Application of vibration analysis in the condition monitoring of electrical equipment

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Abstract

Condition monitoring of power equipment has become an important research direction of fault diagnosis, then vibration signal analysis technology plays an important role. This paper introduces the research status of vibration signal analysis technique, the emphasis is placed on the main research method in the condition monitoring, fault diagnosis of vibration signal. Through the comparison of several vibration signal de-noising method, focuses on the analysis of the operation state of electric equipment through vibration signal.

Keywords: vibration signal, power equipment, fault diagnosis

1 Introduction

Operation state of electric equipment of power grid on the system safety is very important. The previous domestic use off-line routine test and operation for regular maintenance of electrical equipment, this planned maintenance of frequent operation, reliability and excessive disassembly maintenance will reduce the operating electrical equipment. In recent years, state detection technology has been widely attention of power equipment manufacturers and the power sector. Condition based maintenance to the field staff to provide the equipment running information in real time, fault prediction possible, thus assist engineer to make optimal maintenance scheme. Vibration analysis is an additional means of detection, through the installation of vibration signal acquisition process equipment in operation in one or more vibration sensor device surface, feature information extraction time or frequency domain, and then using the method of fault diagnosis of some use to evaluate equipment working state.

We can extract the feature information of equipment operation status more and more rich from vibration signals with the development of signal processing technology [1]. In addition, the vibration sensor has small size, light weight, convenient installation, reliable work and low price, very suitable for online detection or outdoor temporary testing occasions. Analysis of fault diagnosis using vibration for large rotating equipment such as generators and induction motors, there have been a lot of research results and application examples. In the past ten years, the state of vibration analysis technology in power transformer and circuit breaker detection has been continuously study. At present, application of vibration analysis in these two kinds of power equipment is still in the exploratory stage, but the domestic and foreign scholars generally believe that vibration analysis is a kind of new thinking of research potential, the author mainly introduces some research hotspots in the two fields and methods of analysis of the existing.

2 Vibration detection of generators and induction motors

The generators in the power system and induction motor are large rotating equipment. The common characteristics of this kind of equipment is precision rotor of high speed, automation and complexity of structure are very high, associated with each part of the system is also very close [2]. Malignant accidents in the electric power system due to the generator and induction motor due to a mechanical failure occurred frequently, therefore improve its state detection level has become the common concern of the domestic and international problems. All the time since, the vibration detection are the main means of state of generator and induction motor detection, to obtain diagnostic information equipment through the analysis of vibration signal of rotor. This is mainly because the rotor is an important component of the devices, the manufacturing cost is very high, so in the state detection should be the primary object; secondly because many equipment failures will be reflected in the running state of the rotor changes. The actual rotor vibration signal is very complex, mainly for the axial of the rotor, radial and torsional vibration [3]. These kinds of vibration often exist, therefore need to be respectively measured by different vibration sensor. The former two kinds of movement belongs to linear vibration, for their detection using acceleration sensor in general can be. As for the torsional vibration, is usually measured by the rotor speed fluctuation, so it belongs to the vibration velocity measurement. In addition, to detect the induction motor stator winding fault, non-uniform air gap and voltage disturbance by vibration analysis, in recent years also have the relevant reports.

Since proposed in fault diagnosis of rotating machinery, vibration signal analysis method of corresponding constantly change rapidly [4]. At present a comprehensive report of literature, including to analysis techniques: vibration signal filtering and noise reduction; transient analysis (waterfall, Potter diagram, Nyqist diagram, order etc.). Time domain analysis (envelope analysis, correlation analysis, statistical analysis, analysis of orbit and so on). Frequency domain

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analysis based on Fourier transform (amplitude spectrum, power spectrum, spectrum, the envelope spectrum, cepstrum etc.). Time-frequency analysis (short Fourier, Wigner, Cabo transform). AR model analysis of vibration signal.

The development of frequency analysis and wavelet theory to further improve the technical level of the fault diagnosis of rotating equipment [5]. Especially the powerful ability of wavelet transform in signal time scale characteristic analysis, feature extraction, singularity detection and noise filtering area, so its applications in the field of fault diagnosis of rotating machinery are developing rapidly. The literature on Laplace wavelet to identify modal parameters of large hydraulic turbines, has obtained the ideal effect; through the singularity index calculation of the wavelet transform, which is used as features identification index of the signal envelope [6]. On the application of wavelet transform in fault diagnosis of rotating machinery, gives a good summary. In addition, other new methods and new theories are constantly attract people, such as signal blind source separation, fractal, chaos. In the fault diagnosis and decision making, statistical analysis, cluster analysis, neural network, information fusion, fuzzy theory and other methods have been applied and the continuous development. In recent years, some scholars proposed the support vector machine, Bayesian network based on the concept of intelligent diagnosis, further increase profits detection system adaptability.

