A Method of Judging the State Time Point of Mechanical Characteristic Switch

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Abstract. Aiming at the problem of judging the opening / closing time node by directly detecting the switch quantity in the process of detecting the mechanical characteristics of the switch cabinet, this paper puts forward a method to calculate the opening / closing time node with the CT secondary current as the original data. This method through the acquisition of CT secondary side current, current data of any phase, calculating threshold, intercepting alternative data, calculating slope and rate of change, the time node of opening and closing is obtained, solve many scenarios acquisition switch quantity and difficulties, judgement open/close time and the problem of low accuracy of switch performance. Through practical application, compared with the traditional acquisition of switch quantity to judge the opening / closing time node, the method proposed in this paper has universality, low detection difficulty and high judgment accuracy of opening / closing time node.

1. Introduction

With the rapid development of China's economy, the demand for power energy is increasing day by day, which puts forward higher requirements for the reliability, security and stability of power equipment. A large number of switches in power equipment adopt mechanical structure, and there are many problems in the mechanical structure in application. According to statistics, 60% - 70% of the circuit breaker defect or failure is caused by a circuit breaker operating mechanism, mainly including: unsmooth, grease solidification, spring aging, connecting rod shaft fracture, coil turn-to-turn short circuit and closing coil burning etc. [1]. So the switchgear and mechanical characteristic test on a regular basis is to ensure that the switchgear at the right time can the important guarantee of operation in place.

In the process of mechanical performance test of circuit breaker, the performance test and fault judgment of circuit breaker are completed by measuring the key mechanical parameters such as turn-off time, three-phase asynchronous time, reclosing time, bouncing time and so on during the operation process of circuit breaker. It is mainly used in two aspects: on the one hand, it is used for the performance test of circuit breakers before they leave the factory, so as to ensure that the product performance conforms to national standards; On the other hand, it is used for periodic performance test of circuit breakers in operation, so as to ensure timely maintenance and overhaul, and ensure the stability and reliability of high-voltage circuit breakers in operation, which is of great significance to reduce the fault of high-voltage circuit breakers.
Among them, the opening/closing time parameter is an important index to judge the opening and closing performance of the switch cabinet. The existing mechanical characteristics of the opening and closing time node identification mainly through the direct detection and identification of the switch quantity.

In the detection of mechanical characteristics, it is usually necessary to connect the sensor to the auxiliary switch to detect the switch quantity, but the distance between the auxiliary switch and the front-end of the detection of mechanical characteristics is far, and the wiring is difficult. Especially when the monitoring object is the switch cabinet, because of the integrated design of mechanism and circuit breaker, the operation of installing the signal wire on the auxiliary switch is very complex, and the installation is difficult. In addition, the number of auxiliary contacts on the auxiliary switch is limited, and in many cases there are no redundant contacts available [2].

Therefore, when the switch quantity cannot be collected or is difficult to be collected, the information of on-off time cannot be correctly obtained by the traditional method. In addition, when the auxiliary switch is used to measure the switch quantity, the switching time of auxiliary contact is usually used as the point of just opening and just closing. However, the switching time of auxiliary contact and the point of just opening and just closing of the contact have an inherent error that cannot be eliminated, resulting in inaccurate calculation of just opening and just closing.

In this paper, an algorithm is designed to calculate the opening and closing time based on CT secondary current, by calculating the opening and closing time point effectively with CT secondary current information, the problem of accurately calculating the opening and closing time point is solved when the switch quantity information cannot be obtained effectively.

2. Analysis of The Current Situation of Acquisition and Calculation of Mechanical Characteristic Opening / Closing Time Node

At present, there are the following methods for the collection and calculation of the mechanical characteristic opening / closing time nodes [3-6]:

1) Install a current sensor on the auxiliary switch to directly detect the switching quantity. This method can accurately obtain the time point of opening/closing, but the distance between the auxiliary switch and the front end of the mechanical characteristic detection is far, the structural design of the switch cabinet is more and more integrated, the line is difficult, and it is not practical.

