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Abstract- **For rail traction transformer operation may have a failure, using the V/V wired traction transformer model, this paper presents a method based on Fast independent component analysis (ICA) algorithm to monitor the traction transformer of this model. And the traction transformer input and output voltage signal data collected, to get I2 and SPE statistics, to achieve high-speed traction transformer operation in real-time monitoring.**

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I. Introduction

The railway is the great artery of the national economy. It's safe and reliable rapid development is of great significance to speed up the process of national modernization and promote economy and society. In recent years, with the gradual improvement of high-speed rail traction system, there has been wide usage of high-speed rail traction transformer [1]. Therefore, it not only makes the high-speed rail traction transformer failure is coming out one after other, but also poses a hazard to the system. Therefore, how to monitor the traction transformer operation and how to diagnose its fault in time, these problems have become important in research of traction transformer fault diagnosis. Accurate and real-time detection of the fault state of traction transformer, high-speed rail traction system for the efficient and safe operation is of great significance.

In recent years, with the development of data-driven [2] fault diagnosis technology, fault diagnosis of high-speed rail traction system has provided a lot of valuable reference ideas. Based on the expert experience and the model-based fault diagnosis method, the fault diagnosis method based on data can avoid the uncertainties of system modeling, the shortcomings of unknown interference and the difficulty of obtaining expert experience. It can improve the fault diagnosis method the ability to detect faults, and is convenient in practical application. Based on Fast ICA [3] algorithm, the fault diagnosis of high-speed traction transformer derives from the data-driven fault diagnosis method. This paper presents a method of fault diagnosis using the V/V wiring [4] model of the high-speed traction transformer and the Fast ICA algorithm [5]. The simulation results show that the algorithm has high resolution and precision, It is of practical value for fault detection of high-speed traction transformer.

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II. High-Speed Iron Traction Transformer & Fault Diagnosis

V/V type wiring is the two single-phase transformer to V-shaped connection, two transformers secondary winding, each with one end connected to the traction substation two-phase bus. The other end connects to the rail back to the return line. By connecting two single-phase transformers to the three-phase power system in a V-way, each traction substation can be powered by a two-phase voltage of a three-phase system. Turn three-phase voltage of the power system into traction power supply of two-phase voltage power supply.

The so-called fault diagnosis is the operation of the equipment and abnormal circumstances to make judgments, which consists of fault detection, fault separation and fault identification. Specifically, it refers to fault separation and fault identification. With the success of China's high-speed railway has been completed, traction transformer fault diagnosis made a higher demand, that is quick detection of transformer latent fault, and identification of the type of failure. Therefore, it is of great practical significance to study a complete fault diagnosis system of traction transformer, which can deal with the latent fault and reduce the economic loss. Fault diagnosis of traction transformer is a nonlinear mapping process from fault information to fault type, which cannot be described by the precise mathematical model, and it is difficult to obtain a large number of fault samples when the transformer fails. Therefore, the traditional fault diagnosis method has limitations in application.

III. Fault Diagnosis of Traction Transformer based on Fast ICA Algorithm

V/V type wiring is the two single-phase transformer to V-shaped connection, two transformer-secondary-windings, each with one end connected to the traction substation two-phase bus. The other end connects to the rail back to the return line. By connecting two single-phase transformers to the three-phase power

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ICA algorithm has been a new statistical signal processing method developed in recent years. Compared with the traditional methods, ICA algorithm has the following advantages: it is not necessary to assume that the measured data satisfy the Gaussian distribution when modeling. The independent composition of the ICA algorithm can not only remove the relevance of the variables, but also describe the process characteristics with high-level statistical information. The number of independent components to be processed by ICA algorithm is less than that of principal component analysis. It chooses the Newton iteration method as the optimization algorithm for fast speed, no need of selecting the step parameters, easy to use and so on. Given this, this paper mainly uses Fast ICA algorithm to capture and process the voltage signal of the traction transformer and establish the monitoring statistic to diagnose the failure of the traction transformer.

Fast ICA algorithm[6], also known as fixed-point (Fixed-Point) algorithm. Fast ICA is an efficient algorithm for independent component analysis, invented by Aapo Hyvärinen at Helsinki University of Technology, which is a fast optimization iterative algorithm. Despite ordinary neural network algorithm, it uses a batch approach, which means a large number of sample data is involved in each step of operation. Fast ICA algorithm includes several forms such as kurtosis, the maximum likelihood, the largest negentropy, and etc. This paper is based on the largest negentropy, which uses the largest negentropy as a search direction to extract the independent source, fully embodies the projection tracking (Projection Pursuit) this traditional linear transformation of the idea. Also, the algorithm uses a fixed-point iteration scheme maximizing non-Gaussianity as a measure of statistical independence, which is faster than conventional gradient descent methods for ICA.

