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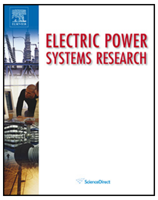

Partial discharge location in power transformer windings using the wavelet Laplace function

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ABSTRACT

Insulation system conditions in power transformers can be evaluated by means of partial discharge (PD) analyses. In fact, PD analysis is used to detect premature damage in transformer insulation system to avoid catastrophic faults. Detection and location of PD is a complex problem and has been widely studied by several researchers. A new method for PD location in transformer windings based on Wavelet Laplace (WL) is developed in this paper. First, the PD reference signals are obtained from a lumped parameter model (RLC) and those signals are used to determine the WL parameters, then PD signals are analyzed using the WL and each PD reference signal is replaced by its envelope wavelet transform (EWT) coefficients. Then, if a PD signal occurred in any section of the winding, its location will be defined by Hellinger distance between the EWT coefficients and the new PD reference signals. Results are discussed for PD along the winding and between sections of the winding.

1. Introduction

Partial discharges (PD) monitoring in power transformers is a useful technique to evaluate the condition of the insulation system. PD signals are linked to the transformer insulation system, high levels of these signals may lead to breakdown of the insulation [1]. In fact, PD analyses in power transformers has been widely applied for detecting and quantifying premature damage in insulation systems [2], therefore detection and location plays an important role. However, detection and location of PD in power transformer has been a complex task, since its random occurrence may produce a wide frequency spectrum from 10 kHz to 3 MHz [3].

Several electrical methods for PD location in transformer windings have been developed in previous studies. For instance, a method in the frequency domain is preposed for PD location in transformer windings using correlation techniques [4]. Furthermore, Nafar et al. [5] applied wavelet packages for PD location, where the high frequency information is used to estimate the PD position, particularly detail coefficients at the first decomposition level are analyzed. Transfer function method is applied in [6], where the PD location is determined by series resonance frequencies. In the same way, transfer functions per section have been applied to determine the PD position along the winding transformer [7–9].

This paper proposes a new method for PD location along the transformer windings and between winding sections. PD signals are processed using the wavelet transform (WT), where the Laplace function is taken as the mother wavelet (Wavelet Laplace, WL), given that WL has a similitude with a PD signal (both have exponential damping). In this work, WL function is applied to PD location in transformer windings. Hence, WL parameters have to be determined and defined using the maximum correlation coefficient between the WL and PD reference signals obtained in the standard calibration process. Furthermore, for each PD signal the Envelope Wavelet Transform (EWT) is computed and the signal references are replaced by the EWT coefficients. Finally, PD signals are compared with the new PD reference signals and the Hellinger distance is applied to determine the PD position along the winding or between sections of the winding. Results show that WL is a better alternative for PD location in transformer windings.

2. Transformer winding model

The transformer winding can be represented by a lumped parameter model or by a multi-conductor transmission line (MTL) model. Both has been used to locate PD, e.g. in [10] a MTL model for PD location in windings using the transfer function method is explained. For other phenomena, like fault location in transformer

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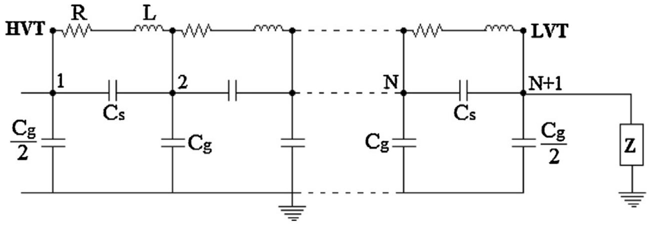

Fig. 1. Lumped parameter model of a winding.

windings, the lumped parameter models are also used [11]. The transformer winding model to be used in this work can be seen in Fig. 1, each section of the winding is represented by lumped parameters of R, L and C.

In Fig. 1 R is the series resistance, L is the series inductance, C_s is the series capacitance, C_g is the capacitance to ground (disc-to-earth). The transformer winding model has N sections with number of nodes equal to $N+1$. In this application, the transformer winding model has 10 sections and their parameters were taken from [12] and are equal to $L = 180\mu$ H, $R = 1.2\Omega$, $C_s = 13$ pF, $C_g = 3000$ pF.

3. PD signals in transformer windings

A PD signal is characterized by an exponential damped function which can be represented using the Heidler function defined by [13]:

$$S_{PD} = A\left(\frac{t}{t-T_f}\right)^n e^{-\left(\frac{t}{\tau}\right)} \tag{1}$$

where t is the time variable, A is the amplitude of the PD signal, T_f is the rise time or front duration, τ is the time where the function amplitude has fallen to 37% of its peak value and n is the factor influencing in the rise time of the function. Besides (1), a PD model to acquire the PD signals between winding sections is shown in Fig. 2, where the circuit solution for the voltage terminals a and b is defined by (2), and its parameters are equal to $R = 2k\Omega$, $C_1 = 300$ pF and $C_2 = 50$ pF.

$$V_{ab} = Ae^{-\left(\frac{t}{RC_1}\right)} \tag{2}$$

If a PD occurs at any position of the transformer winding, its response will be captured at the neutral terminal using the impedance Z in Fig. 1, this circuit is also known as ERA device [14].

