IMPROVED POWER TRANSFORMER WINDING DEFORMATION FAULT DIAGNOSIS METHOD

HongZhong MA	ZhiHui GENG	Kai CHEN	ChunNing WANG	BingBing CHEN
Hohai University – P.R. China	Hohai University – P.R. China	Jiangsu Nanjing Power Supply Company- P.R. China	Jiangsu Nanjing Power Supply Company- P.R. China	Jiangsu Nanjing Power Supply Company- P.R. China
ma@hhu.edu.cn hhumhz@163.com	gzhji2010@163.com	Kaichen78@sohu.com	wangchunning@sina.com	chenbingseu@hotmail.com

ABSTRACT

According to analysing the generation principle of transformer winding deformation and its impact on the vibration signal, and make a large number of trial, it can be found in addition to the fundamental frequency component that can reflect the failure , the new characteristic frequency which conclude 50Hz frequency component and some of its harmonic components, the harmonic components of the fundamental frequency can also reflect the failure . Transformer winding deformation fault diagnosis method is proposed based on the relationship between the characteristic frequencies, it can not only diagnose whether the failure is inside the transformer windings, but also determine the type of fault. In order to verify the proposed method, deformation faults are set to the actual transformer winding. After de-noising, discounted processing, the acquisition monitoring points of vibration signal are used by the proposed method , and the actual transformer is diagnosed, The diagnostic result is same as actual failure . It is shown that the proposed diagnostic method is accurate and feasible.

INTRODUCTION

The reliability and stability of the power transformer greatly affect the safe operation of the entire power grid [1-3]. There is an urgent need for a method to be able to accurately determine the state of winding mechanical. The using of vibration method to detect the state of the winding mechanical gradually becomes a hot research at home and abroad [4][5]. Compared with traditional methods, the vibration method has no electrical connection with the whole power system, and it has strong anti-interference ability and sensitivity. And it can be a safe and reliable monitoring of power transformers in the state, it has a good application prospect [6][7].

Reference [8] proposes that the base frequency of vibration signal is two times the fundamental frequency of the load current. Therefore, the base frequency of the vibration signal in the transformer winding is 100Hz. And the change of the fundamental frequency is as the basis for judging winding fault. Taking into account the variety of power transformer internal fault can cause changes in the fundamental frequency component. So it cannot achieve the purpose of further determines winding deformation failure. Therefore, the approach has brought a lot of errors to diagnose power transformer winding deformation.

To solve the above problem, we proposed a vibration signal correction model considering the current, voltage, and temperature. Then, based on the variation of the frequency of the vibration in different positions and the energy combination relationship between them, a winding deformation fault diagnosis method was proposed. Finally, use the actual transformer surface of the vibration signal, and the transformer winding deformation diagnostic model to diagnose the transformer before and after failure, to verify the accuracy and feasibility of the model.

VIBRATION SIGNAL ANALYSIS

Because the fundamental frequency of the power transformer vibration signal is twice the frequency of the power base and the grid-based frequency is 50Hz, so the transformer vibration fundamental frequency is 100Hz [9]. Even if there is no fault in the transformer internal, 100Hz component is relatively large, and with changing load [10]. Thus, if only 100Hz increase cannot judge the kind of fault.

Due to the non-linear relationship exists between the transformer B and H, when the transformer winding deformation, transformer vibration may have 50Hz, 150Hz-decile several times harmonic. The study showed that, 50Hz, 150Hz vibration signal components can be used as the basis to distinguish other fault. In addition, when winding internal failure occurs, the high frequency of the vibration signal is also significantly changes. But different faults, the changes in the different frequency components are significantly different, the combination of these features can be further discriminated winding fault type.

OPTIMAL AND CORRECTION

Determine the monitoring point

The theoretical analysis and experimental testing show that according to the internal structure of the transformer

Project supported by Science and technology project funded by State Grid Company, contract number:2011-0810-2251

windings and direction of the force, vibration from the top surface at 1/2 height of the tank, as in the front central radial direction of the tank is the shortest path vibration transmit , and the amplitude is largest[11].

Take into account the comprehensiveness of transformer vibration signal; to reflect the vibration accurately, it is proposed that taking the axial direction of the tank, the top of the tank as a vibration measure position. The measure points on the tank are shown in Figure 1.

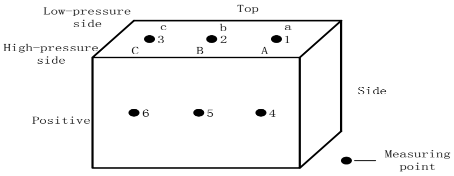

Fig. 1 Acquisition position of vibration signal

Optimal the vibration

The vibration, as well as the results of fault diagnosis will be affected by load voltage, load current, the oil temperature and other factors. Therefore it is important that the vibration should be appropriately modified before analysis.