The matrix model of ICA algorithm is,

$$X = AS + E \tag{1}$$

There are d components in the input signal source,

$$S = [s(1), s(2), \ldots s(d)]^T \tag{2}$$

Which are independent of each other, the observed signal is mixed signal matrix

$$X = [x(1), x(2), \ldots x(m)]^T \tag{3}$$

There are m of mixed signals, this mixed signal is the actual observation signal. A is the mixed coefficient matrix with m rows and d columns, E is the error matrix with m rows and n columns, where n is the number of sampling points. The estimation of the active signal is,

$$\hat{S} = WX = WAS \approx S \tag{4}$$

We can see that W and A are the mutually inverse matrix. The objective of the ICA is to obtain the separation matrix W and the independent component matrix S from the observed signal X in the case where the quantities of the source signals are independent of each other.

Because the Fast ICA algorithm takes the largest negentropy as a search direction, we first discuss the negentropy criterion. From the theory of information theory, we can see that the entropy of Gaussian variables is the largest in all random variables of equal variance, so we can use entropy to measure non-Gaussian, common entropy correction forms, that is negentropy. According to the central limit theorem, if a random variable X is composed of many independent random variables Si(i=1,2,3,...N), as long as Si has a finite mean and variance, the random variable X is closer to the Gaussian distribution, regardless of its distribution. In other words, Si is more non-Gaussian than X. Thus, in the separation process, the independence of the separation results can be expressed by the non-Gaussian measure of the separation result, and when the non-Gaussian measurement reaches the maximum, it indicates that the separation of the individual components is completed.

Negentropy Ng(Y) is defined by

$$N_g(Y) = H(Y_{Gauss}) - H(Y) \tag{5}$$

Where Y Gauss is a Gaussian random variable with the same variance as Y, H() is the differential entropy of the random variable.

$$H(Y) = -\int p_Y(\xi) \lg p_Y(\xi) d\xi \tag{6}$$

In the above equation, $p_Y(\xi)$ is the probability density function. According to the information theory, the random variable of Gaussian distribution has the differential entropy in the random variable with the same variance. When Y has a Gaussian distribution, $N_g(Y)$. The higher the non-Gaussian property of Y, the smaller the differential entropy, the value of $N_g(Y)$, so $N_g(Y)$ can be used as a measure of the non-Gaussian property of the random variable Y. Since the probability density distribution function that needs to be known for calculating the differential entropy according to equation (6) is obviously impractical, so the following approximate formula

$$N_g(Y) = \{E[g(Y)] - E[g(Y_{Guass})]\} \tag{7}$$

Where E[·] is the mean operation, g(·) is a nonlinear function, take it as $g_1(y) = \tanh(y)$

$$g_2(y) = y\exp(-y^2/2) \quad g_3(y) = y^3 \tag{8}$$

ICA optimization algorithm consists of two parts

Step 1: Preprocessing of Observed Data

At first, the signal is de-centered. Removal of the center is to make the mean of each vector zero. The variable itself is subtracted from the mean. After normalization, the center of the data is divided by its own standard deviation to make each variable equal weight for preventing a variable in the process of accounting for a dominant position. In practical applications, according to the actual situation of operation, each variable is given a different weight to get more targeted results.

Step 2: Whitening

The first step is to whiten the data, which can remove the correlation between the observed signals and reduce the computational complexity, thereby makes the convergence of the algorithm better.

Let the random variable x the k^{th} sample value be x(k), the covariance matrix is:

$$R_x = E(x(k)x^T(k)) \tag{9}$$

The characteristic value of Rx is decomposed into

$$R_x = U\Lambda U^T \tag{10}$$

The whitening transformation matrix is:

$$z(k) = Qx(k) \tag{11}$$

$$Q = \Lambda^{-\frac{1}{2}} U^T \tag{12}$$

From the whitening transformation matrix can be obtained:

$$z(k) = Qx(k) = QAs(k) = Bs(k) \tag{13}$$

Where B is an orthogonal matrix and has a relation:

$$E(z(k)z^T(k)) = BE(s(k)s^T(k))B^T = BB^T = I \tag{14}$$

It appears that the operation of ICA becomes simplified by whitening transformation. The problem of solving ICA is simplified from matrix A to solving quadrature matrix B, and the estimation of source signal is:

$$\hat{s}(k) = B^T z(k) = B^T Qx(k) \tag{15}$$

Combining formula (4), which can be obtain,

$$B = (WQ^{-1})^T \tag{16}$$

The Fast ICA Algorithm is:

Step 1: The observation data X is centered so that its mean is zero.