3 Vibration testing transformer

A. Vibration test of the core and winding.

The core and winding fault is the common fault in transformer. Power transformer in the stable operation, magnetostriction vibration caused by iron core, winding will produce vibration in the load current under the action of electric field force. Closely related to compaction condition, vibration and transformer winding and iron core transformer surface displacement and deformation state, so it can pass through the surface of the oil tank of power transformer vibration detection to monitor the working status of the core and winding [7].

From the beginning of twentieth Century 80 time metaphase, American, Russia and other countries in the laboratory to detect winding and iron core vibration signal state of the preliminary study. The main transformer is in offline condition, sinusoidal signal respectively with the low voltage excitation signal and power at high voltage side of the transformer, and then measuring the vibration signals of the surface [8]. The research work in foreign countries mainly in the following aspects:

1) The relationship between the vibration signal and the size of the load current;

2) Modeling parameters of load current, temperature and vibration signal of transformer considering;

3) During normal operation, considering only the load modeling of current and the vibration signal of the transformer;

4) Parameters on vibration signal (effective value, frequency spectrum amplitude) research trend

5) Best installation location of the vibration sensor.

The basic work is performed in the off-line situation, focus on how to consider the vibration signal of transformer

model is established, and this method is used for online detection of problems which should be considered not related to the. The late 90's Chris in twentieth Century, K et al proposed ideas through the detection of the transformer oil tank surface vibration signal to analyze and judge the core and winding condition. But so far, the vibration detecting transformer winding and iron core in the world only Russia had just entered the practical stage, the developed system has been used in more than 60 sets of large transformer. Transformer field results also confirmed that this method is applicable to a variety of models, fault diagnosis accuracy rate up to 80%~90%. The deficiency is not physical characteristics of winding and core vibration are fully studied, such as winding vibration and winding pressing situation. The relationship between the core vibration cause and effect factors, noload voltage on core effect of vibration, the surface of the oil tank is different along with the vibration signal of the similarities and differences between, so the analysis also need to run the more experienced judgment. In addition, vibration signal analysis is limited to the via Fourier transform to obtain the spectrum, in the form is too simple.

China started late in this area, the main work is still in the stage of lab research. The literature [9] through the establishment of mathematical model of winding vibration, on the relationship between the winding vibration and core pressing condition are studied. Aiming at the vibration cause core, studied the magnetostriction and its influence factors. The experimental method is: vibration of core tested in the no-load voltage is different, the corresponding relationship between the study of no-load voltage and core vibration and the similarities and differences between the surface of the oil tank under different conditions of each phase of the core vibration signal. Experiment showed that: the normal running of the transformer and the transformer winding or core fault vibration signal, the surface is very different. But only from the changes of vibration signal in time domain, it is difficult to form a certain criterion to evaluate the extent of the size of transformer faults, so the wavelet packet timefrequency decomposition is applied to the processing of vibration signals, so as to get the energy feature vector of vibration signal, the feature vector as an important basis for judging whether there is fault of iron core. In addition, the surface vibration signal of transformer at different load current were measured, the relationship curve by fitting the load current and the fundamental frequency component of vibration signal, get a load current method to obtain core fundamental frequency vibration signal components without noload operation can. Laboratory simulation tests show the validity of this method.

B. Vibration detection of On-load tap changer.

On load tap changer (OLTC) is the only moving part in the transformer. Statistical analysis showed that, OLTC anomaly is another major cause of operation fault of transformer. The OLTC switching operation contains a series of mechanical motion events. Typical events (such as contact collision) vibration signals generated, not only can sign the contact points, may also contain the three-phase contact period, whether level off, whether the contact surface is in place and operating components jammed switch status information. Foreign related detection device and field operation condition have been reported in the literature. Some transformer on-line detection device in the country also gradually

joined the vibration sensor, but both at home and abroad, the impact of the relevant OLTC working state of vibration signal detail, are also studied [10].

