Research on Abnormal Identification Technology of Circuit Breaker extinction based on wavelet analysis

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Abstract. Circuit breaker is the actuator of power network fault removal and operation mode conversion. If the circuit breaker itself cannot complete the breaking operation, it may cause the accident impact range to expand, or even cause more serious chain failure. The fault phase current is decomposed based on wavelet analysis and Fourier transform, and the unstructured recorded wave data is converted into structured fault characteristic quantity to realize the analysis of current mutation characteristics. The high frequency characteristic singular value at the occurrence of arc is obtained by wavelet transform, which provides the key characteristic quantity for the identification of abnormal arc extinguishing performance of circuit breaker and realizes the identification of abnormal arc extinguishing state of circuit breaker. Issue an alarm before abnormal expansion of circuit breaker or adverse impact, remind relevant personnel to timely check and deal with defects, reduce the occurrence of abnormal tripping circuit breaker phenomenon.

Keywords: circuit breakers; opening time; fault recording; wavelet transform.

1. Introduction
Circuit breaker is the actuator of power network fault removal and operation mode conversion. If the circuit breaker itself cannot complete the breaking operation, it may cause the accident impact range to expand, or even cause more serious chain failure. Therefore, the "prior maintenance" of power equipment state maintenance research was carried out. The realization of state maintenance includes two aspects: on the one hand, it is to obtain the indicators that represent the state of equipment, such as the moisture content of insulating medium in the high-voltage circuit breaker, the current of the open and close coils, and the open and break times, etc., which are the basis for analyzing whether the equipment has potential faults or not. On the other hand, it is the evaluation of equipment state. According to the data of equipment state indicators, it adopts such theories as gray fuzzy theory [1] and matter-element extension theory [2-3] to evaluate the equipment state, so as to provide support for the next step of state maintenance. The above research has reference significance for the research of equipment condition maintenance. At present, the state maintenance of circuit breakers mostly depends on the data obtained from on-line monitoring, and the reliability and accuracy of on-line monitoring of circuit breakers are still far from engineering practice. At present, the evaluation of circuit breaker state performance is mostly dependent on the monitoring of external sensors. Due to electromagnetic interference and other reasons of measurement results, there is still no effective solution to the problem
of abnormal detection of circuit breaker arc extinguishing in existing technologies. However, the recording information contains abundant transient information, which provides a method for abnormal analysis of circuit breakers.

In this paper, the fault phase current is decomposed based on wavelet analysis and Fourier transform, and the unstructured recorded wave data is converted into structured fault characteristic quantity to realize the analysis of current mutation characteristics. The high frequency characteristic singular value at the occurrence of arc is obtained by wavelet transform, which provides the key characteristic quantity for the identification of abnormal arc extinguishing performance of circuit breaker and realizes the identification of abnormal arc extinguishing state of circuit breaker. Issue an alarm before abnormal expansion of circuit breaker or adverse impact, remind relevant personnel to timely check and deal with defects, reduce the occurrence of abnormal tripping circuit breaker phenomenon.

2. Data acquisition and feature modeling

2.1. Data acquisition

In this paper, the portable recording device [4] is used to obtain the recording information of circuit breaker fault. Portable intelligent recording monitoring system adopts modular design, which consists of analog channel/digital channel acquisition module, management unit module and online analysis monitoring software.

Acquisition module includes direct access analog quantity and switching quantity; SV signal and GOOSE signal accessed through ST transceiver port and LC optical port; FT3 signals accessed through ST single port are decoded and packaged to the management unit through FPGA.

The management unit includes hard disk, memory and photoelectric B code interface, etc. CPU is a high-performance 64-bit MIPS64 architecture four-core 16-thread network processor, based on embedded real-time Linux kernel and its dedicated kernel, which receives and processes the original message from the acquisition module, and then sends it to online analysis monitoring software through Ethernet.

Online analysis monitoring software USES flexible data storage and computing technology to process the information from the management unit and provide a friendly human interface to users. The software runs on both Windows and Linux platforms.

