How to Analyze and Test the Location of Partial Discharge of Single-winding Transformer Model

Huang Wangjun, Chen Yijun

HIMALAYAL - SHANGHAI - CHINA

Abstract: In order to detect transformer fault accurately and quickly, a continuous single winding transformer model is established. The multi-conductor transmission wire model consists of 180 turn wires and takes the winding continuity of first-end of all turns as boundary conditions, in which the current is extracted from grounding wires of bushing and winding end extracts the current from grounding lines. With this model, the current transmission functions of different windings from the first position to the final position is discussed. Based on the consideration of the great difference of the current transmission function between different discharge locations, the position of the partial discharge of transformer is realized via the distance function method. The current transmission functions of a 180-turn single winding transformer are measured. The theoretical results are compared with the measured results. The comparison of current transmission functions show that the method is effective.

Key words: single-winding transformer model, electrical location, power transformer, current transmission function, distance function method, multi-conductor transmission wire model

Introduction

The fault detection and treatment of power transformer is essential to stable and reliable operation of power. For manufacturers and on-site staff, how to detect the fault quickly and accurately is one of their core tasks. With the development of high voltage technologies and grid technologies, there have been many advanced methods and technologies for identifying transformer faults up to now. These methods and technologies can detect any possible faults, such as DC resistance, insulation resistance, absorption rate, and faulty features, including temperature, micro-water and oil level. However, these methods cannot determine whether there is partial discharge in the power transformer and accurately locate it. Hence, special research is needed to further analyze the partial discharge fault of power transformer and locate them, which is of significance to elimination of faults and normal operation of electrical system. At present, the most studied methods are ultrasonic wave location and electrical location. It is quite difficult to apply the ultrasonic wave location method on site because ultrasonic wave signals will be affected by many factors when transmitting through different medium such as oil, paper and metals of power transformer. When power transformer has partial discharge, impulse signals transmit to the measuring terminal along windings. Then the partial discharge is targeted according to electrical transmission features in the signals. The electrical location is mainly used for inaccurate location of partial discharge and rarely utilized on site, which needs further researches.

With deep researches into transmission model of discharge impulse in the transformer winding and the development of digital measuring technologies, the transmission function of power transformer winding has been widely applied in many aspects, including transient analysis, insulation cooperation and transformer design. Moreover, the transmission function has been used to diagnose the faults, such as electrical location and winding deformation. In the paper, first of all, based on multi-conductor transmission wire model, simulation calculation is made for features of discharge impulse transmitting in the transformer winding are simulated in order to obtain transmission function of sectional winding between different discharging position and external measuring end; secondly, practical electrical location method based on distance function is established; at last, test results are compared to verify the effectiveness of location method proposed in the paper.

1. Continuous Single-winding Transformer Model

When a group of sine excitation acts on ends of nonuniform multi-conductor transmission wires, actual voltage and current of all conductors decompose into model voltage and model current according to certain proportion; then each group of model voltage and model current transmits along transmission wire according to their own transmission constant; the relation between actual voltage, actual current on the multi-conductor transmission wire and model voltage, model current is listed as follows:

$$\begin{cases} \boldsymbol{U}(z) = \boldsymbol{T}_{\mathrm{U}}(\mathrm{e}^{-rz}\boldsymbol{U}_{m+} + \mathrm{e}^{rz}\boldsymbol{U}_{m-}); \\ \boldsymbol{I}(z) = \boldsymbol{Y}_{\mathrm{C}}\boldsymbol{T}_{\mathrm{U}}(\mathrm{e}^{-rz}\boldsymbol{U}_{m+} - \mathrm{e}^{rz}\boldsymbol{U}_{m-}) \end{cases} \quad (1)$$

Where:

z: coordinate

$U_{(z)}$: actual voltage

$I_{(z)}$: model current

U_{m+} : positive model voltage

U_{m-}: negative model voltage

T_U: voltage model change matrix

Y_C: feature admittance matrix

$Y_C = YT_U r^{-1} T_U^{-1}$ (Y - node admittance matrix of GT-group ; r - mutual impedance or transfer impedance between GT-groups)

z=0, z=l → The relation among head current matrix (I_s), tail current matrix (I_R), head voltage matrix (U_s) and tail voltage (U_R) is listed below:

$$\begin{bmatrix} I_S \\ I_R \end{bmatrix} = \begin{bmatrix} A & -B \\ -B & A \end{bmatrix} \begin{bmatrix} U_S \\ U_R \end{bmatrix} \quad (2)$$

