the battery. In the later stage of charging, the heat production power of the ternary battery showed a downward trend, while the heat production power of the lithium iron phosphate battery decreased first and then increased.

![Figure 5](image)

**Figure 5** The total heat output of the battery changes with SOC

4.2 Comparative analysis of experiment and model heat production

The results of the experimental heat production and model heat production are shown in Figures 6 and 7. It can be seen that under the small charging rate, the trend of experimental heat production and model prediction results are basically the same. When the charging rate is large, although the variation trend is similar, the experimental heat production power has a certain lag compared with the calculated value of the model. Sex, and the degree of hysteresis increases as the charging magnification increases. This is because at a large charging rate, the charging time is short, and it takes a certain time for the internal heat of the battery to pass out to the surface of the battery, so that the experimental measurement results show a certain hysteresis. The gap between experiments and simulations of ternary batteries is even more pronounced.
Figure 6 Experimental and simulation results for thermal generation of NCM battery

(a) 0.5C

(b) 1C

(c) 2C

(d) 3C

(e) 4C

(f) 5C
5. Conclusion

The heat generation of high-power charging affects charging efficiency, cycle life, and even safety performance. Based on the above problems, this study carried out simulation and experimental research on large-rate charging and heat generation based on two typical ternary batteries. The preliminary findings obtained are summarized below.

(1) The greater the charge rate, the less charge the battery can charge during the constant current phase. At the same ambient temperature, an increase in the charge rate will result in a higher battery temperature rise and a lower charge and discharge efficiency. At the same charging rate, the lithium iron phosphate battery has a lower charge and discharge efficiency than the ternary battery.

(2) The larger the charging rate, the larger the heat generation of the single cell. When the charging rate is the same, the total heat output of the ternary battery is less than that of the lithium iron phosphate battery.

(3) In the small rate charging process, the main source of heat generation of the battery is reversible heat; in the large rate charging process, irreversible heat becomes the main source of heat generation of the battery.

(4) When the charging rate exceeds 3C, the parameters of the classical heat generation model begin to adapt, and the error increases. It is necessary to carry out multi-temperature field test and increase the temperature difference correction.

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Reference