

Based on Simple Four Conductors Model Measuring Distributed Parameters of 500kV Power Transformer Winding

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ABSTRACT: - To analyze the propagation characteristic of high frequency signals, such as partial discharge (PD) in power transformer winding, it is necessary to determine the distributed parameters at high frequency of the power transformer winding. This paper discusses an experimental method for measuring the distributed parameters of the power transformer winding. The proposed experimental method only involves the input impedance measurements for the short- and open-circuit tests and then, the distributed parameters can be computed by formula. At last, the finite element method is used to compute the capacitance parameters of the power transformer winding. It indicates that the relative error between the calculational results and the experimental results is less than 20 percent. Thus the experimental method presented in this paper is demonstrated to be effective.

Key-Words: - Partial discharge (PD); Transformer winding; Distributed parameters; Input impedance; Finite element method; Multi-conductor transmission lines (MTLs)

1 Introduction

Transformer winding, which is connected to electric network directly, composes the inner circuit of the transformer, it is the key part of the transformer, and is always said to be the heart of the transformer. The insulating property is one of the important factors which determine whether the transformer works properly in a long term, but in the process of manufacture, accidental factors would produce some congenital local defects, such as air bubble, crack, suspended conductive particle, and electrode burr etc., these defects could cause partial discharge (PD) in the transformer winding. Through a large number of researches, detecting the PD signals of the transformer not only can check out the defect and deterioration of the insulation, but also can forecast the transformer lifetime so as to reduce the accidents. While, according to the PD signals detected from the sensor, the location of PD

signals and the PD severity both are relevant to the propagation characteristic of impulse signal in transformer. Therefore, it is vital to build the accurate and general simulation model that can describe the propagation characteristic of PD pulse in transformer winding, and it forms a good basis for further solving the problem of locating and quantifying the transformer internal PD. Building the high-frequency parameter model of transformer winding is the key to solve the problem.

Per-unit-length distributed parameters are the significant parameters that reflect the electrical character of transformer winding wire, the voltage and current response of each point in winding wire can be got through it. In the practical application, the structure of transformer winding wire is complicated, and the frequency variation characteristic of distributed parameters is obvious. So, in order to correctly analyze the transmission

characteristic of the transformer winding wire, it is necessary to get the distributed parameters of transformer winding wires by experiment.

Reference [1, 2] studies the distributed parameters of multi-conductor transmission lines (MTLs) model, which is laid on the aluminum plate, and the experiment results agree with the theoretical value. But compared with the power transformer winding wire, the structure of model is simple and the model hasn't considered the frequency variation characteristic.

To accurately analyze the propagation characteristic of high frequency signals, such as PD in power transformer winding or in turbine generator stator winding, the theory of MTLs is applied [3-4]. Based on the theory of MTLs, reference [5] establishes a new model for PD pulse propagation in turbine generator stator winding. The experiment results tested on real 200MW turbine generator stator winding agree with the simulation results derived from the model.

Based on the method of reference [6], the Impedance Analyzer is used to measure the input impedance of the four 500KV power transformer winding wires when the far end is short and open and then, from the formula the per-unit-length series impedance matrix \mathbf{Z} and the per-unit-length shunt admittance matrix \mathbf{Y} can be obtained. Compared with the traditional method [1-2, 7], the direct measurement of voltage and current can be avoided and the process of experiment is simple. At last, the finite element method is used to compute the capacitance parameters of the power transformer winding. It indicates that the relative error between the calculational results and the experimental results is less than 20 percent. Thus the experimental method presented in this paper is demonstrated to be effective.

