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Research on Intelligent Online Monitoring and Evaluation of Power Transformer

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Abstract: Transformer is the power equipment of power system core. Intelligent monitoring and operation of transformer can not only monitor the full range of the transformer, the realization of state evaluation, it should be required repair, maintenance required good, but also on the latent fault early diagnosis and prediction. Research on transformer intelligent monitoring and operating technology of safe operation of power system and the substation has great significant and impoertance. According to the theory and method of transformer intelligent, combined with intelligent transformer on-line monitoring technology has been achieved, mainly explores the intelligent cooling and adjustable transformer pressure control technology.

Keywords: Power transformer, on-line assessment, parallel operation, fuzzy membership function.

1. INTRODUCTION

In recent years, with the improvement of science and technology and the rapid growth of electricity consumption, the rapid development of China's power grid construction, the installed capacity of generators increases, the equipment technical level has been further improved [1]. Relevant data show that in 2013 a year of China's new installed capacity reached 125 billion kilowatts. The United States ranked first in the world, with the national power generation capacity of 5.25 kwh trillion, an increase of 7.6%, electricity consumption totaled 5.32 trillion kilowatt society, rose 7.5% [2]. In order to further improve the development of smart grid, the China State Grid Corp plans to build 5 thousand seat of intelligence in the "Twelfth Five Year Plan" period of substation, by the end of 2020 before the total investment of intelligent transformer is expected to increase 35000 billion yuan. This is undoubtedly a great promotion to the development of intelligent transformer up till now. Intelligent transformer with voltage transformation, remote communication and other functions is a variety of transformer technology, communication and automatic control of continuous integration results [3]. In addition, the intelligent transformer should also meet the basic principle of reliability, economy, energy-saving.

Transformer in power system undertakes transform voltage, distribution of electric energy transmission power and responsibility, is the important power transmission equipment in power system. 35kV and below distribution transformer occupies an important position. With 10kV voltage grade rated capacity in 30kVA ~ 1600kVA within the scope of the oil immersed distribution transformers and rated capacity in 30kVA ~2500kVA dry type distribution transformer is the most widely. And the distribution transformer directly with end-users, has important significance for the safe and reliable power supply security. Long-term operation of transformer appears a inevitably deteriorating phenomenon, or even accident [4, 5].

Condition monitoring of transformer is a kind of method through certain technical means or equipment through data acquisition and data analysis of operation state and state change trend of transformer used in real-time monitoring or process [6]. The transformer condition monitoring is not only the foundation to realize the condition based maintenance of electric equipment, the premise of intelligent cooling and pressure regulating control is the implementation of the transformer. Through the research on the information analysis, condition monitoring of transformer can be used not only to burst accident prevention of the transformer, avoid unplanned downtime, but also can evaluate the health level of the equipment state information, provides a lot of valuable for optimal use of transformer. The transformer condition based maintenance is not only for the equipment maintenance, repair and provide decision support, but also reduce the maintenance costs of equipment, reduce the transformer operation cost, prolong the operation cycle of the transformer, thereby creating more economic benefit. In addition, the transformer on-line monitoring of the intelligence and information, but also the realization of intelligent power grid and transformer intelligent control key.

2. RELATED THEORY

A. The Research Status of Distribution Transformer Winding Deformation Detection

Frequency response method, namely Frequency Response Analysis, referred to as FRA method, E.P. Dick and

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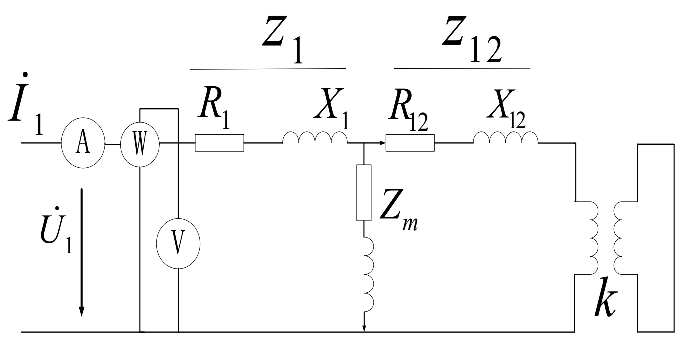

Fig. (1). Wiring diagram of short circuit test method.

C.C. Enren proposed [7]. The basic principle of the method, is the comparative analysis of excitation signal and response signal in frequency domain. A sinusoidal voltage signal to the subjects in transformer is applied stable, at the same time record of each port (including the port) to amplitude and phase angle of voltage signal, get the subjects of transformer winding frequency response characteristics. Comparative analysis of the tested transformer winding deformation before and after in the frequency response characteristics of winding deformation information can be obtained [8].

