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Using correlation coefficients for locating partial discharge in power transformer

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ABSTRACT

Most serious failure of power transformers is due to the insulation breakdown. Partial discharge (PD) that damages insulation by gradual erosion is major source of insulation failure. The effective ability of the wavelet packets analysis as a tool for disk-to-disk partial discharge faults detection and localization in transformer windings is shown in this paper. Techniques for locating a PD source are of the major importance in both the maintenance and repair of a transformer. One of the most well-known methods of PD localization in transformers is based on winding modeling and current of neutral point analysis. Since the impedance between PD location and neutral point of winding depends on the PD location in respect to neutral point, the frequency spectrum of neutral point current varies when the PD location changes. In the other word, the current components of neutral points vary according to the place where PD occurs. So in this paper, detailed model of transformer winding is modeled and the neutral point current is studied for locating PD. The used method is validated by the simulated model of transformer windings. This model produces a very acceptable current when compared to the experimental data. In this paper for locating partial discharge (PD) in transformer windings, a simulated model is developed for the transformer winding and the PD phenomenon mechanism. The impulse current test and wavelet packets transformation are used to locate PD. It is shown that the neutral current measurement of the transformer winding has useful information about PD location.

1. Introduction

Since large power transformers are the most expensive and strategically important components of any power generator and transmission system, their reliability is crucially important for the energy system operation. Most serious failures of a large power transformer are due to the insulation breakdown. The partial discharge (PD) which damages insulation because of the gradual erosion, is the major source of the insulation failure. Techniques for locating a PD source are of the major importance in both the maintenance and repair of a transformer [1–3].

In the previous projects, the discharge between the winding of the transformer and the ground has been analyzed [1–10]. It is too difficult to determine the PD propagation in a complicated multi-material insulation system of a transformer winding accurately. It has been shown in [11] that sectional winding transfer functions, computed by high frequency modeling winding, can be used for PD localization. In [12–14] detailed model and in [15–17] multi conductor transmission line model (MTLM) have been used for PD localization. Although lots of efforts have been made in solving the problem, the localization of PD source in transformers is still a challenge for all testing engineers [18,19]. Recently, Werle et al. [20,21] have worked on PD location investigations in the dry type and distribution transformers. These transformers are sensitive to the effects of partial discharges in this point of view that non-self-restoring insulation is used in the construction of dry type transformers [20]. Although a new method has been investigated by authors of Ref. [21], they have concluded that more experiences are needed for using this method of PD analysis. Analysis of PD in the coil to coil capacitance is so difficult that it was not considered completely in previous papers. In this paper, partial discharge of coil to coil insulation (C_s) is investigated using EMTP simulation tools. The current of neutral point of winding was measured when PD model was located at different positions in the winding. This current was analyzed by the Db12 in wavelet packets; then coefficients at different wavelet packet nodes were saved. PD will be located by comparing the correlation between these coefficients and the neutral current measurement signal.

2. High frequency winding model

In the range of frequency associated to PD, the transformer winding behaves as a complex ladder network consisting of

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inductances, capacitances and conductances. For PD evaluation, a model is required which describes the physical dimensions of windings as precisely as possible within the acceptable frequency rang. The detailed model shown in Fig. 1 has been used for interpreting the high frequency behavior of transformer coils. The simulation model is an equivalent RLC circuit network based on the theory that should have the same external circuit behavior as that of the transformer winding. For PD localization and evaluation applications, usually it is enough to locate the disk unit of the winding in which PD has occurred. Therefore the number of the RLC units has been chosen equivalent to the number of coil sections. Thus each winding section is considered as a black-box represented by a RLC unit [1–3].

Li models the leakage inductance, C_Si and C_gi represent the coil to coil and coil to ground capacitances respectively. *Ri* represents the loss due to the insulation between adjacent winding section. The mutual inductances between each winding section and the other ones are modeled by *M*. This winding model has been previously used for 220 kV winding with 28 disk in [6].

The inductive branch current vector,

$$[I] = [\, i_1 \quad i_2 \quad \ldots \quad i_{n+1} \,]^T \tag{1}$$

and the nodal voltage vector

$$[U] = [\, v_1 \quad v_2 \quad \ldots \quad v_{n+1} \,]^T \tag{2}$$

are the variable vectors of the model. The winding could be mathematically presented by the following state equation:

$$\begin{bmatrix} U^0 \\ I^0 \end{bmatrix} = \begin{bmatrix} -C^{-1}\cdot G & -C^{-1}\cdot A \\ -M^{-1}\cdot A^T & -R_S\cdot M^{-1} \end{bmatrix} \cdot \begin{bmatrix} U \\ I \end{bmatrix} + [\, C^{-1} \quad M^{-1} \,] \cdot \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} \tag{3}$$

where *M*, *G*, and *C* are the nodal inductance, nodal conductance, and nodal capacitance matrixes respectively. R_S and *A* are the series resistance matrix and the incidence matrix of the inductive circuit respectively.