Where:

$$A = Y_C T_U \coth(rl)(T_U)^{-1} = YT_U r\coth(rl)(T_U)^{-1}$$
$$B = Y_C T_U \operatorname{csch}(rl)(T_U)^{-1} = YT_U r\operatorname{csch}(rl)(T_U)^{-1}$$

Assume that the winding of transformer coil has "n" turns, the equation (2) is "2n", which is reduced to "n+1" through the continuity condition (3)-(5).

$$I_R(i) = -I_S(i+1); i = 1, \cdots, n-1; \quad (3)$$
$$U_R(i) = -U_S(i+1); i = 1, \cdots, n-1 \quad (4)$$

$$I_{PD} = I_R(k-1) + I_R(k) \quad (5)$$

A multi-conductor transmission wire model shown in Fig.1 is established for a continuous single-winding object of power transformer with 180 turns. The coil is 580mm high, and inner diameter and outer diameter are respectively 260mm and 380mm.

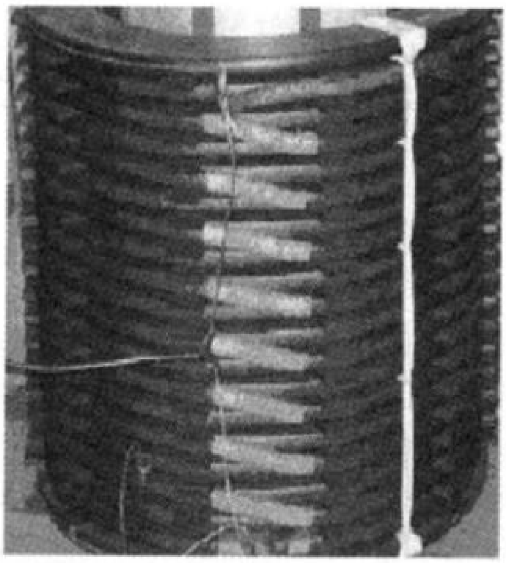

Fig.1 Continuous single-winding image

For specific structure, see Fig.2. There are 18 positions in total and 10 turns for one position. All adopts continuous winding method. The multi-conductor transmission wire model of the winding is composed of 180 wires; the formula of semi-conductor transmission wire is 2×180, which is substituted into the formula (2):

$$\begin{bmatrix} I_S|_{180\times1} \\ I_R|_{180\times1} \end{bmatrix} = \begin{bmatrix} A & -B \\ -B & A \end{bmatrix} \begin{bmatrix} U_S|_{180\times1} \\ U_R|_{180\times1} \end{bmatrix} \quad (6)$$

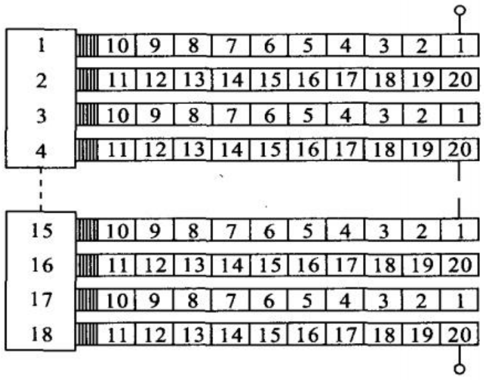

Fig.2 Schematic diagram of winding

Combine formulas (3)-(5); the formula (6) can be converted into (180+1) rank:

$$\begin{bmatrix} I_S(1) \\ 0 \\ \vdots \\ 0 \\ I_{PD} \\ 0 \\ \vdots \\ 0 \\ I_R(180) \end{bmatrix} = YY \begin{bmatrix} U_S(1) \\ U_S(2) \\ \vdots \\ U_S(k-1) \\ U_S(k) \\ U_S(k+1) \\ \vdots \\ U_S(180) \\ U_R(180) \end{bmatrix} \quad (7)$$

YY: feature admittance matrix

The HV head end of winding extracts the current from grounding wires of end shield and the tail end of winding extracts the current from the grounding wires. Based on the above-mentioned boundary conditions, the formula (7) is further solved to obtain the voltage and current transmission function of different winding positions.