Short circuit impedance method, is winding geometry and relative position will be reflected in the reactance component of short-circuit impedance (inductance) based on short circuit reactance transformer, so by detecting the value of monitoring of transformer winding condition, this method has been paid more and more attention [9-12].

When the load impedance is zero, the equivalent impedance of transformer's short circuit impedance. The short circuit reactance reactance component of short circuit impedance, also known as leakage reactance. The transformer leakage reactance with longitudinal and transverse leakage reactance leakage resistance, are determined by the winding geometry. Wiring diagram of short circuit test method was shown in Fig. (**1**):

B. The Traditional Detection Method of off-Line Loss

The current electric power company still is the measurement of no-load and load loss by off-line short-circuit test and short circuit test method, through the no-load test and short-circuit test respectively to calculate distribution transformer no-load loss and load loss. Transformer no-load test can measure the no-load current and no-load loss of transformer core manufacturing process; test design, meets the standards or technical requirements; whether there is a defective part or the whole of the magnetic circuit in check, such as the overall quality of assembly of silicon sheet core loosing bad, silicon steel sheet. Large area silicon steel sheet short-circuit, piece of bad insulation between the silicon steel sheet, inferior quality, penetration bolt pressing plate, and the clamping piece insulation damage; found in time winding defects, such as turn or interlayer short circuiting, parallel branches short circuit, winding and tapping switch wiring turn parallel winding number of errors is not correct [13].

Transformer short-circuit test can measure the short circuit loss and short-circuit impedance of transformer, verify whether these two important performance parameters meet the relevant standards or technical requirements, at the same time can be further inspected for defects in transformer winding.

C. The Existing Problems of Current Transformer with on Load Voltage Regulating

Voltage is one of main indices to measure the quality of electric energy, voltage to deviate too much from the rated value, not only affects the voltage quality, but also affects the stable operation of power system. The current grid new power transformer are mostly using the on load voltage regulating device, and the perfect arrangement of low-voltage distribution network structure and reactive power compensation capacity enough, guarantee the quality of power supply, to meet customer demand on power quality [14]. In addition, in the actual operation of modern power grid substation, mostly adopts the transformer parallel operation technology to improve the reliability and economy of power system for power supply system.

At present, single OLTC generally realize independent automatic voltage regulation, automatic adjustment is still for the technical problems in the research field of distribution automation in unsolved voltage but in the state of transformer in parallel operation. For most in parallel operation state of the on load voltage regulating transformer, the voltage operation are manually by grid staff quite operational experience, but the artificial regulation not only to deal with the frequent transfer lead to the grid voltage fluctuation pressure operation, but also can ensure the accurate synchronization points column grid voltage surge again.

3. STUDY ON DETECTION METHOD OF TRANSFORMER ONLINE

A. The Basic Principle of Distribution Transformer Short-Circuit Reactance on-Line Measurement

This paper presents a method for on-line monitoring of transformer winding deformation based on short circuit reactance. The method only needs in the two one or two secondary side voltage under different load online measurement of distribution transformer and current values, which calculate the short-circuit reactance of distribution transformer. Because the short-circuit reactance is a direct indication of the state of transformer windings, the online measurements will reflect the real health status of current winding.

The equivalent circuit model:

$$\dot{U}_1 - \dot{U}_{12} = \dot{I}_1 Z_1 - \dot{I}_{12} Z_{12} \tag{1}$$

$$\frac{\dot{U}_1 - \dot{U}_{12}}{\dot{I}_1} = Z_1 + \frac{\dot{I}_{12}}{\dot{I}_1} Z_{12} \tag{2}$$

According to equation $\dot{I}_{12} = \frac{\dot{I}_2}{k}, \dot{U}_{12} = k\dot{U}_2$ (3)

We can get: $\frac{\dot{U}_1 - k\dot{U}_{12}}{\dot{I}_1} = Z_1 + \frac{\dot{I}_2}{k\dot{I}_1} Z_{12}$ (4)

For a specific transformer, the primary winding impedance Z1 is a constant, two secondary side winding resistance to Z2 is a constant, so the two secondary side winding impedance in a side of the imputed value Z12 is a constant.