3. Comparison of measurement and modeling results in time domain

Using the state equation presentation of the transformer winding, the input current of the winding can be numerically calculated for a measured impulse voltage. The measured and simulated input currents of the transformer are compared in Fig. 2. As seen in the figure, a logical coordination is obvious between the results in the first 0.5 ms of the test that can verify the validity of the transformer winding model. The difference between these curves for the times after 0.5 ms can be neglected for detection and localization of winding faults considering the acceptable frequency range of PD phenomenon.

4. Wavelet packets

The main idea in wavelet packets is to use standard filter bank structure (orthogonal and biorothogonal), but to expand it further to allow a narrow partitioning of time–frequency space and a more focused study of the details of signal expansion in wavelet packet, the standard QMF structure composed of low and high pass filters in a perfect reconstruction (PR) filter bank are used. Decomposition of signal i.e. splitting of signal into high and low resolution, is not only limited to output of the low pass channel, but it is also applied to high resolution details as shown below. Similarly during the synthesis stage, the outputs of the high pass filter and the low pass filter are combined sequentially to construct signal components at different scales. Decomposition stage of wavelet packet is shown in Fig. 3.

Subspace decomposition of details as stated above, is shown in Fig. 4. Wavelet packet decomposition of a signal corresponds to partitioning the subspaces W_j, $j = 1, 2, 3, \ldots$, into low and high frequency components as illustrated.

5. PD model

Generally, a 3-capacitance model as shown in Fig. 5 is used to analyze the PD pulse current that appears at outer electrodes. C_g

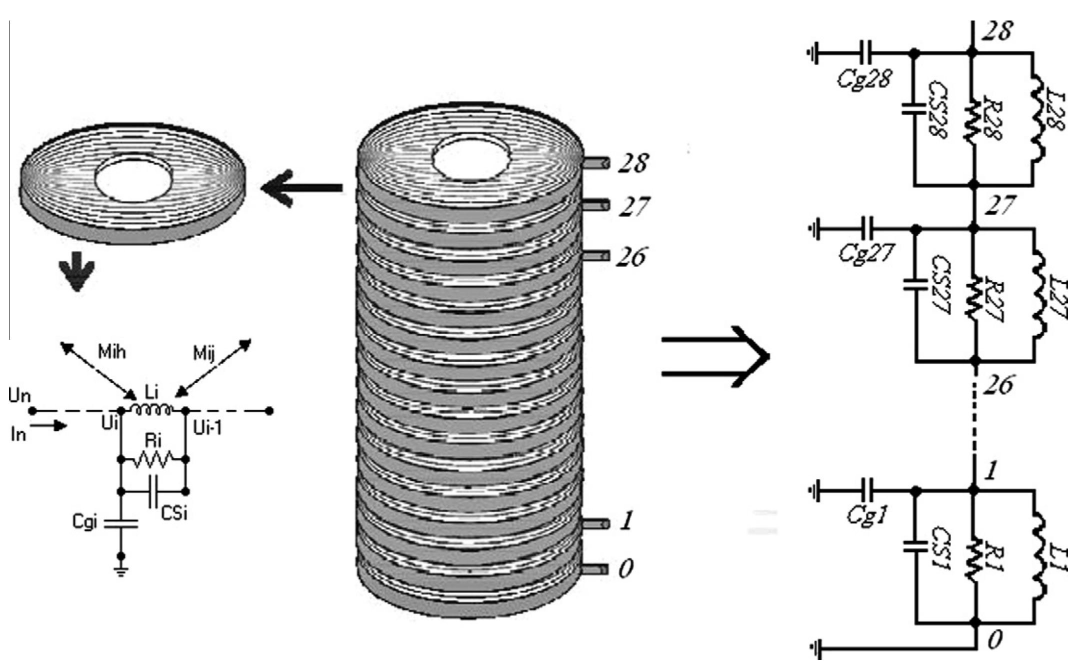

Fig. 1. Equivalent circuit of the transformer winding.