Research on battery pack fault pre diagnosis method

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Abstract. At present, most of the BMS in the market set a constant fault threshold, but with the increase of the number of power battery recycling, the external characteristics of the battery will also change. A constant fault diagnosis threshold may also occur after battery aging diagnosis is not timely. Battery cell voltage is the direct embodiment of the external characteristics of battery cell, so the fault diagnosis of battery cell voltage is the most important. Too high or too low cell voltage is the most obvious fault. Normally, this should not happen. Of course, due to the gradual aging of the battery pack, the inconsistency between the monomers and the charged state of each cell, the inconsistency of the voltage of each cell can not be avoided. However, the voltage difference caused by cell manufacture or inconsistency is limited in the case of aging degree. Based on the battery discharge data, the purpose of this study is to propose a method to identify the gradual fault signal in advance and reduce the problems caused by the sudden failure of the battery by detecting and diagnosing the change trend of the extreme value difference of the historical operation data.

1. Instruction
With the support of a series of national energy storage policies, the development of energy storage industry in China has entered the fast lane since 2018, especially the release of the “531 New deal” has made the photovoltaic industry fall overnight. Enterprises and experts push the combination of photovoltaic and energy storage to the outbreak window [1]. But behind the hot development, due to battery, PCS quality problems or system integrator construction capacity is mixed, the potential fire risk also followed, energy storage power station fire accidents frequently. Recently, a large number of batteries have been replaced by smoke in the power grid side energy storage power station. The most serious is the burning and burning of lithium iron phosphate battery containers in Zhenjiang Yang Zhong user side energy storage project in early August. After the accident happened, it immediately aroused wide attention in the industry. The safety of lithium battery, which affects the whole industry, is once again on the front road of the rapid development of energy storage industry.

2. Research Status
The detection of lithium ion battery is directly obtained by the size of the voltage, and the voltage and current of the battery are proportional to the amount of electricity, so the charged state of the battery can be known by observing the voltage and current directly. With the development of lithium batteries, the earliest SOC detection algorithms —— the ampere method appeared, and then the open circuit voltage method, load voltage method, internal resistance method and so on appeared one after another. These methods all have relatively large errors. Later, relatively mature methods such as mathematical...
model method and Kalman filter method have been well used. After the emergence of neural network, intelligent control is applied to the on-line detection of batteries\cite{2}. A series of algorithms in the field of intelligent control, such as artificial neural network method and fuzzy control reasoning method, have been well used in on-line detection through improvement. While the current lithium battery on-line detection technology has changed qualitatively compared with this century, the real-time on-line detection of battery SOC and SOH has been realized. However, the current research and industrialization practice is still only the beginning. There is a lack of an academic or industry-approved standard for battery SOC and SOH evaluation and their errors. More importantly, there is a lack of a preventive diagnosis implementation scheme for battery thermal runaway and internal short circuit.

3. Failure Mechanism of Lithium Battery

(1) Internal short circuit fault mechanism

It is important to note that the internal short circuit caused by overcharge does not necessarily trigger thermal runaway immediately. It is possible that the temperature rise of this process is not enough to reach the thermal critical threshold\cite{3}. After the vehicle leaves the charging station, the battery temperature continues to climb and the runaway temperature causes the vehicle to catch fire. The internal short circuit caused by mechanical damage is caused by the extrusion/puncture of the battery when the car collides. This kind of situation is difficult to predict and can only be reduced by appropriate countermeasures.

(2) Fault Mechanism of Overcharge

At present, the fault mechanism of battery overcharging has been studied. When the battery is overcharged, because the storage grid of the negative electrode is full, the subsequent lithium ions will accumulate on the surface of the negative electrode material to form lithium metal.