2 Principle of Measurement

The MTLs equations for sinusoidal steady-state excitation are [8]

$$\begin{cases} -\frac{dV(x)}{dx} = \mathbf{Z}\mathbf{I}(x) & (\mathbf{Z} = \mathbf{R} + j\omega\mathbf{L}) \\ -\frac{d\mathbf{I}(x)}{dx} = \mathbf{Y}\mathbf{V}(x) & (\mathbf{Y} = \mathbf{G} + j\omega\mathbf{C}) \end{cases} \quad (1)$$

Where $\mathbf{V}(x)$ and $\mathbf{I}(x)$ respectively represent the voltage and current vectors, \mathbf{Z} and \mathbf{Y} respectively represent the per-unit-length series impedance matrix and the per-unit-length shunt admittance matrix. The equations for \mathbf{Z} and \mathbf{Y} are [1, 9]

$$\begin{cases} \Gamma = \frac{1}{l} \arctan h[(\mathbf{Z}_{sc}\mathbf{Z}_{oc}^{-1})^{1/2}] \\ \mathbf{Z}_c = (\mathbf{Z}_{sc}\mathbf{Z}_{oc}^{-1})^{1/2} \mathbf{Z}_{oc} \\ \mathbf{Z} = \Gamma\mathbf{Z}_c \\ \mathbf{Y} = (\mathbf{Z}_c)^{-1}\Gamma \end{cases} \quad (2)$$

where the l represents the length of power transformer winding wire, Γ represents the propagation constant matrix, \mathbf{Z}_c represents the characteristic impedance matrix, \mathbf{Z}_{sc} and \mathbf{Z}_{oc} , which are symmetric matrix, respectively represent the short-circuit impedance matrix and open-circuit impedance matrix.

Reference [1, 2] gives a method that, when the far end shorted and the near end of all but the driven conductor open, the short-circuit impedance matrix \mathbf{Z}_{sc} is performed with measuring the voltage and current, while when the far end open and the near of all but the driven conductor shorted, the open-circuit impedance matrix \mathbf{Z}_{oc} is performed with measuring the voltage and current. But this method has to measure voltage and current many times.

Based on the theory of multi-port network, the equations for the input impedance of wires are [6]

$$\begin{cases} \mathbf{Z}_{sc}(i,i) = \mathbf{Z}_{in}^{sc}(i,i) \\ \mathbf{Z}_{sc}(i,j) = [\mathbf{Z}_{in}^{sc}(i,i) + \mathbf{Z}_{in}^{sc}(j,j) - \mathbf{Z}_{in}^{sc}(i,j)]/2 \\ \mathbf{Z}_{oc}(i,i) = \mathbf{Z}_{in}^{oc}(i,i) \\ \mathbf{Z}_{oc}(i,j) = [\mathbf{Z}_{in}^{oc}(i,i) + \mathbf{Z}_{in}^{oc}(j,j) - \mathbf{Z}_{in}^{oc}(i,j)]/2 \end{cases} \quad (3)$$

With $i, j=1, 2, \dots, N$, $i \neq j$, N represents the number of wires.

Where $\mathbf{Z}_{sc}(i,i)$ and $\mathbf{Z}_{sc}(i,j)$ respectively represent

the diagonal and non-diagonal elements of \mathbf{Z}_{SC} , $Z_{OC}(i,i)$ and $Z_{OC}(i,j)$ respectively represent the diagonal and non-diagonal of \mathbf{Z}_{OC} , $Z_{in}^{SC}(i,i)$ represent the input impedance between the i th wire and the reference conductor when the far end shorted, $Z_{in}^{SC}(i,j)$ represent the input impedance between the i th wire and the j th wire when the far end shorted, $Z_{in}^{OC}(i,i)$ represent the input impedance between the i th wire and the reference conductor when the far end open, $Z_{in}^{OC}(i,j)$ represent the input impedance between the i th wire and the j th wire when the far end open.

\mathbf{Z}_{SC} and \mathbf{Z}_{OC} can be got through equation (3) in terms of the input impedance of the power transformer winding wires and then, from (2) the per-unit-length series impedance matrix \mathbf{Z} and the per-unit-length shunt admittance matrix \mathbf{Y} can be obtained.

