Study on the Identification of the Signal Component of Circuit Breaker Based on Blind Source Separation

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Abstract. Acoustic analysis is an effective method for fault diagnosis of contacted high voltage circuit breakers. Acoustic signals are often mixed with different perturbations in the circuit breaker’s practical operation within the complex environment. The low frequency disturbance can be fully filtered by filtering equipment. Circuit breaker's error action or running state’s misjudgment may be caused by high intensity and the disturbance noise such as thunder, car horns. In this paper, a new blind source separation method is proposed to identify the signal component of acoustic signal. Firstly, the K-means algorithm is used to estimate the number of blind sources. Secondly, the IMF component is obtained by improving the EEMD decomposition signal, and then the signal is reconstructed to form a new multi-dimensional signal. Finally, the Fast ICA algorithm is used to realize the blind source separation of the signals.

Introduction

High voltage circuit breaker is a very important control function in power system, and its reliable operation is the basis to ensure the uninterrupted power supply of the whole power network. With the construction of strong smart grid, the circuit breaker needs higher reliability. So it’s urgent to improve the operation state of the circuit breaker, and to evaluate the operating state of the operating mechanism of 220kV. A new method for the diagnosis of non - contact type circuit breaker failure is presented in this literature, which overcomes the problem of traditional contact measuring fixture’s installation problem. The method is based on the analysis of homologous vibration and acoustic signal of different frequency of the circuit breaker in the operation process to identify the mechanical state of the circuit breaker. Acoustic signals measurement is non - contact measurement, which makes sensor installation convenient and the signal change frequency band wide. However, air is the propagation medium of sound, which can be disturbed by external noise from the sound source to the sensor easily. The results may not be accurate if we use the acoustic signal to judge the circuit breaker running state, so we need to carry out blind source from sound signal received firstly.

Because of the inherent characteristics of blind separation, the result of the separation has uncertainty on order and magnitude. The source signal number is an important prerequisite for blind source separation. When the number of observed signal M is less than the source number N, it is called the underdetermined blind separation.

The acoustic signal of the actual circuit breaker belongs to the underdetermined blind separation. At present, the underdetermined set blind source separation method has no mature experience in the field of circuit breaker status identification. This paper aims at judging the development trend of high voltage circuit breaker; its estimation of the blind source number, improved blind source separation method which combined analysis of acoustic signal and vibration signal and finally improved the accuracy of fault diagnosis and state identification of circuit breaker.
Process of Blind Source Separation of Acoustic Signal in Circuit Breaker

In the normal operation of the circuit breaker, the weak vibration of different amplitude can be generated by the electric current. Meanwhile the acoustic signal with different intensity can be generated. As well the operation of circuit breaker will produce a very strong acoustic signal and vibration signal. Though the frequency may have discrepancy, the two kinds of signals are transformed by the sensor. They are homologous generated. There must be a certain correlation which can be used for the circuit breaker operation state of online identification. At the same time there likely to be a high intensity of disturbance in the acoustic signal, and the actual number of potential source signals is unknown, which demand to extract the signal characteristics to blind source separation, and the recovery of each component of the blind source separation directly affects the performance of the circuit breaker.

Process is needed before using the circuit breaker sound signal to judge operation status. This paper proposes a blind source number estimation of the signal blind source separation method. As for the acoustic signal for field acquisition, it is decomposed by EEMD on the basis of estimation of signal source number by using improved clustering algorithm. Then the blind source is separated by reconstructing the IMF component. Finally, the certain sound signal components can be determined by comparing with the signal component of circuit breaker sound signal the prior knowledge base.

Blind Source Separation Based on The Improved Eemd-fast Ica

Blind source separation means directly obtaining the required signal components through the observation signal when the source signal information is unknown. Its model description is $x(t)=As(t)$. $t=0,1,...,N-1$ means the time domain sampling point; $A \in \mathbb{R}^{m \times n}$ is the unknown mixing matrix, which reflects the transmission characteristics of the source signal to the sensor. $U_1,...,U_n$ determined blind source separation in the actual situation is shown as Fig. 1.

Blind source separation algorithm is generally used for processing the problems of non-underdetermined ($m>n$) when the blind source number is known. The above chart shows that a separate matrix $W$ needs to be constructed to make $y(t) = wx(t) = wAs(t)$. $w= [w_1, w_2,... w_m]$ is a extraction weight vector of m-dimensional. $y(t)$ is a source signal recovered by this method. All of the source signals are extracted by n times, but the signal sequence after separating is not consistent with the original sequence. In other words, the separation sequence is not determined. Fast independent component analysis (Fast ICA) algorithm is one of the most common methods in the field of blind source separation in recent years, which is mainly based on Newton iteration method for the objective function optimization. However, the direction of the iterative algorithm is not necessarily down, so the convergence is unknown when initial point is far away from the pole. In order to overcome this problem, Damped Newton method has been introduced, increasing one dimensional search in the iteration direction of Newton method. Its iterative formula is shown as equation (1).

$$\begin{align*}
\lambda_\alpha &= \min_{\lambda} f \left( x^{(k)} - \lambda d^{(k)} \right) \\
\lambda^{(k+1)} &= x^{(k)} + \lambda^{(k)} d^{(k)} \\
d^{(k)} &= -\frac{1}{\lambda^2} f^{-1} \left( f^{-1} f \left( x^{(k)} \right) - \lambda d^{(k)} \right)
\end{align*}$$

(1)
‘λₖ’ is called damping factor. ‘ρ’ means the second-order partial derivatives of the function. ‘/’ means the first-order partial derivatives of function. The objective function optimization solution can be achieved by Loop iteration.