For comparison, this method will first be accurate alignment of the envelope signal under different conditions on the time axis. In fact, because of large amount of random noise is always present signal captured in the field, so that the application of this method is restricted by the. The event start time (Literature) and morphological analysis for OLTC state detection, to determine the OLTC state by comparing the vibration event change time and amplitude, and achieved very good results, but there is no reports of the application in the field.

The literature [11] envelope analysis of vibration signals of the normal state of OLTC, and then extract the average large test as the state testing standards. Through comparing the difference between vibration signal envelope to judge whether the OLTC normal in the fault state. For comparison, this method will first be accurate alignment of the envelope signal under different conditions on the time axis. In fact, because of large amount of random noise is always present signal captured in the field, so that the application of this method is restricted by the. The event start time and morphological analysis for OLTC state detection, to determine the OLTC state by comparing the vibration event change time and amplitude, and achieved very good results, but there is no reports of the application in the field.

The literature [12] based on Bengtsson C and others in the intelligent recognition of the state of the OLTC have made a lot of research work. First of all, smoothing the multi-scale analysis of vibration signal envelope using wavelet, and then calculate the various states of the signal envelope autocorrelation function as state characteristic quantity, with the state characteristic quantity to train self-organizing mapping neural network (S0M) as the basis of fault diagnosis. During operation, calculated the minimum quantization error of the vibration signal, through the comparison and the normal value to judge the running state of OLTC.

The energy entropy is a method of positioning system in a certain state, it is a measure of the degree sequence is unknown. For the vibration of high voltage circuit breaker, a variety of normal state is pulsating a standard normal state, the fault state can be thought of as different mutations in this standard normal state. First of all, the IMF envelope signal along the time axis are divided into N segments, and the signals of each segment by segment energy time integral calculation:

$$Q(i) = \int_{t_{i-1}}^{t_i} \left| A(t) \right|^2 dt \ . \tag{1}$$

In the Equation $i = 1,2,...,N$, t_{i-1}, t_i is the i segment starting and ending point of information. The envelope of the signal energy of each segment were normalized:

$$q(i) = \frac{Q(i)}{\sum_{i=1}^{N} Q(i)} \ . \tag{2}$$

According to the energy entropy theory, Empirical mode (EMD) decomposition of signal $x(t)$:

$$H = -\sum_{i=1}^{N} q(i) \lg q(i) \ . \tag{3}$$

TABLE 1 The Euclidean distance between the energy entropy

The fault type	Euclidean distance
The fault signal A_1	0.8463
The fault signal A_2	0.7895
The fault signal A_3	0.8537
The fault signal B_1	1.2569
The fault signal B_2	1.2967
The fault signal B_3	1.3023
The fault signal C_1	1.4879
The fault signal C_2	1.5033
The fault signal C_3	1.4932

Kang P et al developed on the basis of a set of OLTC based online detection system vibration analysis. Using the analysis software on the PC machine, can accurately identify and OLTC: fault on the sudden change. 11/33kV transformer substation has been installed in a plurality of the current system, the results of application show that, the system can correctly reflect the running state of OLTC, such as aging, contact spring failure and loose parts etc.

In recent years, the literature [13] and the continuous wavelet transform (CWT) applied in the OLTC state recognition of. Because the wavelet transform has good characteristics in time domain, multi scale refinement, so it can extract the local features of more information from vibration signals. The result of field operation shows that, the CWT method not only can make the correct judgment on OLTC fault contingencies, make the right evaluation but also on the OLTC deterioration degree and remaining life, thus formulates the reasonable maintenance plan.

4 Vibration detecting of circuit breaker

According to the practice of statistics at home and abroad for high voltage circuit breaker, the breaker in the accident, which belongs to the mechanical, causes most (fault). Among them, agencies refused classification, closing and maloperation accounted for the vast majority of. Therefore, to improve the detection method of mechanical fault circuit breaker, have very important sense to identify potential risks in advance.

The fault diagnosis for high voltage circuit breaker has a good application prospect by mechanical vibration signal in the process of operation. But due to mechanical vibration signal can be obtained during its operation, so the number of signals is obviously insufficient, the method of signal processing and accuracy are demanding. Analysis and treatment of almost all the circuit breaker vibration signal of research concentrates on vibration signal. Twentieth Century since 90 time, foreign made a lot of research work in this area, so far has identified a number of vibration signal processing method is more practical, mainly concentrated in two aspects.