Assume:

$$\frac{\dot{U}_1 - k\dot{U}_{12}}{\dot{I}_1} = m + jn; \quad \frac{\dot{I}_2}{k\dot{I}_1} = a + jb \tag{5}$$

We can change the equation (5) into a new formula as follows:

$$m + jn = R_1 + jX_1 + (a + jb)(R_{12} + jX_{12}) \tag{6}$$

Among them, $R_1 + jX_1 = Z_1$ is the primary winding resistance, $R_{12} + jX_{12} = Z_{12}$ is the secondary winding impedance imputed value of the primary side,we can be obtained by transform the right type expressions of (7):

$$m + jn = (R_1 + aR_{12} - bX_{12}) + j(X_1 + aX_{12} + bR_{12}) \tag{7}$$

Acquisition transformer primary side voltage, current, and the magnitude of the secondary voltage and current to the value can be obtained by m, n, a, b values. Then let m, n, a, b values into the formula (8):

$$\begin{aligned} m &= R_1 + aR_{12} - bX_{12} \\ n &= X_1 + aX_{12} + bR_{12} \end{aligned} \tag{8}$$

Adjust the load distribution transformer (within the rated range), measured under a load of twice the primary side of the transformer under test voltage $\dot{U}_{1i}$, the secondary-side voltage $\dot{U}_{2i}$, the primary current $\dot{I}_{1i}$b, the secondary side current $\dot{I}_{2i}$, where i = 1.2.

$$\frac{\dot{U}_{1i} - k\dot{U}_{2i}}{\dot{I}_{1i}} = m_i + jn_i; \quad \frac{\dot{I}_{2i}}{k\dot{I}_{1i}} = a_i + jb_i \tag{9}$$

Solution of M_1, N_1, A_1, B_1 and M_2, N_2, A_2, B_2. Transformer winding impedance is constant, can write column matrix equation.

$$\begin{pmatrix} 1 & 0 & a_1 & -b_1 \\ 0 & 1 & b_1 & a_1 \\ 1 & 0 & a_2 & -b_2 \\ 0 & 1 & b_2 & a_2 \end{pmatrix} \begin{pmatrix} R_1 \\ X_1 \\ R_{12} \\ X_{12} \end{pmatrix} = \begin{pmatrix} m_1 \\ n_1 \\ m_2 \\ n_2 \end{pmatrix} \tag{10}$$

B. Loss Analysis of Transformer Distribution

Transformer, using the principle of electromagnetic induction to the transmission of electrical energy and electrical signals, with transmission power, voltage, current transform function. Ideally the transformer power loss is zero, but for transformer in practical operation in the energy transformation process include: loss of magnetic circuit, circuit loss, loss of mechanical component loss and dielectric loss, the loss of the transformer can be divided into the following (Fig. **2**).

Transformer iron loss mainly for consumption and additional iron consumption of iron. Among them, the basic iron loss of FeP are mainly the eddy loss, magnetic hysteresis loss.

Pw and the induction of eddy current loss is proportional to the square of the electric potential, and the induced electromotive force and the maximum magnetic flux density Bm square and F is proportional to the square of the frequency of alternating, namely:

$$P_w = C_1 f^2 B_m^2 V \tag{11}$$

Where: C1 determined by the material properties, V as the core volume.

Hysteresis loss of Pc and is proportional to the area of hysteresis loop. The area of hysteresis loop and frequency is proportional to f and Bm with the maximum flux density is proportional to the square of the calculation formula is as follows:

$$P_C = C_2 f B_m^2 V \tag{12}$$

The additional loss of transformer Ps, eddy current loss is mainly composed of a tank, clamps and other member leakage flux caused by the loss, and because the distribution of magnetic flux density unevenness caused in core joints. For medium and small capacity transformer, additional loss accounted for a very small proportion of the total loss. The calculation of transformer iron loss medium capacity, will generally be the additional loss is negligible. Transformers iron loss of PFe can be expressed as:

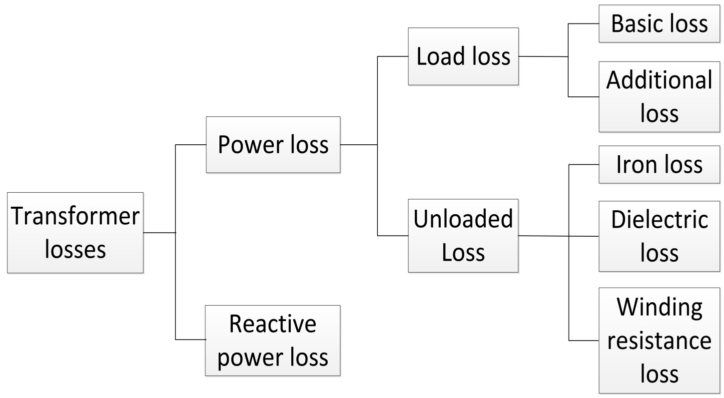

Fig. (2). Composition transformer losses.