2. Simulation and Measurement of Section Current Transmission Function of Transformer Winding

The section current transmission function of transformer winding can be obtained via two methods: simulation calculation and the test measurement. The former is based on the semi-conductor transmission wire model of 180-turn continuous single winding established in the last section.

The test measurement is similar to the impulse response measuring method, which is shown in Fig.3. Available researches on discharge impulse waveform measurement show that the typical discharge impulse in the transformer is steep as a whole and gradually attenuates with short duration and energy concentrated within tens of MHz. Hence, ns-level HV impulse source is used as simulation discharge impulse and injected into different positions of winding in this paper. Meanwhile, the 50Ω no-inductance resistance is employed as HV impulse response current of head end and tail end represented by I_i and I_f. Therefore, the current transmission function $\beta = I_i / I_f$.

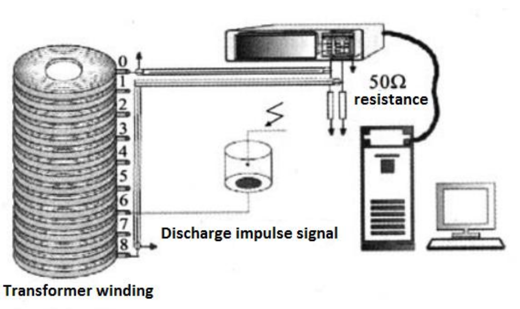

Fig.3 Measurement system for transformer winding current transmission function

Based on the 180-turn continuous single winding multi-conductor transmission wire model, the 50Ω resistance without inductance is grounded. Then the current transmission function is calculated. The theoretical and test values are shown in Fig.4.

3. Research on PD Location Method Based on Transmission Function

The distance function method is utilized to locate, namely, regarding section current transmission function in different positions as to-be-identified class field. Assume that different discharge positions represent different kinds of models, these models can be distinguished because their categories are in different areas. Therefore, the geometrical distance or deviation measurement can be used for separability basis.

Based on Fig.4, there is a large discrepancy between section current transmission function curves in different positions. The distance function analysis method can be used to locate the partial discharge of power transformer. Details of the method are as follows: based on the multi-conductor transmission wire model, a series of current transmission functions are obtained, which serve as feature information and priori knowledge; when the partial discharge occurs in the power transformer, current transmission function which corresponds to the partial discharge position, is obtained from the response signals of measuring discharge impulse; the distance function between current transmission function curve and priori curve; the discharge location is determined according to the distance function.

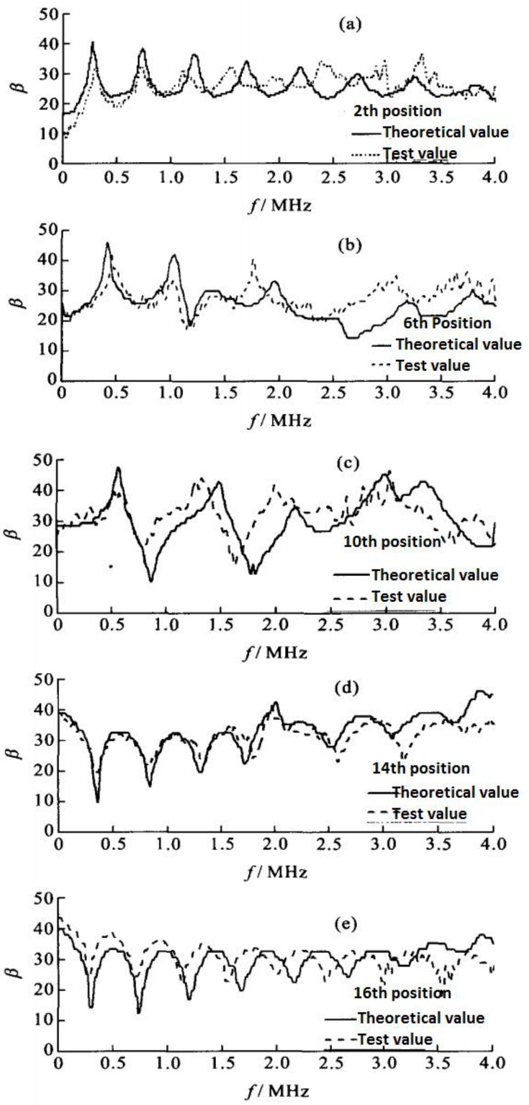

Fig.4 Comparison of theoretical and test values of current transmission function in different positions