3 Measurement Technique and the Experimental Results

The experimental model used in the distributed parameters measurement for four 500KV power transformer winding wires is shown in Fig.1 and the cross-sectional view is shown in Fig.2 and Fig.3. The model comprises two 1.45-m lengths of conductor (3, 4) in a insulated block supported 8.8-mm and two 1.45-m lengths of insulated wire (1, 2) in a insulated block supported 4.4-mm above a 2.0-m by 1.0-m aluminum plate. The single wire are of 25 insulated transposed conductors insulated with insulation paper jacket ($\epsilon=3.5$). To simplify the experimental model, the 25 insulated transposed conductors are performed with the far end shorted and the near end shorted. Thus the model is formed by five conductors plus a reference conductor (aluminum plate).

The experimental devices, which are used in the measurement, are Digital Oscillograph, Impedance Analyzer, etc.

The Impedance Analyzer is used to measure the

input impedance of the four 500KV power transformer winding wires when the far end is short and open. The frequency is being swept from 0.1MHz to 5.0MHz. \mathbf{Z}_{SC} and \mathbf{Z}_{OC} can be got through equation (3) in terms of the input impedance of the power transformer winding wires and then, from (2) the per-unit-length series impedance matrix \mathbf{Z} and the per-unit-length shunt admittance matrix \mathbf{Y} .

The curves of the per-unit-length resistance parameters are shown in Fig.4. Based on the theory of the MTL, the relation between the per-unit-length resistance and the frequency is the following

$$R_s \propto \sqrt{f}$$

It indicates that the theory analysis is consistent with the experiment results.

The curves of the per-unit-length inductance parameters are shown in Fig.5. The per-unit-length self-inductance and the per-unit length mutual inductance are monotone decrease along with frequency increase. But because of the resonance at 20MHz ($\lambda/4$), the tendency of the curves is slow even rise at the neighborhood of 5MHz, This problem waits for the further research.

The curves of the per-unit-length conductance parameters are shown in Fig.6. The per-unit-length conductance is increase along with frequency increase. But the G12, G13, G14, G23, G24 and G34 are decrease along with frequency increase, because the value of the per-unit-length mutual conductance is negative value.

The curves of the per-unit-length capacitance parameters are shown in Fig.7. The per-unit-length capacitance is decrease along with frequency increase. But the C12, C13, C14, C23, C24 and C34 are increase along with frequency increase, because the value of the per-unit-length mutual capacitance is negative value.

