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Research on Reactor Condition Evaluation Method Based on Acoustic Vibration Characteristic Parameters and Weight Factors

Peng-fei JIA [1,*], *Shu-guo* GAO[2], *Xing-hui* ZHANG[3], *Ling-ming* MENG[2], *Li-hua* LI[1] and *Yang* YANG[1]

[1]China Electric Power Research Institute, High Voltage Research Institute, 15 Xiaoying East Road, Qinghe, Haidian District, Beijing, China
[2]Electric Power Research Institute, Hebei Electric Power Co., Ltd, 238 South TIYU street, Shijiazhuang, China
[3]Equipment Management Department, State Grid Corporation Limited, 86 West Chang'an Street, Xicheng District, Beijing, China

Abstract. Compared with the traditional reactor abnormal state detection method, the acoustic vibration detection method combines the advantages of acoustic detection and vibration detection, which has the advantages of simple installation, strong portability and good signal integrity, and has a broad application prospect. In this paper, the characteristic parameters of reactor acoustic vibration, including sound pressure level, sound power level, acoustic signal spectrum, vibration amplitude, vibration acceleration value, vibration signal spectrum, harmonic proportion and frequency complexity, are obtained to analyze the range and distribution rule of each characteristic parameter under long-term operation condition of reactor, and the weight factor of each characteristic parameter is determined by analytic hierarchy process On the basis of fuzzy reasoning, the state evaluation model of reactor is established.

1 Introduction

The acoustic vibration measurement of the reactor in operation can detect many abnormal states that do not endanger the insulation and do not cause changes in electrical quantities, such as internal and external parts loosening[1]. However, most scholars at home and abroad regard the acoustic signal generated by reactor operation as noise, and the research purpose is mostly qualitative or quantitative research on reactor noise reduction, rarely taking vibration and acoustic signal of reactor as effective means of abnormal state detection[2].

As the carrier of mechanical state information, acoustic vibration signal of high-voltage shunt reactor contains rich characteristic states. How to extract vibration characteristics to express the mechanical state of transformer is the key to analyze the vibration signal, and it is also a research hotspot for a long time[3].

Compared with the traditional reactor abnormal state detection method, acoustic vibration signal detection method has its own advantages in various aspects of application[4]. Compared with the partial discharge detection method, acoustic vibration detection method can detect the mechanical fault which does not cause the change of electrical signal. At the same time, there is no electrical connection with the main circuit, so the detection method is safer. Compared with the frequency response method for detecting winding deformation, live detection can be realized without shutting down the transformer. Acoustic vibration detection method combines the advantages of acoustic detection and vibration detection. It is easy to install, has strong portability and good signal integrity, and has a broad application prospect.

According to the working state of reactor and the stability of vibration signal, the vibration signal can be divided into steady-state vibration signal and transient vibration signal. The steady-state vibration signal is the external performance of the mechanical state of the reactor in the stable state, while the transient vibration signal is mainly the vibration of the reactor in the sudden situation[5]. The time domain analysis methods of steady-state vibration signal mainly include waveform analysis, correlation analysis, envelope analysis, and frequency domain analysis methods mainly include amplitude spectrum analysis, power spectrum analysis, wavelet analysis and high-order spectrum analysis.

In this paper, the characteristic parameters of reactor acoustic vibration, including sound pressure level, sound power level, acoustic signal spectrum, vibration amplitude, vibration acceleration value, vibration signal spectrum, harmonic proportion and frequency complexity, are obtained to analyze the range and distribution rule of each characteristic parameter under long-term operation condition of reactor, and the weight factor of each characteristic parameter is determined by analytic hierarchy process On the basis of fuzzy reasoning, the state evaluation model of reactor is established.

2 Acoustic fingerprint extraction of reactor acoustic

* Corresponding author: jiapengfei@epri.sgcc.com.cn

From the practical point of view of the existing robot inspection system:

During the operation of the reactor, the acoustic signal and vibration signal are both nonstationary signals. Even in case of fault or abnormal operation, acoustic signal and vibration signal are also unstable. There will be multiple curves in time domain, and the original signal contains various components with different frequencies. Therefore, time-frequency analysis is needed to extract acoustic vibration fingerprint of reactor.

In this paper, Hilbert Huang transform method is used to obtain the non-stationary acoustic and vibration signals of reactor in time domain and frequency domain, and then the harmonic proportion and frequency complexity in frequency domain are extracted. The differences of characteristic quantities between different manufacturers, different voltage levels and different types of reactors are analyzed, and the acoustic fingerprint database is established by selecting the characteristic quantities which can effectively distinguish different reactors. The core of this part is HHT algorithm.

In HHT algorithm, firstly, two envelope lines are established by cubic spline according to all local maxima and local minima of signal $x(t)$. Reestablish signal data $y_1(t)$:

$$y_1(t) = x(t) - \mu_1 \tag{1}$$

μ_1-mean value of envelope

Judge data $y_1(t)$ whether conforms to the intrinsic single mode component IMF, if data $y_1(t)$ does not meet the IMF conditions, and Y is redefined according to the above formula $y_1(t)$ until $y_1(t)$ satisfies the IMF condition, $c_1(t) = y_1(t)$, $c_1(t)$ As the first IMF component of signal $x(t)$, represents the highest frequency component of signal $x(t)$.