Winding vibrations are due to electro-dynamic forces caused by the interaction of the current in a winding with leakage flux, so as the current in winding changes, the electro-dynamic forces changes. The transformer's vibration depends on current squared [6], as follow:

$$F_w \propto i^2 \qquad (1)$$

The impacts of the load current need to be considered when diagnose winding conditions.

Core vibration is caused by magneto-striction and magnetic forces. Taking into account the linear relation between applied voltage and flux density, the result is magneto-striction forces being portioned to voltage squared [6], as follow:

$$F_c \propto U^2 \qquad (2)$$

The impacts of the applied voltage need to be considered when diagnose core conditions.

Loss of the transformer windings distributing in the form of heat causes the temperature rise, the variation of temperature of the windings changes with the oil temperature, and there will be a thermal interference of the vibration signal acquisition.

In order to ensure the accuracy of the diagnosis, by the laboratory fault simulation and verification, a model of the transformer tank vibration taking into account the change of current, voltage, and temperature is established as follows:

$$v_{\text{tank},100} = (\alpha + \beta\theta_{\text{t0}}) i_{50}^2 + (\gamma + \delta\theta_{\text{t0}}) u_{50}^2 + \varepsilon\theta_{\text{t0}} i_{50} \qquad (3)$$

Where $v_{\text{tank}100}$ is 100Hz frequency vibration of the tank . i_{50}, u_{50} are 50Hz of the current and applied voltage, θ_{to} is the temperature of the oil, α, β, γ, δ, ε are complex parameters whose value depends on transformer geometry and which must be computed from data measured on the transformer.

METHOD

Energy

After The vibration signal S(t) by the FFT into the frequency domain signal $H(f)$, the energy of each frequency band can be expressed as

$$\mathrm{E}_f = \frac{1}{T}\int_0^T |S(t)|^2 dt = \sum_{m=1}^{n} |X_m|^2 \qquad (4)$$

Where: E_f is the energy of a frequency segment value, X_m（m=1, 2… n）represents the amplitude of the various discrete points of a frequency segment in $H(f)$.

Method

After a large number of experiments, and combined with the variation of each frequency segment after winding deformation fault, when the winding deformation is happened, the amplitude at the original frequency changes. By using this conclusion, a method is designed to detect winding deformation, following these steps:

1) Measuring the normal and fault vibration signal from the top and front central of the tank respectively.

2) Obtain the vibration energy of the fundamental frequency component from the central of transformer positive, if it obviously increases, there will be a fault inside the transformer.

Characteristic values C_1, C_2, and C_3 respectively as follows:

$$\begin{cases} E_{T50} + E_{T150} = C_1 \\ (E_{T50} + E_{T150})/(E_{T100} + E_{T200}) = C_2 \\ E_{F100}/E_{T100} = C_3 \end{cases} \qquad (5)$$

E_{T50}, E_{T100}, E_{T150}, E_{T200} are 50Hz, 100Hz, 150Hz, 200Hz component of the vibration from the top of the tank. E_{F100} is 100Hz component of the vibration from the center of the tank.

Feature vector T is shown as T= [C_1 C_2 C_3], calculation of the normal and fault condition is characterized as vector T_N and T_F.

3) Calculate $\Delta T = T_F - T_N = [\Delta C_1\ \Delta C_2\ \Delta C_3]$ at the measuring points 1, 2, 3, if ΔC_1, ΔC_2, ΔC_3 are positive, it can be determined the transformer internal winding deformation failure exists.

4) If one of the three measurement point on top of the tank satisfies the following equations:

$$\begin{cases} \Delta C_{1n} = \max\{\Delta C_{11},\ \Delta C_{12},\ \Delta C_{13}\} \\ \Delta C_{2n} = \max\{\Delta C_{21},\ \Delta C_{22},\ \Delta C_{23}\} \end{cases} \qquad (6)$$

Where, ΔC_{1n}、ΔC_{2n} are the value of ΔC_1、ΔC_2 for the position n (n = 1, 2, 3) respectively, the location of the measurement points n can be considered as the position of the winding deformation fault phase occurs initially.

The following two points described in the above-described process:

i) Step 2) can only determine the transformer whether there is an internal fault, but cannot directly determine the type of fault.

ii) The load current, the load voltage, temperature correction of the fundamental frequency of the vibration component should be modified by using the corrected model (3) to ensure the accuracy of the diagnosis.

iii) The premise of the diagnostic features C_3 is E_{T100} not increase significantly, but E_{F100} not. If E_{T100} increased significantly, we can't consider the winding deformation fault, it maybe core loose fault.