Usually when in the acquisition of circuit breaker signal m equals to one (m for the number of the sensors), which is underdetermined. In this paper, in order to use Fast ICA algorithm for blind source separation, the original signal is decomposed into multiple IMF components by using the improved EEMD method. Then, the separated IMF component is composed of a new multi-dimensional signal, and its dimension is equal to the number of sources. After such a process, the new signal is satisfied with the precondition of using Fast ICA algorithm. In EEMD method white noise is added before the signal is decomposed by EMD method, thus the phenomenon of the mode mixing can be improved. In this paper, the improved EEMD method mainly adds the median filter processing of the residual function r(t) in the process of the decomposition, so it can more precisely control the end point of decomposition. Median filtering method is a nonlinear smoothing technique, which is based on a theory of the sort. It can suppress noise of nonlinear signal effectively. The output is an ordered set of values.

The main steps of blind source separation algorithm based on improved EEMD-Fast ICA are as follows.

a) Source number estimation. For the collected breaker acoustic signal, the number of signal source is estimated by K-means algorithm which is based on the between-within proportion (BWP) index;

b) Make the single channel observation signal x(t) decomposed by the improved EEMD method. IMF component x_{IMF}=(h_1, h_2,\ldots, h_n, r_n) can be obtained after the single channel observation signal is decomposed.

c) Compose new multi-dimensional signals. Composing IMF components to a new multi-dimensional signal x_{IMF}, and makes its dimension equal to the estimated source signal number.

d) Blind signal separation. For the new multidimensional signal, blind source separation can be realized by the improved Fast ICA method, and the separated source signal y can be obtained.

The Result Analysis of the Blind Source Separation Experiment

The complex noise environment is simulated in the laboratory, and meanwhile the breaker closing operation is being experimenting, mixed acoustic signal is collected.

The estimation of source signal number. Mixed acoustic signal altogether 90,000 data points, using the improved K-means method to estimate the source signal number. The upper limit of signal clustering is \( k_{\text{max}} = \text{Int}(\sqrt{90,000}) = 300 \). The number of particles in the experiment is 10, maximum iteration number m equals to 10. Initial weight \( w_{\text{max}} \) equals to 0.9, final weight \( w_{\text{min}} \) equals to 0.3, learning factor \( c_1 \) equals to 1.5 and \( c_2 \) equals to 2.

Processing results are shown as Fig. 2.
Figure 2. The relationship between clustering number and BWP index.

The Fig. 2 shows that BWP index reaches the maximum when k=3, which is consistent with the previously known information. And what can be seen from the chart, only when k=3 the BWP's value is the largest and is much larger than in other cases. The experimental result shows that the fluctuation of BWP is more stable than that of the K=3. In this paper, k is taken until 20.

Acquisition signal decomposition. The mixed signal is decomposed by the improved EEMD method. In this experiment, the white noise intensity is 0.1 times of the standard deviation of the original signal, and its decomposition results are shown as Fig. 3.

Signal reconstruction and separation. According to the estimated results of (1), the mixed signal is composed of three original signals, so the first three IMF components are taken to form a new multi-dimensional signal $x_{IMF}(t)$. Then the blind source separation is carried out by using Fast ICA algorithm. Although the separated signal has some differences with the source signal in the amplitude and the order, the signal obtained after decomposition is mainly used for the identification of the mechanical state of the breaker, as long as there is no change in the trend, so this method can be used for the prediction of the breakers' state and fault.

After calibrating sound signal time by multiple data amplitude, the mean differences between signal component of solution mixing value and parameters of circuit breaker in quiet environment are calculated. The results are shown as table 1. The acoustic signals of the breaker’s closing sound signal can be estimated by comparison. Then the acoustic vibration analysis is performed to predict the state and key characteristics of the circuit breaker.
Table 1. The average difference between the separated signal and the original signal.

<table>
<thead>
<tr>
<th>signal</th>
<th>(separated signal 1, original signal )</th>
<th>(separated signal 2, original signal )</th>
<th>(separated signal 3, original signal )</th>
</tr>
</thead>
<tbody>
<tr>
<td>the average difference</td>
<td>0.3133</td>
<td>-0.0010</td>
<td>0.0037</td>
</tr>
</tbody>
</table>

Conclusions

The disturbance of the acoustic signal is one of the key steps in the joint analysis of the acoustic vibration of circuit breaker. In this paper, an improved EEMD-Fast ICA algorithm is proposed, which can be more accurate to calculate the number of unknown mixed signal source, as well shorting the computation time of the number of clusters. The mind decomposes the single path signal and then composes the multidimensional signal to the blind source separation. The problem that the number of signal acquisition sensor in the actual is less than the mixed signal is solved. The make Fast ICA is made better used in the blind separation of the circuit breaker mixed acoustic signals as mentioned above. It provides a basis for the multi information fusion of the external characteristics of the circuit breaker, as well as the identification of the mechanical state and the prediction of the fault trend.

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References


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