Remove the high frequency component C from the signal $x(t)$. A new original data $r_1(t)$ can be obtained by $c_1(t)$ is:

$$r_1(t) = x(t) - c_1(t) \tag{2}$$

Put $r_1(t)$ as the original signal data, the separation process is repeated to obtain the IMF component $c_2(t)$, n IMF components obtained by repeated calculation n times can be recorded as follows:

$$r_1 - c_2 = r_2 \tag{3}$$

$$r_{n-1} - c_n = r_n \tag{4}$$

Cycle until $c_n(t)$ or $r_n(t)$ satisfies the termination condition such that the function $r_n(t)$ until it is a monotone function.

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n(t) \tag{5}$$

Among them, $r_n(t)$ is a residual function, indicating an average trend of the signal, while the IMF component $c_i(t)$ contains the information of each frequency band of the signal. Each frequency band contains different frequency components and varies with the signal itself.

The IMF component is transformed into HHT:

$$H\left[c_i(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{c_i(t')}{t-t'} dt'\right] \tag{6}$$

Construct analytic signal

$$s(t) = c_i(t) + jH[c_i(t)] = a_i(t)e^{j\varphi_i(t)} \tag{7}$$

Instantaneous amplitude function

$$a_i(t) = \sqrt{c_i^2(t) + H^2[c_i(t)]} \tag{8}$$

Instantaneous phase function

$$\varphi_i(t) = tan^{-1}\frac{H[c_i(t)]}{c_i(t)} \tag{9}$$

Available instantaneous frequency

$$\omega_i(t) = \frac{d\varphi_i(t)}{dt} \tag{10}$$

$$x(t) = Re\sum_{i=1}^{n} a_i(t)e^{j\varphi_i(t)} = Re\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt} \tag{11}$$

Ignore the residual function $r_n(t)$, the expansion of the above formula can be transformed into Hilbert spectrum formula and marginal spectrum formula, which can accurately describe the variation law of signal amplitude in frequency domain and time domain

$$H(\omega, t) = Re\sum_{i=1}^{n} a_i(t)e^{j\int \omega_i(t)dt} \tag{12}$$

$$H(\omega, t) = \int_{-\infty}^{\infty} H(\omega, t)dt \tag{13}$$

3 State evaluation method based on acoustic vibration characteristic parameters and weight factors

The state assessment method based on characteristic parameters and weight factors is essentially a reactor state assessment method based on signal processing. In this project, fuzzy analytic hierarchy process (FAHP) combined with variable weight model based on equilibrium function is considered to establish the state evaluation model of reactor. The evaluation model consists of five parts: establishing characteristic parameter set, dividing state grade, determining weight factor, determining membership function and fuzzy operator, and determining state evaluation level.

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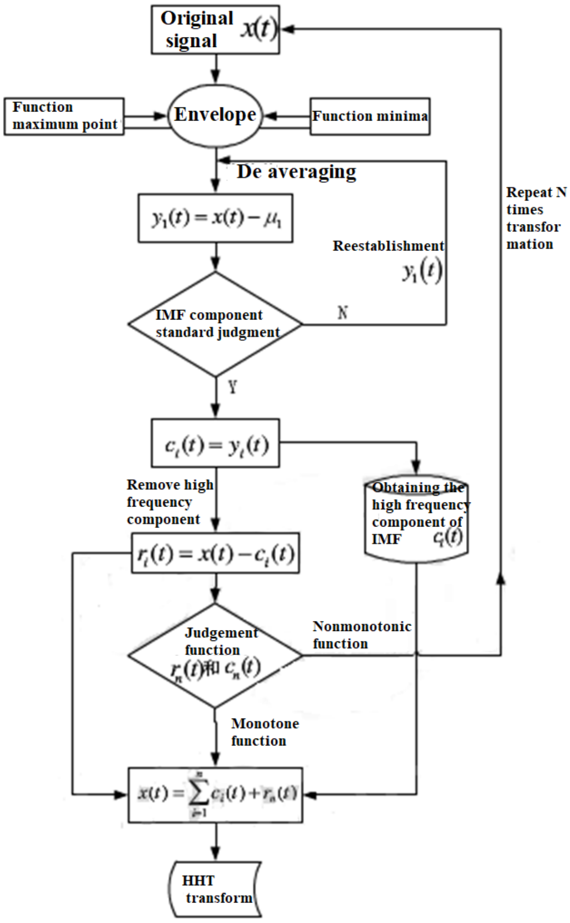