2.2. Feature modeling

Circuit breaker from receiving protection issued by the break signal to the contact separation process, mainly by the operation mechanism and linkage mechanism to complete. The time spent in this process is the time of breaking, which reflects the mechanical properties of the circuit breaker. The time taken from the separation of the contact of the circuit breaker to the extinction of the arc current when it crosses zero is the arc burning time, which mainly reflects the performance of the circuit breaker's arc burning medium. The opening and breaking time is the time from the moment of receiving the opening instruction to the moment when the circuit breaker has no current, that is, the sum of the opening time and arc burning time. When the arc occurs, the conductivity and cross-sectional area of the arc increase with the progress of the ignition arc, which leads to the decrease of the arc resistance value and the large distortion of the transient current. When the fault causes protection and circuit breaker action, it will be recorded in SOE system and credit guarantee system protection action events. Changes in the primary system electrical quantity and secondary channel information will be reflected in the recording file. The abrupt change of arc extinguishing exists in the high frequency information after wavelet decomposition. In the record file, the data association of breaker break indicator is shown in figure 1.
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3.1. Wavelet transform theory

Wavelet transform and Fourier transform are two effective methods for signal analysis. Fourier transform can effectively provide frequency domain information while time domain information is basically lost. Unlike Fourier transform, wavelet transform can obtain signal time information by translating the parent wavelet, while frequency characteristics of signal can be obtained by scaling the width (scale) of wavelet. Therefore, wavelet transform is a signal analysis method in time-frequency domain. The following conditions must be satisfied to be a generating wavelet function.

\[ \int_{-\infty}^{\infty} \varphi(t) dt = 0 \]  

If the signal \( f(t) \) is a real function and the square is integrable, the continuous wavelet transform of the signal can be expressed as:

\[ W(a, b) = \int_{-\infty}^{\infty} f(t) \varphi(t) dt \]  

Therefore, the spectrum of arbitrary accuracy at any time can be obtained only by expanding the parameters \( a, b \). However, due to the large amount of calculation, it is necessary to discretize \( a, b \) and obtain the coefficients of discrete wavelet transform. Discrete wavelet can be expressed as:

\[ WT_j(a_j^k, b^k_j) = \int f(t) \varphi^j_k(t) dt \quad j = 0, 1, 2 \cdots, k \in \mathbb{Z} \]  

The shape of the time-frequency window in wavelet analysis includes two rectangles, namely the time window and the frequency window, which are different from the time-frequency window characteristics of Fourier transform. The center of the time window is \( t \), the center of the frequency window is \( \omega \), the radius of the time window is \( \Delta t \), the radius of the frequency window is \( \Delta \omega \), then the time-frequency window used for signal analysis can be expressed as:
Therefore, wavelet transform overcomes the disadvantage that Fourier transform can only obtain frequency domain information, while time domain information is lost. It can extract information from both time domain and frequency domain of signal.

### 3.2. Critical characteristic quantity

The time domain characteristic of the transient waveform characteristic of fault recording includes the breaking time, the breaking current and the calculated value of waveform distortion point based on wavelet analysis. Characteristic quantities in frequency domain include harmonic maximum, dc content of zero sequence current and harmonic content of zero sequence current.

The opening and breaking time shall be obtained from the moment when the circuit breaker receives the opening instruction to the moment when the circuit breaker has no current, and the corresponding time shall be identified by combining the action information of the circuit breaker protection.

The tripping current mainly obtains the maximum and minimum current.

The calculated value of waveform distortion point based on wavelet analysis is to calculate the singularities index of signal envelope crest according to the transmissivity of modulus maxima on various scales of wavelet transform, which is a characteristic parameter of circuit breaker arc extinguishing anomaly.

Maximum harmonics. In order to eliminate the difference of circuit breaker parameters, the ratio between the actual maximum harmonic and the rated current of circuit breaker is used as the calculation result of the maximum harmonic when calculating the maximum harmonic of zero sequence current.

Harmonic and dc content characteristics of zero-sequence fault current. For the fault current with non-standard sinusoidal waveform, Fourier transform is used to decompose it into a series of sinusoidal sums with positive integer multiples of power frequency. By converting the time domain signal collected by the fault recorder into frequency domain signal, the harmonic and dc content characteristics of the zero-sequence fault current can be analyzed.