ACTUAL APPLICATION ANALYSIS

Feature vector extraction

In order to verify the correctness of the proposed the winding deformation diagnostic method, the vibration signal are measured when the winding under normal and fault, the load experiments wiring is shown in Figure 2. The operate object is a retired power transformer of Nanjing Electric Power Company. The voltage ratio is 10/0.4kV, and type is S9-M-100/10, the join group number is Yyn0. The axial sensitivity of acceleration sensor is 20Pc/g, maximum transverse sensitivity is <5%, the measured frequency is 0.5~12 kHz, it meets coil vibration test requirements. The same six accelerometers are fixed on the 1~6 position as shown in Figure 1, collected the Nicolet Data Acquisition Instrument and transferred to PC to be analyzed and determined the fault.

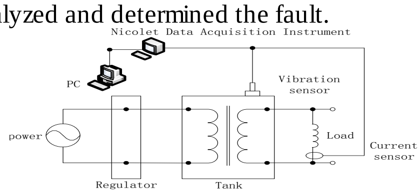

Fig. 2 Wiring diagram of load test

In normal operation of the transformer, the vibration signal of tank surface is collected, as the normal signal. Phase A of transformer winding is set to be deformation. Hanging transformer core with the crane, you can see the core and windings immersed in transformer oil. Remove the two pads beside the A-phase coil ends. Bamboo gently inserted into the winding wire cake gap to make winding loose, and then use the mallet to knock bamboo, causing line cake radial deformation shown as Figure 3, collect the signal of the transformer after failure and the fault signal is set as the current signal.

Fig. 3 Fault setting of winding deformation

The winding vibration signals in two states are converting by FFT, normal signal spectrum can be obtained in Figure 4, and the current signal spectrum is shown in Figure 5.

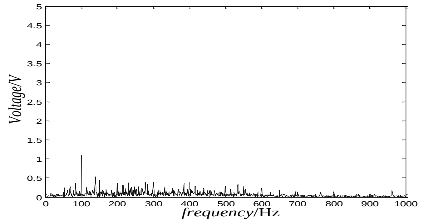

Fig. 4 The vibration signal spectrum of the normal signal

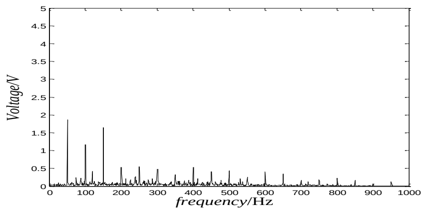

Fig. 5 The vibration signal spectrum of the normal signal Current signal

It can be seen from Figure 4, when the transformer windings are in the normal state, the amplitude of baseband component is larger, as the main frequency component. It illustrates that the winding vibration is generated by the electric power caused by the load current flowing through the windings, and its vibration frequency is twice the fundamental frequency of the load current.

Analysis of transformer current situation, that is setting the winding deformation fault condition as shown in Figure 5, addition to the changes of 100Hz, on the surface of the transformer tank, 50Hz, 150Hz, 200Hz component amplitude all changes.

Fault type discriminant

Use the method mentioned in section 3 to diagnose power transformer fault. First of all, use model (3) to correct fundamental frequency component of the vibration signal, and then analyze vibration signal fundamental frequency component energy value E_{F100} of transformer's front side, as shown in Figure 6.

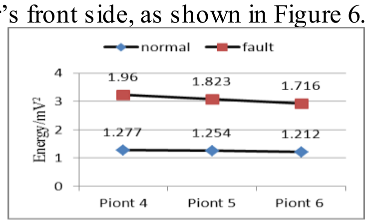

Fig. 6 Comparison of energy values of fundamental frequency vibration signal

By contrast fundamental frequency signal of measuring from point 4, 5, 6, it can be seen that the transformer the current value of the fundamental frequency energy is significantly increased, compared with normal condition. This means there is internal fault.

Further diagnosis is needed in order to distinguish the type of fault.

Using the formula(5) to extract the measured transformer 1~3 measuring point vector T_N and T_X feature vector T failure, as Table 1.

Use formula(5) to extract feature vector of original signal and the current signal of point 1, 2, 3, marked as T_N and T_F, respectively, as shown in Tab.1.

Table 1 Eigenvectors of monitoring points

Point	T_N	T_F
No.1	[0.3125 0.2404 1.055]	[6.132 3.627 1.361]
No.2	[0.2554 0.2343 1.277]	[5.785 3.443 1.563]
No.3	[0.2512 0.2156 1.118]	[5.955 3.514 1.516]

Calculate ΔT of point 1, 2, 3 according to Tab.1, ΔT=T_F-T_N= [ΔC_1 ΔC_2 ΔC_3], results are shown in Tab.2.