In the signal generation, propagation and characteristics analysis, literature [14] of experimental research and analysis of large amount of field data. Study on some basic problems of circuit breaker mechanical vibration detection, such as acceleration sensor installation, the choice of measurement point and the vibration signal repeatability, and adopts the dynamic time warping (DTW) technology to achieve fault diagnosis of circuit breaker. On this basis, analysis of vibration for high voltage circuit breaker is developed, the site has been applied to the 145KV SF_6 of the circuit breaker status detection, can be on the operating mechanism of bad

lubrication, improper installation, crank position moving contact insulating rod length inappropriate common fault make correct judgment. Combined with the parameters of contact travel and coil current, but also can realize the comprehensive evaluation of the mechanical state of the breaker.

In feature extraction volume, a research team at the State University of New York American a method is presented to identify the vibration signal characteristics. Through several groups of data measuring circuit breaker in normal state and the tested condition, calculation of single parameter RR as a characteristic quantity of state recognition [15]. The research team includes the main signal processing technology: 1) short time spectrum analysis; 2) correction of spectral analysis; 3) modified structure; 4) the time of accident; 5) envelope analysis; 6) morphological analysis. On this basis, developed a portable breaker vibration signal detection system (PCPDS). The literature [16] show that: this system has been applied in the 115kV and above the oil circuit breaker and SF_6 on the circuit breaker, can successfully identify the crank arm is shortened, excessive wear of the contact spring compression, and buffer failure of mechanical fault.

In recent years, to explore the correspondence between mechanical vibration signal detection circuit breaker and circuit breaker mechanical state in theory began to some foreign research institutions. Some new signal processing method has been widely used in this field. The literature [17] the wavelet analysis and neural network are applied to the vibration analysis of the circuit breaker, by choosing suitable wavelet function to extract the feature vector representing different states of the circuit breaker, and then as the input of BP neural network, so as to realize the recognition of different fault types. The method is used in the 66kV oil circuit breaker status detection, result shows that the correct recognition rate reached 100%, significantly higher than the traditional Fourier analysis and single neural network identification results.

At present, the circuit breaker status detection and fault diagnosis of machinery vibration signal is still in the exploratory stage based on domestic, the main content of this study focused on the development of vibration signal acquisition, vibration signal processing method and diagnosis expert system. In twentieth Century 80's and 90's, the Tsinghua University electrical engineering and applied electronic technology system of circuit breaker mechanical vibration signal had preliminary research and achieved certain results. On the basis of experiment and Study on the circuit breaker of the vibration signal, the vibration analysis is applied to high voltage circuit breaker online status detection, and developed the corresponding state detection device (literature). In addition, the analysis method of vibration signal of circuit breaker hall had detailed research, put forward some practical algorithms, including:

1) The amplitude method and the cross-correlation method to extract appear different vibration events back when, to judge the mechanical status of the circuit breaker according to each of the vibration event time changes, also can calculate the amplitude of each of the vibration signal, and a small amount of calculation, clear physical meaning.

2) Application of Wigner distribution are combined on the time-frequency analysis of vibration signal. The analysis can reasonably describe the time-frequency characteristic of the circuit breaker vibration signals more than the traditional

Fourier analysis. The disadvantage is the large amount of calculation, in determining the characteristic quantity also has certain difficulty.
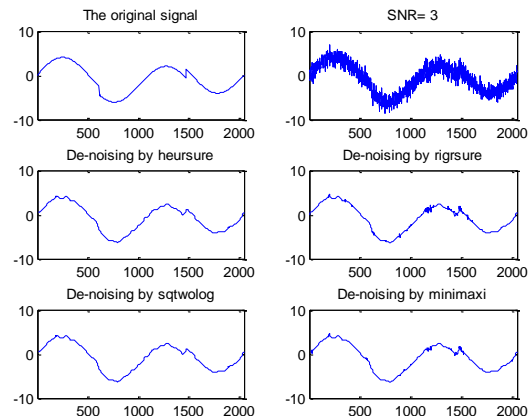

FIGURE 1 The distribution of Wigner joint time-frequency analysis of vibration signal

3) The vibration signal with a group delay of exponential decay oscillating description, 4 characteristics of each frequency component values are determined by curve fitting (amplitude, attenuation index, angular frequency and starting time), compare to normal signal parameters and the. The study found that, when there are more random noise signal, the calculation accuracy of the method is restricted, and later on the basis of mathematical analysis, the above model method has been improved, put forward with the singular value decomposition (SVD) method, to a certain extent, improve the ability of restraining noise.