The definition of distance function is as follows: in the p-dimension feature distance, the Euclidean distance between X = $(x_1, x_2......, x_p)^T$ and Y = $(y_1, y_2......, y_p)^T$

$$d(\boldsymbol{X},\boldsymbol{Y}) = \left(\sum_{j=1}^{p}(x_j - y_j)^q\right)^{\frac{1}{q}} \quad (8)$$

Where:

q=2

In the previous section, the distance function between current transmission function curve and simulation priori curve is solved step by step. Results are shown in Tab.1. In order to facilitate the analysis, distance functions are normalized,that is, the minimum distance function is set as 1 and correspondingly, other distance functions are also treated. In the Tab.1, d_{pu} represents the Euclidean distance after normalization; M represents actual measured winding position and K is for simulation winding position.

Tab.1 distance function of 180-turn continuous single winding

K/P	d_{pu} M=2	M=4	M=6	M=8	M=10	M=12	M=14	M=16
2	1.176	1.434	1.714	1.650	1.754	1.735	1.810	1.942
4	1.362	1,259	1.571	1.592	1.648	1.582	1.490	1.732
6	1.513	1.631	1.426	1.706	1.620	1.787	1.924	1.839
8	1.608	1.580	1.602	1.309	1.426	1.571	1.895	1.873
10	1.574	1.493	1.478	1.607	1.291	1.494	1.575	1.600
12	1.745	1.565	1.594	1.579	1.630	1,173	1.570	1.637
14	1.826	1.683	1.742	1.650	1.634	1.475	1.109	1.571
16	1.728	1.897	1.837	1.752	1.656	1.503	1.493	1.258

Based on Tab.1, the distance function matrix diagonal element composed of actual measurement and simulation is the smallest. On the one hand, it shows that the established multi-conductor transmission wire model better reflects the actual transmission feature of discharge impulse along the transformer winding. On the other hand, the distance function can be used to locate the partial discharge; the partial discharge position is determined through finding the minimum value of response curve and known simulation curve distance function. Details of the process are as follows: suppose the impulse injected by HV ns in the 10^{th} position as the actual discharge signal; the 10^{th} position transmission function curve is obtained through the measurement, which is shown in Fig.4; then distance function is calculated and the sixth row result of Tab.1 comes; at last, find the position which corresponds to the minimum value.

4. Conclusions

a) The basic principle of PD location based on transmission function method is analyzed. The simulation analysis and test measurement are used to study the transmission feature of transformer winding. The current transmission functions in different positions of transformer are obtained.

b) The distance function method is recommended to obtain the discharge position of transformer winding. Moreover, the location test of 180-turn continuous single winding transformer proves the effectiveness of the method.

REFERENCES

[1] Peng Jian, Luo An, Zhou Ke, et al. Application of information fusion technique to transformer fault diagnosis [J]. High Voltage Engineering, 2007, 33(3): 144-147.

[2] Fan Xian-feng, Zuo Ming. Fault diagnosis using multi-source [C]// Proceedings of the 5th International Conference on In formation Fusion. Florence, Italy: [s.n.], 2006:1-6.

[3] Thang K F, Aggarwal R K, Mcgraila J, et al. Analysis of power transformer dissolved gas data using the self-organizing map [J]. IEEE Trans on Power Delivery, 2003, 18 (4): 1241-1248.

[4] Jiang Yanjun, Ni Yuanping. Fault diagnosis method of transformer based on rough set and support vector machine [J]. High Voltage Engineering, 2008, 34(8): 1755-1760.

[5] Fu Yang, Jiang Yurong, Cui Chunhong, et al. Fuzzy theory and probability reasoning applied for identifying power transformer fault [J]. High Voltage Engineering, 2008, 34(5): 1040-1044.

[6] Chen Weigen, Qian Guochao, Li Ming. Method of fault diagnosis for power transformer with multi-parameters [J]. High Voltage Engineering, 2007, 33(8): 92-97.