(3) Fault Mechanism of Over discharge

The primary manifestation of battery over discharge is the destruction of active material structure, which will cause permanent damage to the positive and negative electrodes of lithium battery. The continuous over discharge process will cause the negative electrode potential of the battery to increase continuously\cite{4}. When the negative electrode potential reaches the copper foil collector dissolution potential, the electrochemical reaction of the copper foil dissolution occurs. The dissolved copper ions pass through the diaphragm to the positive electrode of the battery and are reduced to metal copper in the low potential region\cite{5}. The gradually deposited metal copper grows from the positive direction and eventually passes through the diaphragm, triggering a short circuit inside the battery\cite{6}.

However, a large number of fault warning and phenomena are focused on electrochemical research. For lithium batteries in operation, it is difficult to avoid safety risks through existing fault research methods. The lithium battery can only collect the data of voltage, current, temperature and so on. How to directly characterize the fault characteristics of the battery through these external characteristic parameters is the focus of this paper.
4. Fault Identification Steps

Based on the battery discharge data, this experiment puts forward a method to detect and diagnose the change trend of the extreme value difference of the historical operation data, identify the gradual fault signal in advance, and reduce the problems caused by the sudden failure of the battery. Remove outliers Lower outlier, get new indata, output final diagnostic results (normal).

Step 1 deals with the real-time discharge curves of all monomer batteries in the target lithium ion battery, extracts the voltage values of a SOC value of all monomer batteries, and records the voltage range. When the number of voltage range sets is more than 2, the change rate of voltage extreme value difference of i discharge curve is $k_i$, The specific steps indata; recording the data set are as follows: recording the data satisfying a certain SOC±X% condition during the discharge of the battery pack ; $\Delta V_i = V_{imax} - V_{imin}$ The polar difference is calculated and $k_i$ by the formula when $i>2$ $k_i = \frac{\Delta V_i}{\Delta V_{i-1}}$ The change rate of extreme value difference is calculated, in which the $\Delta V_i$ is the voltage dif-
ference under a SOC of the i discharge curve, and the V is obtained Vimax For The maximum voltage at a certain SOC of the i discharge curve, Vimin For The minimum voltage at a certain SOC of the i discharge curve.

The value range of the X is $0.5 \leq X \leq 1$.

The step 4 box diagram determines whether the indata exists Upper outliner. or not. If there is an exception Upper outliner, Step 5; If Upper outliner, does not exist. Determine whether Lower outliner, exists If there is an exception Lower outliner, Step 6. If it doesn’t exist, Then output the final diagnosis (normal), After inputting the indata data set, Using the box diagram to determine the outliers, Where Upper outliner is calculated by formula Upper outliner $\geq Q3+1.5\ IQR$, Lower outliner calculated from Lower outliner $\leq Q1-1.5\ IQR$ formula, Among them, IQR=Q3-Q1, And the Q3 is the upper quartile, About to indata data sets from small to large, First quarter quartile, third (n+1)/4, Q1 is the next quar-tile, About to indata data sets from small to large, A quarter quantile is the number (n+1)/4.

The target lithium ion battery comprises a lithium iron phosphate battery and a ternary material battery. The battery pack can be a battery pack system with multiple cores connected in parallel and then in series. The data includes the voltage value of a SOC value when all single cell discharge. The SOC value can be 0-100% of any SOC value.

5. Experimental verification

The WXL12S537300A power module ladder battery produced by Wan Xiang 123 system Co., Ltd. is subjected to constant current charge and discharge cycle, which is carried out under the condition of 300 A constant temperature, until the battery pack cannot work normally. The experimental results took a total of 3 days, the battery pack was scrapped, and the battery was in a constant temperature state.

From the monomer voltage data of previous discharges, Extract the extreme value difference of battery pack voltage under 50% SOC= condition, Get the voltage extreme difference dataset $\Delta V_{50\%} = \{\Delta v_1, \Delta v_2, \ldots, \Delta v_n\}$, n is the number of cycles. The extreme value difference of discharge voltage of battery pack varies with cycle times as shown in figure 2. The specific time corresponding to the number of discharge cycles is shown in Table 1. Overall, the voltage extreme value difference increases in an orderly manner before the battery pack is completely scrapped, Except for the partial maximum at the 9th

![Figure 2 the diagnostic results of box pattern discharge](image)
discharge and the 18th discharge, affected by external temperature factors; 25 discharge to 28 discharge cycles, the variation rate of the extreme voltage difference increases, especially in the 27th and 28th discharge voltage extreme value difference appeared to deviate greatly from the data set, a sharp rise. Table 3 is the partial detection input and output data of the battery pack from the beginning to the detected fault. The 25th discharge before the fault occurs is early warning.