Step 2: And whiten the data $X \to Z$.

Step 3: Select the number of m components to be estimated, set the number of iteration $p \leftarrow 1$.

Step 4: Choose an initial (e.g., random) vector b_p possessing a unit norm.

Step 5: Set

$$b_p = E\{Zg(b_p^T Z)\} - E\{g'(b_p^T Z)\} b_p \tag{17}$$

Step 6: Do the following orthogonalization

$$b_p = b_p - \sum_{j=1}^{p-1} (b_p^T b_j) b_j \tag{18}$$

Step 7: Normalize

$$b_p = b_p / \|b_p\| \tag{19}$$

Step 8: If it is not converged, go back to Step5.

Step 9: Let $p = p + 1$. If p is not greater than the desired number of m, go back to Step4.

IV. Theoretical Analysis & Simulation

First of all, to create the simulation model with MATLAB / SIMULINK (Fig.1):

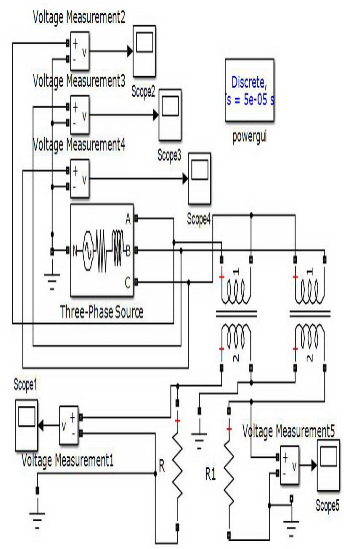

Fig. 1: Correct Simulation Model

Secondly, offline modeling. The mixed signal matrix X = [x (1), x (2), ... x (m)] T is taken as the signal observation point in the Fast ICA algorithm. The matrix is m rows and n columns, Where m is the number of observed signals. In this model, m is the number of observation vectors m = 5, and n is the number of sampling points, and X is the actually observed signal.

Thirdly, establish historical statistics. Here in the Fast ICA fault diagnosis method, the two most widely used statistics, I^2 statistics and Squared Prediction Error (SPE) statistics, are used to monitor whether the process is normal or not. The I^2 statistic is used to measure the system change of the process, whereas The SPE is used to measure the random variation, and the I^2 and SPE statistic with reasonable control limits can detect different types of faults. Therefore, this method combines the two statistics for better monitoring effect. Combine the formula (16), The estimation of the mixed signal by independent component analysis is:

$$\hat{x}(k) = Q^{-1} BWx(k) \tag{20}$$

The error of the estimated and actual value of the mixed signal is:

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$$e(k) = x(k) - \hat{x}(k) \tag{21}$$

You can get the SPE statistic expression as:

$$SPE(k) = e(k)^T e(k) \tag{22}$$

The I^2 statistic expression is:

$$I^2(k) = \hat{s}(k)^T \hat{s}(k) \tag{23}$$

By substituting the collected historical data into the above formula, there can get the historical statistics during operation.

And then the traction transformer system for real-time data acquisition is to monitor the data, the monitoring data for pretreatment. The standardized data is decomposed by ICA to compute the corresponding I^2 and SPE statistics, and is compared with the control limits obtained in the historical statistical data. If the statistics are not exceeded, the system is running normally. If the statistics are overrun, the system is faulty.

In MATLAB, the model of the high-speed traction transformer, which simulates the V/V wiring, is used to monitor the voltage signal of the input and output. The monitoring signal is a mixed signal and the observation signal. And then after collecting 500 sampling points, as shown in Fig.3 below, which input and output signals have five sampling points. Add a short circuit fault to Fig.1 above, As shown in Figure Fig.2 below. In the Fig.2, the phase A and phase B of the V/V traction transformer input phase are interrupted. And then continue to sample this simulation, the same collection of 500 sampling points, sampling diagram shown in Fig.4, then use the 1000 sampling points as Fast ICA algorithm in the signal observation points.