Regarding the reference signals, they are obtained from a simulation process using the Alternative Transient Program (ATP) software in agreement with the standard calibration process described in [15]. The calibration process is carried out using a voltage pulse with a capacitor in series, where the amplitude pulse is equal to 1 V and the capacitor value is 50 pF, equivalent to a charge of 50 pC. The voltage or current signals are captured at the neutral terminal and used as references for PD location in transformer windings. In Fig. 3, the voltage when a PD signal is injected to the high voltage terminal is shown (solid line). Taking into account that a PD signal was previously characterized by the Heidler function, an equivalent calibration process should be done.

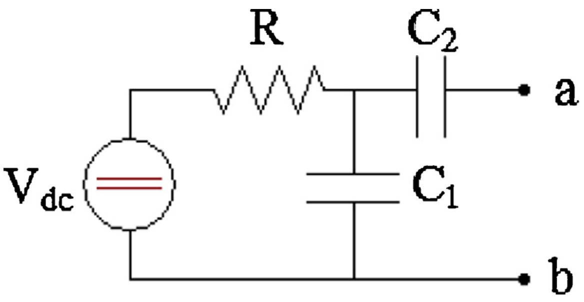

Fig. 2. PD Model among winding sections.

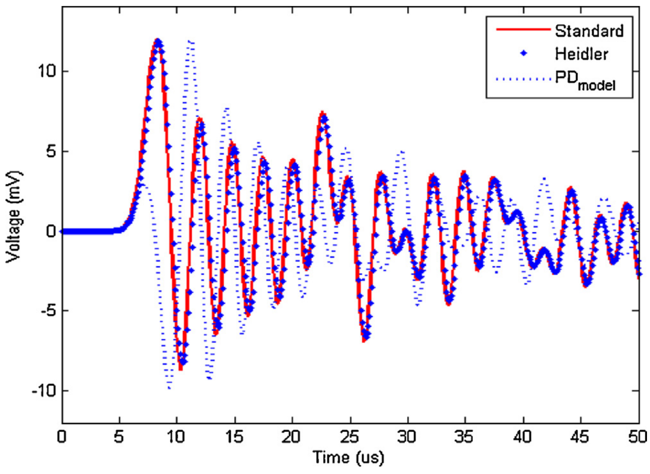

Fig. 3. Calibration signals.

Calibration process using the Heidler function must be equivalent to the standard calibration. Hence, the equivalent responses are also shown in Fig. 3, where the standard calibration signal is quite similar to the PD signal corresponding to the calibration due to the Heidler function. It is also shown the calibration signal for PDs between sections (dotted signal), which is equivalent to 50 pF, this signal has slight differences with respect to the standard calibration signal.

The PD reference signals used in this work are the obtained from the Heidler function, using the following parameters: $A = 327\mu$A, T_f=1 ns, $\tau = 200$ ns and $n = 2$. In Fig. 4 the current signals measured at the neutral terminal, when PD signals were injected at different sections (1, 5 and 9) of the transformer winding, are shown. The number of reference signals will be equal to the number of the winding sections. The complete PD reference signals will be processed using the WT to determine the PD location in transformer windings.

4. Wavelet transform and the Laplace function

The continuous wavelet transform (CWT) for a signal $x(t)$ is defined by the inner product of the signal and a complex conjugate

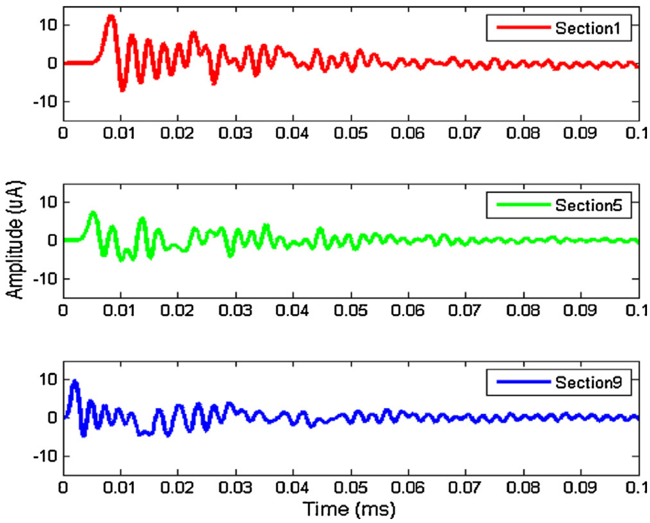

Fig. 4. Current signal measured at the neutral point.