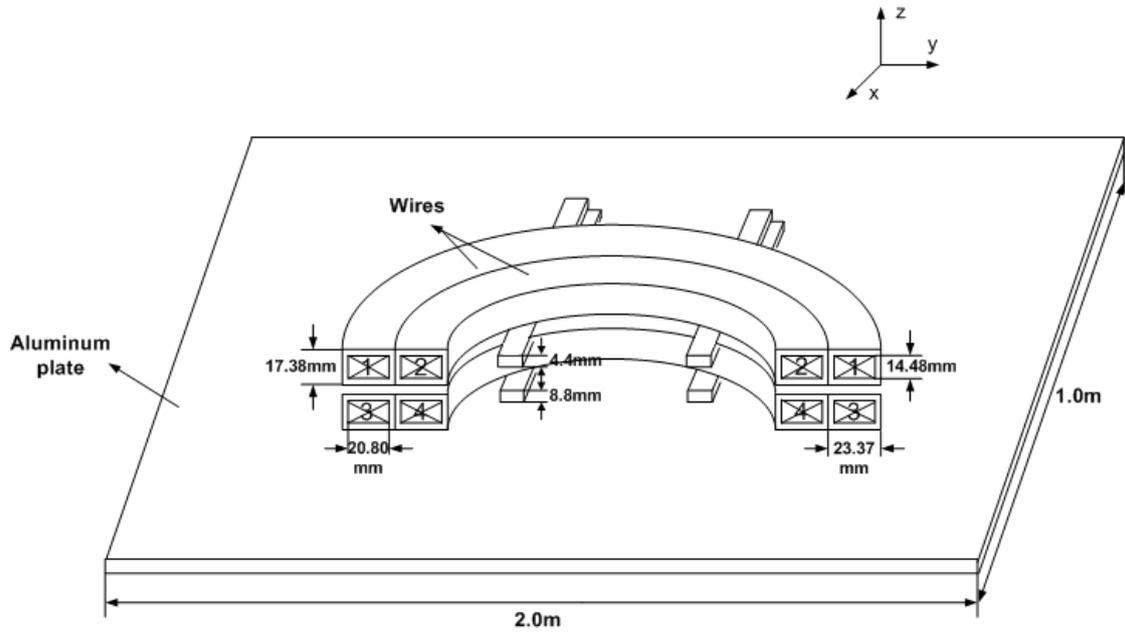


Fig.1 Experimental model of four transformer winding wires

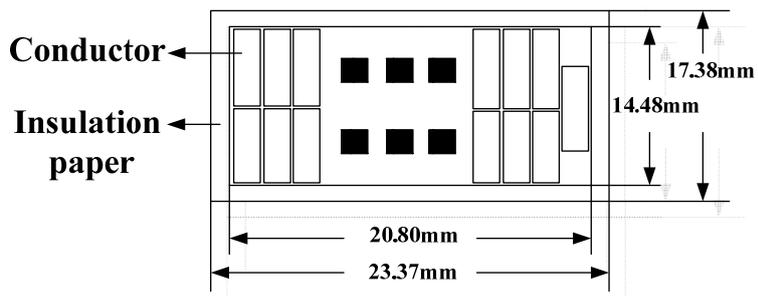


Fig.2 Cross-sectional of the single wire

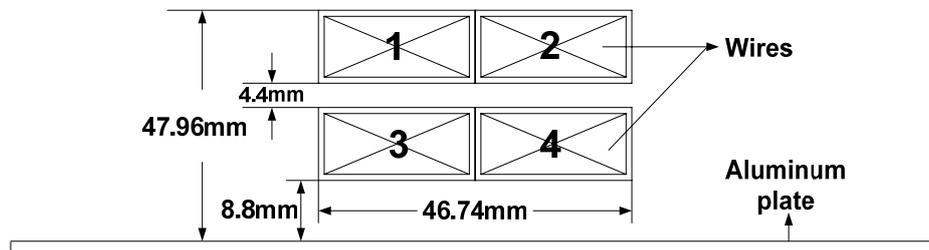


Fig.3 Cross-sectional of the model

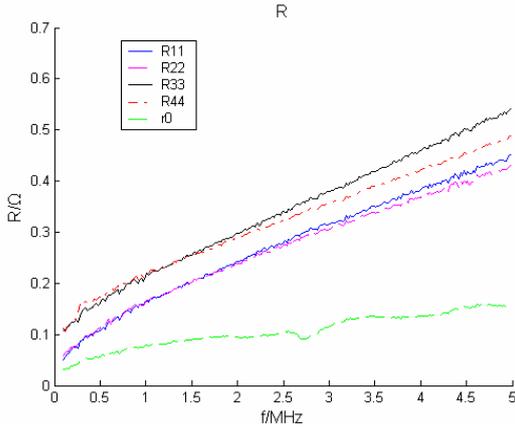


Fig.4 Parameters of the per-unit-length resistance

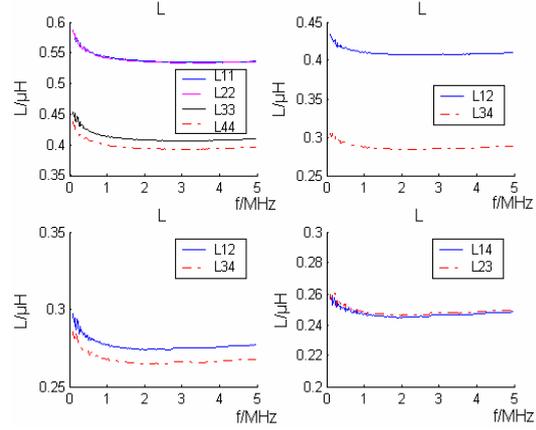


Fig.5 Parameters of the per-unit-length inductance

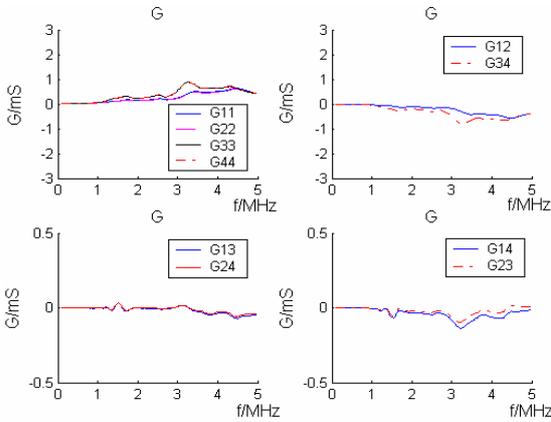


Fig.6 Parameters of the per-unit-length conductance

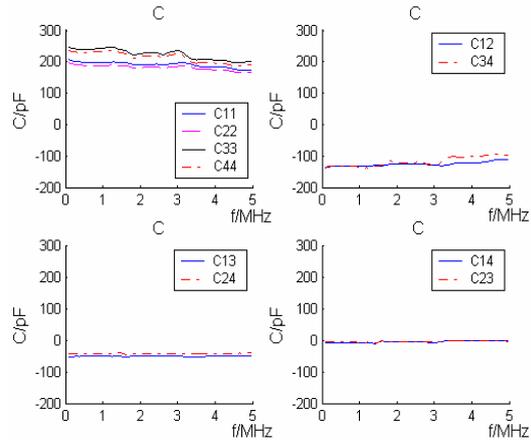


Fig.7 Parameters of the per-unit-length capacitance

4 Verification of the Capacitance Parameters

To verify the effectiveness of the proposed measuring method, the finite element method is applied to compute the capacitance parameters of the experimental model [10]. The per-unit-length capacitance matrices obtained from the experimental data are the following

$$C_{exp} = \begin{bmatrix} 190.65 & 129.90 & 48.88 & 2.69 \\ 129.90 & 186.52 & 2.61 & 41.68 \\ 48.88 & 2.61 & 234.76 & 120.91 \\ 2.69 & 41.68 & 120.91 & 222.65 \end{bmatrix} pF/m$$

The per-unit-length capacitance matrices calculated from the finite element method are the following

$$C_{cal} = \begin{bmatrix} 200.38 & 147.76 & 41.50 & 2.35 \\ 147.76 & 198.87 & 2.78 & 40.22 \\ 41.50 & 2.78 & 221.65 & 143.18 \\ 2.35 & 40.22 & 143.18 & 218.88 \end{bmatrix} pF/m$$

The relative error percentage matrices between the experimental value and the calculational value are the following

$$C_{rel} = \begin{bmatrix} 4.86\% & 12.09\% & 17.78\% & 14.47\% \\ 12.09\% & 6.21\% & 6.12\% & 3.63\% \\ 17.78\% & 6.12\% & 5.91\% & 15.89\% \\ 14.47\% & 3.63\% & 15.89\% & 1.72\% \end{bmatrix}$$

The results indicate that the relative error between the calculational results and the experimental results is less than 20 percent. Thus the experimental method presented in this paper is demonstrated to be effective.

5 Conclusion

An experiment model of four power transformer winding wires has been designed and a measurement technique for measuring its distributed parameters has been presented. The proposed experimental method only involves the input impedance measurements for the short-circuit and open-circuit tests and then, the distributed parameters can be computed by formula. Compared with the traditional method, the direct measurements of voltage and current can be avoided. At last, the finite element method is used to compute the capacitance parameters of the model. It indicates that the relative error between the calculational results and the experimental results is less than 20 percent. Thus the experimental method presented in this paper is demonstrated to be effective. The experimental results indicate that the distributed parameters vary with frequency, so that the frequency variation characteristic must be considered when the MTLs model is calculated.

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