The historical voltage extreme difference data set of 6 and 13 series battery packets is detected in an orderly manner. Table 2 shows the rate of change of the cycle discharge voltage extreme difference.

Table 1. Number of discharge cycles

| Time          | First day | Day 2 | Day 3 |
|---------------|-----------|-------|-------|
| Number of discharge cycles | 1~8       | 9~17  | 18~28 |

Table 2. Variation of voltage extremes

| Diagnostic object | ki of recession path values | Diagnostic object | ki of recession path values |
|-------------------|-----------------------------|-------------------|-----------------------------|
| Second discharge  | k2=-6.00553                 | 15th discharge    | k15=0.154257                |
| Third discharge   | k3=-0.76985                 | 16th discharge    | k16=1.539707                |
| Fourth discharge  | k4=0.616074                 | 17th discharge    | k17=-0.15378                |
| 5th discharge     | k5=2.002001                 | 18th discharge    | k18=10.00905                |
| 6th discharge     | k6=0.92387                  | 19th discharge    | k19=-4.15778                |
| 7th discharge     | k7=1.07789                  | 20th discharge    | k20=-0.61584                |
| 8th discharge     | k8=1.078129                 | 21st discharge    | k21=-0.308275               |
| 9th discharge     | k9=23.09823                 | 22nd discharge    | k22=-1.07789                |
| 10th discharge    | k10=-17.7088                | 23rd discharge    | k23=0.000238                |
| 11th discharge    | k11=-2.15602                | 24th discharge    | k24=-0.92411                |
| 12th discharge    | k12=0.000477                | 25th discharge    | k25=3.695965                |
| 13th discharge    | k13=-0.76985                | 26th discharge    | k26=3.850699                |
| 14th discharge    | k14=1.385689                | 27th discharge    | k27=18.47982                |

Table 3. Table of diagnostic results of box charts

| Discharge sequence | Input       | Exception value | Diagnostic output | Ondata output |
|-------------------|-------------|-----------------|-------------------|---------------|
| 2                 | k2          | No              | Normal            | k2            |
| 3                 | k2, I3      | No              | Normal            | k2, I3        |
| 4                 | k2, I3, I4  | No              | Normal            | k2, I3, I4    |
| 5                 | k2, I3, I4  | No              | Normal            | k2, I3, I4    |
| 6                 | k2, I3, I4  | No              | Lower outlier=k2  | Delete        |
| 23                | k2, I3, I4  | Lower outlier=k2 | Delete           | Normal        |
| 24                | k2, I3, I4  | Lower outlier=k2 | Delete           | Normal        |
Up to 26 discharge, the detection result is a fault, indicating that the battery pack has a gradual fault, need to be repaired or replaced. In the experimental results of cycle aging, the battery pack carried out 28 discharge cycles before complete failure (unable to charge and discharge normally). The progressive fault detection method based on box diagram in this paper can identify the fault information in advance. This method avoids the safety and economic effects of sudden failure on engineering / system.

It is also found that the battery pack core has obvious bulging phenomenon. After the disassembly and recombination test, the internal resistance of the monomer also reaches the level of 20 Ma, and the internal resistance value is too large.

6. **Conclusion**

In general, the voltage extreme value difference increases in an orderly manner before the battery pack is completely scrapped. Under normal conditions, the change rate of voltage extreme value difference changes smoothly. So, it is feasible to predict battery failure by monitoring the rate of change of battery voltage difference.

**Acknowledgements**

Acknowledgements for the funding provided by the Zhejiang Huayun Information Technology Co., Ltd for science and technology projects (contract number: HYJT/JS-2019-004).

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