Research on Anti-Interference Screening of On-line Measurement of Battery Ageing under Smart Grid Big Data

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Abstract: By analyzing the traditional operation and maintenance mode of substation batteries, the paper proposes a new remote online maintenance and management system for batteries based on smart grids, which changes the traditional maintenance method of using discharge load meters to check offline battery discharge packs. Single battery online voltage inspection, internal resistance test, and dynamic equalization, as well as battery pack remote online verification discharge and equalization charging, real-time monitoring of battery aging, promote intelligent, efficient, and unmanned maintenance battery status in substations, Provide strong technical and program guarantees.

1. Introduction
The battery pack plays an important role as an emergency backup power supply in the substation's DC system. Its operating status is very important to ensure the safe and reliable operation of the power grid. The service life of the battery pack is greatly affected by the operating temperature. The system cannot compensate for the battery voltage, capacity, internal resistance, and other parameters according to temperature changes, resulting in inaccurate measurement data. Besides, the DC system can only monitor the battery pack's voltage and current in real-time, cannot analyze the battery's operating state, and cannot timely assess whether the battery capacity meets the operating requirements [1]. To understand the battery pack's operating status in time, this paper has developed an online monitoring system for the battery pack in the substation (starting now referred to as the "monitoring system"). The system can monitor, collect and store battery pack operating data in real time, and wirelessly send voltage, current data, alarm signals, and aging process to the background software. Operation and maintenance personnel can know the battery pack operating status and transcribe battery pack data at any time through mobile phones. Which not only saves manpower and material resources, but also improves the operational reliability of the DC system.

2. New technical principles of battery aging monitoring and maintenance

2.1. Principle of online test of battery internal resistance
Take the test module as a unit, divide the battery into multiple unit segments, and use the DC discharge method to test the internal resistance of each battery in each unit segment in turn. The test principle is shown in Figure 1.
Figure 1. Principle of online test of battery internal resistance

Based on the four-wire wiring method, the test module controls the discharge resistance $R_0$ through the multiplexer MUX, and then performs instantaneous DC discharge of each battery in the unit section in turn, measures the instantaneous discharge current $I_0$ of each battery, and obtains the voltage $U_{i1}, U_{i2}$ before and after discharge. The voltage drop between $\Delta U_i$ is used to calculate the equivalent internal resistance of each battery using Ohm's theorem.

\[ R_i = \Delta U_i / I_0 = (U_{i1} - U_{i2}) / I_0 \]  

(1)

We set the input sine signal:

\[ V_i(t) = U \cos(\omega t + \phi) \]  

(2)

In the formula: $V_i(t)$ is the input sinusoidal signal, $R_i$ is the equivalent internal resistance of the battery, and $R_s$ is the sampling resistance. Then the voltages across the battery and the sampling resistor are:

\[ V_{r_i}(t) = U_s \cos(\omega t + \phi_{r_i}) \]

\[ V_{r_s}(t) = U_s \cos(\omega t + \phi_{r_s}) \]  

(3)

From the above derivation, it can be concluded that as long as the resistance of the sampling resistor is known, and the sampling resistance and the peak value of the AC signal at both ends of the battery are measured, the equivalent internal resistance of the battery can be calculated, which effectively avoids the use of phase lock amplification to calculate the phase [2].

2.2. Principle of battery dynamic balance

During the charging and discharging process of the battery pack, especially in the supplementary charging of the battery, the charging after the accident discharge and the charging after the check discharge, due to the large charging and discharging current, the equalization effect is slow, and long-term overcharging and undercharging have different performance. Single batteries can cause damage.
Therefore, according to the trend prediction principle, real-time detection of the voltage deviation between each battery and the average cell of the battery pack. When the difference is greater than the set value, it is predicted that the battery may be overcharged or undercharged, and the equalization is involved in advance to avoid causing substantial damage to the battery [3]. This article adopts the high-discharge low-charge balance principle of the bidirectional DC/DC converter, and the trend prediction intervenes in the control strategy in advance to realize the dynamic balance of the battery pack. The balance principle is shown in Figure 2.

![Figure 2. Principle of battery dynamic balance](image)

The high-voltage side of the bidirectional DC/DC converter is connected to the DC bus BM, and the low-voltage side is connected to each battery of the battery pack through the B1-Bn switch. The undercharged single battery is switched on by the B1-Bn corresponding switch and the DC bus BM is supplemented by the two-way DC/DC converter, and the overcharged battery is switched on the B1-Bn corresponding switch to the DC bus BM through the two-way DC/DC converter Perform bypass discharge. In the equalization process, the single battery with the largest voltage deviation is always screened for operation, and so on, to finally achieve the balance of each battery in the entire battery.

3. System Architecture

3.1. System structure
This battery online monitoring system includes two parts: a substation and a master station. The substation refers to the terminal collection equipment of the substation, and the master station refers to the server and server software. The equipment at the substation is mainly composed of a voltage acquisition module, a temperature acquisition module, a discharge module, an internal resistance acquisition module, a control communication module and a display module. The system adopts modular design, the independence between modules is good, the online maintainability is strong, and the online maintenance does not affect the normal operation of the monitored equipment. The station equipment collects the battery pack data and uploads the data to the background server through the MIS network. Operation and maintenance personnel and professionals can view the online monitoring data of the battery pack in real time by accessing the server [4]. The system structure is shown in Figure 3.
Figure 3. System structure