$$P_{Fe} = P_w + P_c + P_s = C_1 f^2 B_m^2 V + C_2 f B_m^2 V + P_s \tag{13}$$

C. Data Acquisition and Control

In order to achieve higher accuracy and facilitate subsequent data processing method in this paper, according to the characteristics, after many tests, sum up experience, the design of data acquisition and control module is suitable for this method, as shown in Fig. (**3**) of its design process. Data acquisition work according to the requirements of starting, orderly according to the needs analysis, module according to the need to upload or data preprocessing and start data.

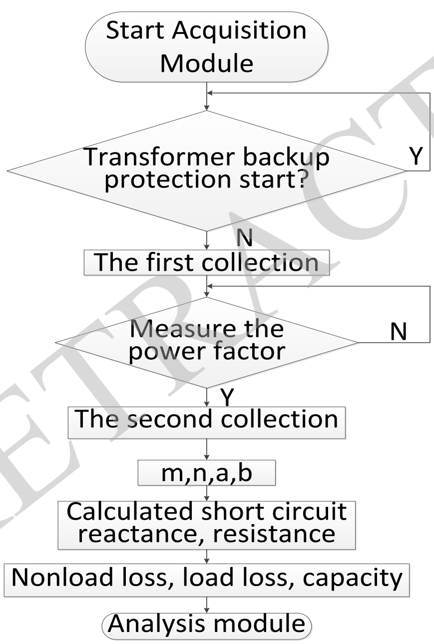

Fig. (3). Design of data acquisition process.

To characterize health state characteristic parameters of distribution transformer many, status of distribution transformer can be good or bad by their different levels, from different aspects and different degree to reflect. Because the distribution transformer is itself a structure of multi, multi system accessories, extremely complex, state assessment needs assessment index participation factor is many, and state information between the existence of fuzziness and uncertainty, thus to realize the evaluation of online status on its effective and accurate in the presence of the difficulties.

4. EXPERIMENTAL RESULTS

A. Online Measurement Simulation Experiment

The short circuit reactance online measurement of five kinds of different capacity of the distribution transformer value, in off-line measuring short-circuit reactance value as reference, error analysis was shown in Table **1**.

In off-line measurements as the benchmark of distribution transformer with different capacity, using this method to calculate the distribution transformer online each phase short circuit reactance values have certain difference, but the relative error was stable at 0.12% ~ 0.33%, show that the proposed algorithm has higher on the measurement accuracy of the distribution transformer short-circuit reactance. The short-circuit reactance of three-phase mutual deviation should be considered the actual existence. This proves that the short-circuit reactance method proposed in this paper can be accurate and effective measurement of the value of online distribution transformer.

B. Error Analysis of Measurement System

In order to influence the amplitude error, test reliability and voltage current transformer the method of phase errors on the short circuit reactance measurement accuracy, with 100kVA three-phase distribution transformer as an example, do the following several kinds of digital simulation.

Voltage, current transformer primary side of transformer and the two side of the first with the same amplitude error and phase error. Considering the situation of the four kinds of. Case 1: +0.3% and -10 DEG; case II: +0.3% and +10 degrees; situations: -0.3% and +10 degrees; the situation: -0.3% and -10 degrees.

Table 1. On-line measuring data of short-circuit of10KV S11 Series distribution transformer.

Rated Capacity (KVA)	Phase Order	Short-Circuit Reactance(Ω)		Error (%)
		On-Line	Off-Line	
30	A	115.4981	115.4701	0.0242
	B	115.5672		-0.0841
	C	115.7433		0.2366
50	A	72.2673	72.035	0.3225
	B	71.9727		-0.0865
	C	72.2368		0.3225
100	A	37.0391	37.081	-0.113
	B	37.1167		0.0966
	C	37.1877		0.2877
400	A	9.6486	9.6321	0.1713
	B	9.6352		0.0322
	C	9.6418		0.1007
1000	A	4.3842	4.38054	0.0836
	B	4.3832		0.0607
	C	4.3826		0.047

Table 2. Error analysis.