2) Through a method of wavelet analysis and Hilbert transform to calculate the rigid separation point and rigid combination point of current data. This method needs to highlight the displacement features with wavelet analysis first, and then extract the signal envelope through Hilbert transform; the calculation complexity is high, the hardware performance requirements are high, and it is difficult to be widely used.

3) Through a calculation method of just opening point and just closing point based on travel sensor. The limitation of this method is as follows: ① The installation of travel sensor is complicated, especially when facing the switch cabinet, it is limited by the space and difficult to realize; ② It can be seen from the results that there is a significant deviation from the ex-factory test monitoring results; ③ The determination of the point of just opening adopts the indirect method, which introduces the inevitable measurement error.

3. A Method for Determining the Time Point of Switching State Based on Secondary Side Current of CT

Based on the judgment method of switch state time point of CT secondary side current, through the collection of CT secondary side current, current data of any phase, calculation threshold, judgment of opening or closing, interception of alternative data, calculation of slope and change rate and other processes, the opening and closing time node is obtained. The basic flow chart is as follows:
3.1. CT Secondary Side Current Acquisition and Threshold Calculation
The current transformer is installed on the CT secondary side of the switch cabinet. When the switch cabinet is opened and closed, the corresponding current waveform can be collected. The current waveform data of any phase can be used as the data source for threshold calculation. This paper takes the current waveform of phase A as an example to illustrate. Take the A-phase current waveform data, take the absolute value of all the data in the data, get the data AbsData, calculate the average value Avg of the data AbsData, and calculate the median value Mid of the data AbsData, and calculate the threshold value through the following formula, laying the foundation for the subsequent judgment of opening / closing action:

\[ T_h = \frac{\text{mid} + 0.5 + \text{Avg}}{2} \]  

(1)

3.2. Judgment of Opening/Closing Action
The data length Len per power frequency cycle is calculated according to the sampling rate SampleRate and system frequency SystemRate, as shown in the following formula:

\[ Len = \frac{\text{SampleRate}}{\text{SystemRate}} \]  

(2)

Figure 1. Flow chart.
In A-phase current waveform Data, the Data with length Len is taken from front to back to calculate the maximum amplitude of SliceMaxAmp. When the switch action is opening, SliceMaxAmp and Th satisfy the following equation:

\[ \text{SliceMaxAmp} > T \cdot h \] (3)

When the switch action is closing, SliceMaxAmp and Th satisfy the following equation:

\[ \text{SliceMaxAmp} < T \cdot h \] (4)

3.3. Calculation of Just Opening Point
When \( \text{SliceMaxAmp} > T \cdot h \), the just opening point can be calculated by the following method:

1) Traverse the data from the back to the front, and find the first point p greater than the threshold Th;
2) Starting from point p, data of length Len*0.3 is selected from Data as alternative data set SelectData;
3) For each data point i in SelectData, the range of i is \([0 \sim Len \cdot 0.3 - 1]\), and the slope is calculated by the following formula:

\[ \text{Slope}[i] = \frac{(\text{SelectData}[i+1] - \text{SelectData}[i]) \cdot 50}{\text{Len}} \] (5)

4) For each data point in SelectData, the rate of slope change is calculated by the following formula:

\[ k[i] = \text{Slope}[i + 1] - \text{Slope}[i] \] (6)

5) Take the maximum value of \( k[i] \) in SelectData and convert i into time according to the sampling rate, that is, the moment of just opening point is obtained.

3.4. Calculation of Just Closing Point
When \( \text{SliceMaxAmp} < T \cdot h \), the just closing point can be calculated by the following method:

1) Traverse the data from front to back, and find the first point q that is greater than the threshold Th;
2) Starting from point q, data of length Len*0.3 is intercepted forward in Data as alternative data set SelectData.
3) For each data point i in SelectData, the range of i is \([0 \sim Len \cdot 0.3 - 1]\), and the slope is calculated by the following formula:

\[ \text{Slope}[i] = \frac{(\text{SelectData}[i+1] - \text{SelectData}[i]) \cdot 50}{\text{Len}} \] (7)

4) For each data point in SelectData, the rate of slope change is calculated by the following formula:

\[ k[i] = \text{Slope}[i + 1] - \text{Slope}[i] \] (8)