The acquisition device has the following advantages: (1) The traditional battery pack inspection instrument is a common ground system, and voltage fluctuations at the battery terminal or the DC bus terminal will affect the stable operation of the inspection instrument. The acquisition device adopts the optical coupling circuit isolation method, which can completely isolate the grounding of the battery and the single-chip microcomputer, thereby ensuring the stable operation of the monitoring system. (2) The traditional battery pack inspection instrument usually only has one sampling channel. During detection, the battery is connected to the only sampling channel to read the data through the optocoupler relay or solid-state relay. The inspection time for one battery needs at least 10ms. The inspection time of the entire battery pack needs at least 1040ms [5]. If the battery is abnormal during the inspection, it will be discovered at least until the next inspection cycle. The acquisition device is equipped with an isolation optocoupler for each battery as a sampling isolation device. At the same time, it adopts high-performance STM32F4 series single-chip microcomputer, with up to 24 acquisition channels, which can read all battery status information and upload it at the same time the background meets higher real-time monitoring requirements. (3) The acquisition device adopts an integrated design, with functions such as current acquisition, battery parameter detection, remote data upload, background analysis, temperature monitoring, and human-computer interaction. It can monitor 104 batteries at the same time, and the entire device weighs less than 6kg.

3.2. Software process
The parameter detection software in the on-site monitoring point single-chip microcomputer is written in C language, which mainly includes sub-modules such as reading clock information, data transmission, current, voltage, temperature and internal resistance parameters detection and calculation. In the detection of battery operating parameters, the current, voltage, and temperature are tested in turn, and the test results with time stamps are sent to the regional monitoring service center after each test. In order to reduce any possible influence of the sine AC small signal on the battery, the internal resistance of the battery is checked every 2h. During the test, a sine wave is added to the battery, otherwise the sine wave is not added, and the internal resistance test will also be time stamped after the end of the test. The internal resistance information is sent to the regional service centre.
4. On-site monitoring and aging test

4.1. On-site monitoring
A substation uses 2V/104 batteries (model GFM-300, capacity 300AH). The intelligent online maintenance monitoring and management system of the battery is applied to it, and the parameter results obtained from the initial test and retest of the battery are compared and analysed (Table 1).

| Related parameters                      | Initial test | Retest  |
|-----------------------------------------|--------------|---------|
| Battery terminal voltage                | 201.3        | 201.6   |
| Release capacity                        | 90.2         | 145.3   |
| Maximum cell voltage                    | 2.1          | 2.0     |
| Lowest cell voltage                     | 1.9          | 2.0     |
| The highest/lowest cell voltage section number | Section 104, Section 25 | Section 102, Section 80 |
| Average cell voltage                    | 2.0          | 2.1     |

It can be found from Table 1 that under the action of the intelligent online maintenance monitoring and management system, the battery voltage has been increased. For example, the voltage of the 104th battery dropped to 1.9V during the initial test, but the voltage rose to 2.0V after the retest. At the same time, the overall uniformity of the battery voltage and the capacity of the entire battery group have also been greatly improved compared with the initial measurement, mainly because the online maintenance monitoring and management system effectively monitors the voltage of each single cell battery during the discharge process of the DC power supply battery of the power system [6]. It can also detect the backward single battery in the entire battery pack in time, and assign relevant maintenance personnel to carry out targeted inspection and maintenance of the battery, which can not only detect potential battery hazards in time, but also make the voltage of the single battery more balanced, the battery performance and power supply capacity of the entire battery pack will also be significantly improved.

4.2. Accelerated aging test of pool samples
In order to obtain the actual charge-discharge cycle capacity of the sample battery in a relatively short time, the accelerated aging cycle test is performed on each cell under the same working conditions. The basic process of the test is shown in Figure 4, and the test temperature condition is room temperature.

![Figure 4. Battery sample accelerated aging test process and capacity calibration flow](image-url)
The 16 batteries are divided into two groups, of which 11 are in category 1 and 5 are in category 2. The standard deviation $k$ of the accelerated cycle life of the battery is used as the evaluation index of the consistency of the battery cycle life in the group, and the consistency of the random grouping of the batteries is compared with the consistency of the grouping of the scheme [7]. The results are shown in Table 2, which shows that the random separation cycle life of the batteries in each group varies greatly; after clustering and grouping by this scheme, the consistency of the cycle life of the two groups of batteries formed has been improved to a large extent. In addition, according to Table 2, the characteristic average value of type 1 batteries is significantly higher than that of type 2 batteries. This feature can be used to distinguish the cycle life of battery packs: a group of batteries with a larger characteristic average value has a longer cycle life. A battery pack with a smaller characteristic mean has a relatively short cycle life. The above tests verify the effectiveness of the battery screening scheme in this paper, and the clustering results obtained by using this scheme are stable and convenient for engineering applications.

Table 2. Clustering performance analysis and discrimination

| Evaluation index | Random grouping | Mean filter |
|------------------|------------------|-------------|
|                  | Class 1 (1-8)    | Class 2 (9-16) | Class 1 | Type 2 |
| Lstd             | 11.78            | 11.76        | 9.91    | 5.77   |
| Feature mean     | -                | -            | 0.11    | 0.078  |

5. Conclusion

The research and application of battery remote online maintenance and management system has changed the traditional operation and maintenance mode of substation battery, prolonged the service life of battery, improved the safety and reliability of DC power supply system, strengthened substation anti-failure measures, and realized DC power supply system. The large management and maintenance of the DC power system have significantly improved the maintenance level of the DC power supply system, thereby effectively avoiding the occurrence of DC power system accidents, and providing powerful technologies and solutions for promoting the intelligent, efficient and unmanned DC power system of the smart grid support. At the same time, the battery packs screened by this solution obviously have a more consistent cycle life, and indeed have the ability to group new batteries according to the expected cycle life of the battery, which can achieve the expected battery screening goal.

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