Since the current sampling data are discrete values, the discrete Fourier transform (DFT) is used to decompose them into N harmonics.

$$I(k) = \sum_{n=0}^{N-1} i(n)e^{-\frac{2\pi kn}{N}}$$

$$k = 0, 1, 2, \cdots N - 1$$ is the frequency of harmonics, and N is the total number of sampling points in a period.

The fundamental wave component of the zero-sequence current is calculated as follows:

$$I(1) = \sum_{n=0}^{N-1} i(n)e^{-\frac{2\pi n}{N}} = \sum_{n=0}^{N-1} i(n)[\cos\frac{2\pi n}{N} - j\sin\frac{2\pi n}{N}]$$

The dc component of the zero-sequence current is calculated as follows:

$$I(0) = \sum_{n=0}^{N-1} i(n)$$

The dc content of zero sequence current is the ratio of dc component to fundamental wave component:

$$I_o = I(0) / I(1)$$
Since the third harmonic has more obvious characteristics than other subharmonics in arc extinction anomaly, the harmonic content of zero sequence current is the ratio of the third harmonic component to the fundamental wave component:

\[ I_3 = I(3) / I(1) \]  \hspace{1cm} (9)

3.3. Waveform distortion point calculation based on wavelet analysis

In the circuit breaker to open the operation, the dynamic and static contact began to separate, the contact insulation dielectric breakdown produces arc. Since the conductivity of the arc increases with the increase of the current and the arc section also increases, the arc can be equivalent to a nonlinear resistance, and its resistance value has negative resistance characteristics, that is, the resistance value decreases with the increase of the current. At the same time, when the arc is generated, not only the transient current amplitude changes, but also the high-frequency component is introduced. These characteristics are consistent with the fact that wavelet analysis can analyze any frequency component.

The high frequency components caused by current distortion can be extracted by wavelet analysis and the time of occurrence can be determined. The specific method is to judge the position of singular points and the calculation of singular exponent according to the transmissibility of the maximum modulus of each scale of wavelet change. If the maximum modulus of wavelet transform at each scale is set as \( M_i \), then the singular exponent can be approximately expressed as:

\[ \alpha = \log_2 M_{i+1} - \log_2 M_i \]  \hspace{1cm} (10)

3.4. Abnormal Identification of Circuit Breaker extinction

Based on the characteristic quantities constructed above, the trip fault characteristics of 23 circuit breakers in a power network are analyzed. Analyze circuit breaker statistics data and establish circuit breaker time index database. Since the discriminant index of abnormal arc time of circuit breaker is a large sample event, the confidence interval under a certain confidence degree can be obtained, so as to determine whether the circuit breaker is abnormal or not.

Taking one of them as an example, the arc time is analyzed and calculated. The wavelet analysis method is used to analyze the current record waveform of circuit breaker. If the sampling frequency of the recorded waveform is 5kHz, the wavelet decomposition structure and the wavelet decomposition results are shown in Fig 2.

![Fig. 2 Wavelet Decomposition Results](image-url)
According to the transmissivity of the maximum modulus at the singular point, the arc burning time can be determined. Then, according to the protection emitting time, the breaking time and arc burning time analyzed by wavelet decomposition method are 20ms and 4ms respectively. The sample data satisfies the obtained confidence interval, and it can be determined that there is no abnormality in this data sample. If it is outside the confidence interval, it is considered as abnormal break.

4. Summary
In this paper, the fault phase current is decomposed based on wavelet analysis and Fourier transform, and the unstructured recorded wave data is converted into structured fault characteristic quantity to realize the analysis of current mutation characteristics. The high frequency characteristic singular value at the occurrence of arc is obtained by wavelet transform, which provides the key characteristic quantity for the identification of abnormal arc extinguishing performance of circuit breaker and realizes the identification of abnormal arc extinguishing state of circuit breaker. This method provides a new method for identifying the fault of circuit breaker.

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