Fig. 1. Flow chart of HHT transform algorithm

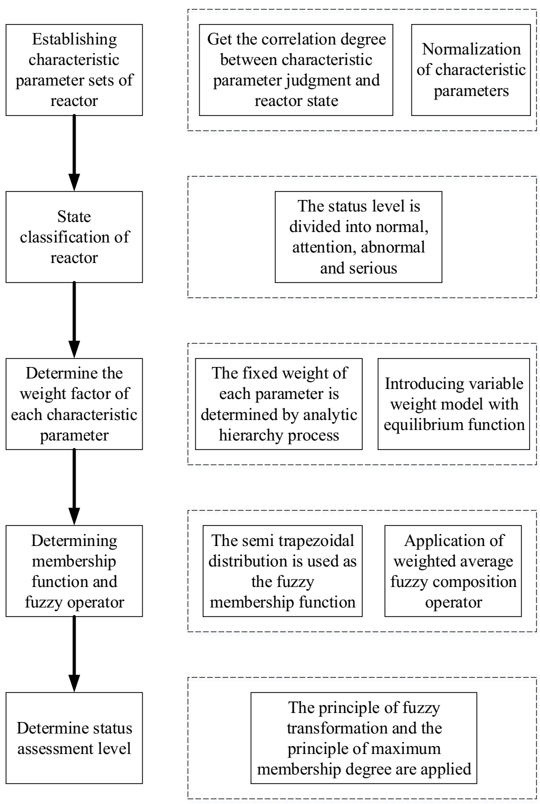

Fig. 2. State **evaluation** method based on characteristic parameters and weight factors

1) The characteristic parameter set of reactor is established, which is the nth evaluation characteristic parameter and N is the number of evaluation factors. The parameters including sound pressure level, sound power level, acoustic signal spectrum, vibration amplitude, vibration acceleration value, vibration signal spectrum, harmonic specific gravity and frequency complexity are preliminarily considered. Firstly, the correlation between each parameter and reactor state should be tested, and the parameters with strong correlation degree should be selected as the characteristic parameters of reactor acoustic vibration.

Because the selected characteristic parameters reflect the state and reliability of reactors, in order to avoid the characteristic parameters with small weight not reflected in the overall evaluation when they seriously deviate from the normal value, variable weight method is considered to reflect the reliability of different characteristic parameters. In the evaluation, different characteristic parameters have different orders of magnitude and different dimensions, so normalization is needed. The normalized characteristic parameters are between [0,1]. The processed characteristic parameters are directly brought into the variable weight formula and membership function, which can easily calculate the variable weight of each characteristic parameter and the membership degree of each state level.

2) The evaluation level of reactor state is divided. According to the relevant standards formulated by the State Grid Corporation of China, the reactor condition assessment results are divided into four levels: normal, attention, abnormal and serious, which are represented by Z1, Z2, Z3 and Z4 respectively.

3) Determine the weight factor of each characteristic parameter

In the constant weight evaluation model, the weight of evaluation factors is given according to the amount of information provided by each factor and the sensitivity of reflecting the state. However, in the process of actual state evaluation, the greater the deviation of index parameters from the normal value, the higher the reliability of reactor state, which may be inconsistent with the weight given under the constant weight model It is objective to calculate the weight by mathematical theory. Therefore, the equilibrium function is introduced into the variable weight model to obtain the formula

$$\omega_i(x_1,\cdots,x_m)=\omega_i^{(0)}x_i^{\alpha-1}\Big/\sum_{k=1}^{m}\omega_k^{(0)}x_k^{\alpha-1} \quad (14)$$

Where: x_i is the normalized value of the first evaluation characteristic parameter, m is the number of evaluation characteristic parameters, is the constant weight of the first evaluation characteristic parameter, which is calculated according to the analytic hierarchy process, and is the variable weight of the first evaluation characteristic parameter. In general, the variable weight model is equivalent to the constant weight model when it is not necessary to consider the equilibrium problem of each evaluation characteristic parameter too much, when it is necessary to pay special attention to some evaluation characteristic parameters with serious defects. For the reactor, if some key characteristic parameters deviate from the normal value too much, the overall performance of the reactor will be seriously affected.

4) Determination of membership function and selection of fuzzy operator

Considering the background of reactor condition assessment, considering the convenience of practical operation, the "descending (ascending) half trapezoidal distribution method" is considered as the membership function to determine the degree of each evaluation belonging to different evaluation levels.

The commonly used comprehensive evaluation functions include weighted average type, geometric average type, single factor determining type and main factor prominent type. The fuzzy composition operator of weighted average type is considered.

5) Determination of evaluation level

The comprehensive evaluation is carried out. The fuzzy transformation principle and the maximum membership principle are applied to comprehensively analyze the characteristic parameters in the characteristic parameter set by using the weight and relation matrix. The state grade of the evaluated object is determined by the maximum membership principle according to the calculation results, and then the comprehensive evaluation results are obtained.

4 Conclusion

In this paper, the characteristic parameters of reactor acoustic vibration, including sound pressure level, sound power level, acoustic signal spectrum, vibration amplitude, vibration acceleration value, vibration signal spectrum, harmonic proportion and frequency complexity, are obtained to analyze the range and distribution rule of each characteristic parameter under long-term operation condition of reactor, and the weight factor of each characteristic parameter is determined by analytic hierarchy process On the basis of fuzzy reasoning, the state evaluation model of reactor is established.

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