4) Research on the propagation process of vibration signal of circuit breaker in operation process, so the method is proposed to process the vibration wave propagation is described by using signal phase frequency characteristic and phase frequency characteristic, through the analytical signal and vibration signal corresponding to the analysis method of the vibration event, get an identification in time mixed with each other.

Mechanical failure of high voltage breakers not only can cause vibration event time shift, but also caused the changes of some crest shape in time domain. The literature [17] is proposed for fault diagnosis of square wavelet singularity index based on the river, can well describe the circuit breaker vibration signal time-frequency characteristic, in the open and close to the singularity index: local feature for vibration signal envelope to characterize the signal, determine the type ten fault changes according to the degree of the index. At the same time, the fuzzy wavelet singularity index,. Multi scale feed forward neural network are combined to get a new diagnosis method - fuzzy Singular neural network. Tests prove that, the fault diagnosis accu-racy of this method can reach 90%, is a good way to improve the fault diagnosis process of the emergence of distinguishing the inaccuracy and uncertainty.

Xi'an Jiao Tong University electrical equipment and electrical insulation National Key Laboratory in recent years also started the research work in this field [18]. According to the characteristics of vibration signal of circuit breaker

operation, studied several vibration signal processing method is practical to the bow, the circuit breaker vibration signal characteristic extraction method is the member shall.

1) The Euclidean distance between the concept of vector in mathematics based on Euclidean distance. This method is simple, small computation

2) Integral parameter method can effectively be subtle changes in the vibration signal reflected, at the same time, eliminate the dispersion of the same state of multiple measurement, characteristics of vibration signals can express multiple parameter combination.

3) Signal entropy method. The concept of entropy in information theory based on entropy calculation through the signal, vibration signal, are established to describe vibration signal under different conditions.

4) The short-time energy method. Advantages of short-time energy method is effective to eliminate the effect of noise signal, can extract the starting time of vibration events from the field complex electromagnetic environment, improve the event time resolution. Analysis of the vibration signal of the closing test method is applied to the vacuum circuit breaker, load accurately obtained under the three-phase contact closing time, and thus calculate the state under different mechanical closing simultaneity and closing time state parameter.

5) Based on the algorithm of wavelet packets, the circuit breaker operation the vibration signal is decomposed into independent band, variations of the signal energy in different bands reflect the breaker machinery operating state change. Extracting frequency band energy as the feature vector of main circuit breaker status monitoring, and to determine the variation range of the energy eigenvector of the different states according to the test results, thus achieving a simple classification of different circuit breaker status. Repeated experiments show that the method has higher precision state detection.

In a variety of signal characteristic quantity analysis method that as the basis, studied the application of artificial neural network in circuit breaker status recognition, we propose an improved RBF neural network, the network can not only recognition of known state, but also through the neural network self-learning ability, to recognize the new state, thereby greatly improving the detection system identification ability.

Method for analysis of the vibration signal and related tests are performed in the lab, but mostly in the offline simulation of different state of circuit breaker. Circuit breaker in

the load operation, influence of the mechanism will be between the contacts of electric power. For short circuit breaking under the influence of electric power to the vibration signal, the current lack of relevant analysis experiment. In order to better vibration analysis method is extended to the online application, should be strengthened in the future research work in this area, the field data as much as possible to obtain the circuit breaker to be analyzed and compared, in order to constantly improve the practicability of these methods. In addition, the correspondding relation between the mechanical state of the breaker and feature, has been a common challenge the circuit breaker status detection, in the future research should be paid more attention.

5 Conclusions

Extracting the characteristic parameters of suitable is always the most important issue facing the vibration analysis of power equipment. Wavelet transform can decompose signal into the time scale domain, having excellent properties of time-frequency localization analysis, very suitable for non-stationary signal analysis therefore has become a common method to analysis of various power equipment vibration signal.

On load tap vibration switches and circuit breakers are non-stationary signal in the transient of transformer, so not many methods of rotating equipment to apply, to a certain extent also limits the application of vibration analysis and development in these two areas, the focus of future research is still looking for a suitable signal processing method.

In the aspect of fault diagnosis, artificial neural network because of its powerful self-learning ability and the ability of parallel processing has been widely applied. However, in the field of the transformer and circuit breaker status detection equipment status, lack of a large number of samples is the main factor that restricts the neural network practical training method, therefore it is necessary to find a better.

Acknowledgments

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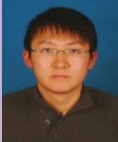
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