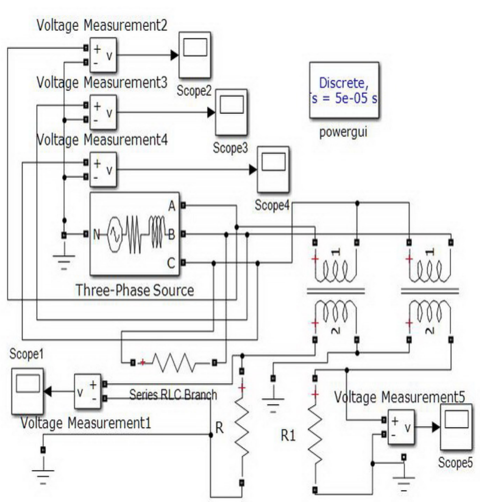

Fig. 2: Fault Simulation Model

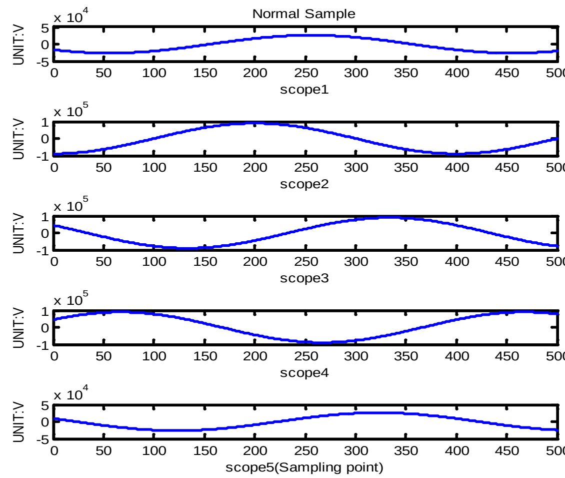

Fig. 3: Normal Operation Sampling Signal

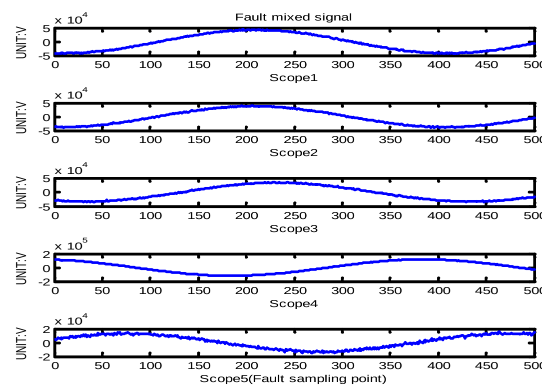

Fig. 4: Fault Sampling Signal

The monitoring data were pretreated, the standardized data were ICA decomposition, Calculate the corresponding I2 and SPE statistics to compare it with the control limits obtained from historical statistics. It reveals that a failure has occurred after the 500th sampling point, as shown in Fig.5 below.

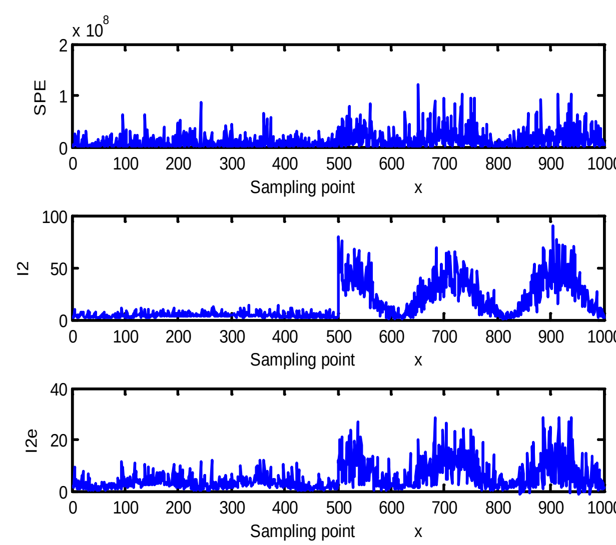

Fig. 5: Fault Simulation Model

V. Conclusion

The Fast ICA algorithm based on the maximum negative entropy criterion is used to analyze the data in the precision range, and the I and SPE monitoring statistics are calculated by Fast ICA algorithm. In the data simulation experiment, the waveform was also successfully monitored for failure.

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