Table 2 Comparison of eigenvectors

Point	ΔC_1	ΔC_2	ΔC_3
No.1	5.8195	3.3866	0.3060
No.2	5.5296	3.2087	0.2860

The values of ΔC_1、ΔC_2、ΔC_3 are positive, so it is initially considered the winding internal deformation. Calculated from formula(4), fundamental frequency energy on transformer top E_{T100} increases from 1.232 to 1.416, and front energy E_{F100} increases from 1.277 to 2.016, which increases more than the top one. It can determine the failure of the transformer winding is the winding deformation fault.

As shown in Tab.2, ΔC_1, ΔC_2 meet the conditions as $\begin{cases} \Delta C_{11} = \max\{\Delta C_{11}, \ \Delta C_{12}, \ \Delta C_{13}\} \\ \Delta C_{21} = \max\{\Delta C_{21}, \ \Delta C_{22}, \ \Delta C_{23}\} \end{cases}$, it can been see that the points is just at the position where winding deformation failure occurred, and the winding deformation failure is in the A phase, which is fully consistent with the default location of the fault. This result proves the diagnostic model can accurately diagnose a winding fault.

CONCLUSIODN

It can be found that in addition to the fundamental frequency component can reflect the failure，the new characteristic frequency which concludes 50Hz frequency component , some of its harmonic components and the harmonic components of the fundamental frequency can also reflect the failure. A base frequency translation model is proposed by considering the vibration signal will be influenced by operation state quantities which contain the current，voltage，temperature，etc. Transformer winding deformation fault diagnosis method is established, they can determine the type of fault and preliminary fault location. After de-noising，discounted processing ， the acquisition monitoring points of vibration signals are used by the proposed method，and the actual transformers are diagnosed，The diagnostic results are same with actual failure.

The proposed method can be not only used for winding deformation fault diagnosis, but also provide a reference for other fault diagnosis. The transformer winding deformation diagnostic system based on the proposed method has practical applications in Nanjing Power Supply Company (P.R. China).

REFERENCES

[1] Li Yongli, Gu Fuhai, Liu Zhihua, 1999, "The Application of Neural Network in the Fault Identification of Transformers", *Automation of Electric Power Systems*, vol. 23, 22-23.

[2] Guo Chuangxin, Zhu Chengzhi, Zhang Lin, 2010, "A Fault Diagnosis Method for Power Transformer Based on Multiclass Multiple-kernel Learning Support Vector Machine", *Proceedings of the CSEE*, vol. 30, 128-134.

[3] Jin Wenlong, Chen Jianhua, Li Guangfan, 1999, "Statistics and Analysis on Power Transformer Damages Caused By Short-circuit fault in 110kV and Higher Voltage Classes", *Power System Technology*, vol. 23, 70-74.

[4] Wang Yu, Li Yanming, Zhang Chengliang, 1997, "The Comparisonal Study on LVI and FRA Method of Detecting Winding Deformation Faults in Transformers", *High Voltage Engineering*, vol. 23, 13-15.

[5] Huang Hua, Zhou Jianguo, Jiang Yiming, 1999, "Diagnosis of Winding Deformation of Transformer by Impedance Method and FRA", *High Voltage Engineering*, vol. 25, 70-73.

[6] Garcia B, Burgos J C, Alonso A M, 2006, "Transformer Tank Vibration Modeling as a Method of Detecting Winding Deformations-part I: Theoretical Foundation", *IEEE Transactions on Power Delivery*, vol. 21, 157-163.

[7] Garcia B，Burgos J C，Alonso A M, 2006, "Transformer Tank Vibration Modeling as a Method of Detecting Winding Deformations-part II:Experimental Verification", *IEEE Transactions on Power Delivery*, vol. 21, 164-169.

[8] Ji Shengchang, Wang Shishan, Li Qingquan, 2002, "The Application of Vibration Method in Monitoring the Condition of Transformer Winding", *High Voltage Engineering*, vol. 28, 12-15.

[9] Cipriano Bartoletti, Maurizio Desiderio, Danilo Di Carlo, et al, 2004, "Vibro-acoustic Techniques to Diagnose Power Transformers", *IEEE Transactions on Power Delivery*, vol. 19, 221-229.

[10] Ji Shengchang, Li Yanming, Fu Chenzhao, 2003, "Application of On-load Current Method in Monitoring the Condition of Transformer's Core Based on the Vibration Analysis Method", *Proceedings of the Chinese Society for Electrical Engineering*, vol. 23, 154-158.