Error Situation	Amplitude Phase Error	Reactance Line Measure	A	B	C
no error	0 and 0	Obsd	37.0391	37.1167	37.1187
Same error	Situation①	Obsd	37.0391	37.1167	37.1187
		Error(%)	0	0	0
	Situation②	Obsd	37.0391	37.1167	37.1187
		Error(%)	0	0	0
	Situation③	Obsd	37.0391	37.1167	37.1187
		Error(%)	0	0	0
	Situation①②③④	Obsd	37.0391	37.1167	37.1187
		Error(%)	0	0	0
different error	Situation⑤	Obsd	36.5629	38.8388	38.3663
		Error(%)	-1.286	4.6397	3.1693
	Situation⑥	Obsd	35.1964	35.8669	35.6003
		Error(%)	-2.666	-3.552	-4.269

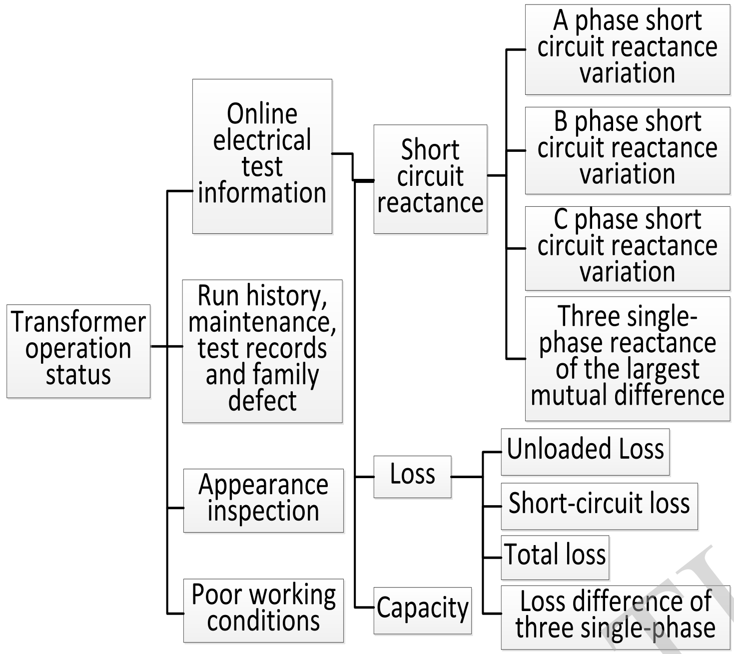

Fig. (4). Established index system.

Voltage, current transformer error of a side the transformer and the secondary side two different. Considering the most serious 5 and 6 of two cases. Situation: the primary side voltage magnitude error, phase error for +0.3% transformer is -10 degrees, a primary side current amplitude error is -0.3%, the phase error of +10 degrees, two secondary side voltage magnitude error, phase error +0.3% -10 degrees, two side current magnitude error, phase error +0.3% -10 degrees; the situation: a primary side voltage magnitude error, phase error of -0.3% transformer +10 degrees, two side current magnitude error, phase error +0.3% -10 degrees, two secondary side voltage magnitude error, phase error -0.3% +10 degrees, two side current magnitude error, phase error of +10 DEG -0.3%.

For online measurement data is not only similar to the standard industry standard of comparison, historical records also compared also with the same acquisition system, so the error of measurement system itself does not cause a miscarriage of justice.

C. The Multi State Information Evaluation System

State information of the data is very complex and large distribution transformer. For oil immersed distribution transformers and dry-type distribution transformer, to achieve their healthy condition online monitoring, the characteristics of electrical characteristics of the data obtained in the operation of the online detection because of its data with real-time, authenticity, objectivity, and is a concrete manifestation of the transformer current state of health, the data amount is far greater than the important index of preventive data has become the transformer condition evaluation. In addition, regular routine preventive test record is added online monitoring data, real-time evaluation of distribution transformer in the operation state of the auxiliary. In addition, other factors to consider are: test records, maintenance records and operation history, family defect, visual inspection situation, bad condition and other information data.

In summary, established index system as shown in Fig. (**4**).

CONCLUSION

This paper studies the distribution transformer on-line detection method based on short impedance. Still the above several distribution transformer as an example, using the method of short-circuit impedance of their capacity for online calculation, the simulation results show that, high accuracy, good stability. Online calculation to get the actual capacity of distribution transformer operation, solve the possible actual operation of missing the nameplate, nameplate capacity does not match with the actual problems, help the power supply company to additional nameplate capacity false enterprise basic electricity power system, help the timely adjustment of the power supply to the load, the transformer in the best running state, avoid overload and light load operation.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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