5) Take the maximum value of \( k[i] \) in SelectData and convert i into time according to the sampling rate, that is, the moment of just closing point is obtained.
4. Application Case of 110kV Switch Cabinet

4.1. Test preparation
In a 110kV switch cabinet, a current transformer is installed on the secondary side of CT to collect current data during the operation of the switch cabinet. The mechanical characteristic monitoring equipment is composed of 1 monitor, 3 current sensors and background software. The pass-through current sensor monitors the A/B/C three-phase of the secondary side of the CT, and the output of the sensor is connected to the mechanical characteristic monitor through the 2-core cable. Installation schematic diagram and effect diagram are as follows:

![Figure 2. CT secondary side current monitoring.](image)

The installation effect of monitoring instrument is shown in the following figure:

![Figure 3. Monitor installation effect.](image)

The monitoring data of the monitor is transmitted to the monitoring software in the remote server through the network cable, and the current data of the test can be viewed. The software interface is shown as follows:
4.2. Test data analysis

After the arrangement of the mechanical characteristic monitoring system, the power supply of the switch cabinet is restored and the mechanical characteristic test is carried out.

According to the calculation method proposed in this paper, the A-phase current waveform Data is taken as the data source for calculating the threshold value. By taking the absolute value of all the data in the Data, the AbsData is obtained. The average value Avg of the calculated data AbsData is 0.63, and the median value Mid of the calculated data AbsData is 0.77. Through the application of the threshold calculation formula, the threshold value Th is 0.5075;

Next, judge the opening / closing action. The sampling rate SampleRate adopted by the system is 10kHz and the system frequency SystemRate is 50Hz, then:

\[
Len = \frac{SampleRate}{SystemRate} = \frac{10000}{50} = 200
\]  

(9)

Take the data with length Len from front to back, and calculate the maximum value of amplitude SliceMaxAmp = 0.05;

Then the maximum amplitude SliceMaxAmp and threshold Th satisfy:

\[
SliceMaxAmp < Th
\]  

(10)

It can be judged that the switch cabinet moves as closed.

Next, calculate the just closing point. Traverse the data absdata from the front to the back, find the first point q greater than the threshold th is 950, start from the q point, forward to intercept the data with length Len * 0.3 in the data as the alternative data set SelectData, get Slope through slope calculation formula, and get k through slope change rate calculation formula. Take the maximum value of k[i] in the SelectData, the corresponding I is 900. Its corresponding time point is the just closing point. When
the sampling rate is 10kHz, the corresponding time point of 900 is 90ms. According to this, the switch quantity map is drawn as follows:

![Switch Quantity](image)

**Figure 5.** Calculation results of closing time node.

According to the analysis of the CT side current transformer's current map (as shown in the figure below), the current is 0A from 0ms to 90ms, and the three-phase current increases instantaneously and continues at 90ms, indicating that the closing operation is completed at 90ms. The current map measured by CT side current transformer is consistent with the judgment conclusion of the switch state time point proposed in this paper, both of which are 90ms.

![Current of CT](image)

**Figure 6.** CT secondary side current curve.

4.3. Test conclusion

This paper presents a method for determining the time point of switching state of mechanical characteristic. The test results show that it can accurately calculate the opening/closing time of switchgear and provide an auxiliary decision for the diagnosis of testing data of mechanical characteristic of switchgear.

5. Conclusion

In this paper, a method of calculating the point of just opening and just closing by CT secondary current is proposed. The slope and the rate of slope change are extracted by CT secondary current, and then the point of just opening and just closing are calculated by the rate of slope change. The practical application shows that it has the following advantages:

1) It does not depend on the switch quantity information collection, and can accurately obtain the just opening point and just closing point when the switch quantity information cannot be directly collected due to the complex wiring or the auxiliary switch design.
2) The inherent error between the auxiliary contact switching time and the actual just opening point and just closing point is eliminated, and the computational accuracy of the just opening point and just closing point is improved.

3) The mechanical feature acquisition device designed based on the algorithm can save the switch quantity acquisition channel, reduce the design difficulty and design cost.

4) The algorithm design is simple, the computational complexity is small, the computational efficiency is high.

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