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Evaluation of transformer core contribution to partial discharge electromagnetic waves propagation

Reza Rostaminia [a,*], Mohsen Saniei [a], Mehdi Vakilian [b], S. Saeedollah Mortazavi [a]

[a] Faculty of Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran
[b] Electrical Engineering Department and Center of Excellence in Power System Management and Control, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Accurate Partial Discharge (PD) measurement requires the expansion of the measurement frequency range to Ultra High Frequency (UHF) band. For this it is needed to implement modern techniques when monitoring an important element of power system, such as power transformer. Different kind of experimental models, such as insulation defect models, and the complete transformer windings models are used to simulate the partial insulation failure situations which occur in a real transformer. However, since in these models, some kind of simplifications are employed which may result in an electromagnetic waves (EM) propagation pattern different from what exists in a real transformer and encounter errors in its PD measurement results. In this paper, the transformer core effects on PD EM wave propagation are investigated. To address this concern, different core designs are simulated. Finite Integration Time (FIT) method is used for electric field calculation through application of Microsoft CST microwave studio Software. The probes recorded electric fields are analyzed using wavelet transform (WT). A new approach based on energy scale coefficient (for each decomposition level) is used for mother wavelet selection. Results of these simulations demonstrate how existence of core and its design affect the characteristics of measured PD signal.

Introduction

Power transformer is one of the most precious apparatus in a power system and its unplanned outage can cause irrecoverable costs due to the corresponding load outages. Hence the power transformer condition monitoring is necessary to detect the incipient faults. Partial Discharge (PD) measurement is one of the prevalent methods for power transformer condition monitoring. Different methods are introduced for PD measurement. In recent years, a high range of interest is raised toward application of Ultra High Frequency (UHF) methods for PD measurement [1–5]. The main reason for this great interest is related to the capability of UHF based methods to detect and measure a PD signal more accurately in a noisy environment and its high sensitivity when employed in an on-line monitoring process.

Transformer defects PD signals characterization trusts a real power transformer to accurately explore the type of defect occurred in transformer insulation. To facilitate these simulations on a real transformer major restrictions exist. Additionally performing basic research on the transformer PD signal characterization where multiple defects may exist in real transformer insulation, made it to be unfeasible.

To overcome this obstacle, different models are suggested to simulate the real transformer accurately. Defect models, which represent a defect in the insulation system of a transformer (i.e. discharge across two plane electrode, or between one pin type electrode and one plane electrode are employed), are frequently used to simulate different partial discharge phenomena in a real transformer, and consequently to use the results for PD signals classification and diagnosis [6,7].

These models are simple and their PD measurement results can be compared with real transformer related results if the conventional PD measurements methods have been used in accordance with the IEC 60270. In application of unconventional methods such as UHF methods, the artificial defect models may not simulate the real transformer defects properly due to discrepancies exist in responses over a wide frequency range. Although in [8], a comparison carried out between the results of IEC60270 measurements and the results of radio frequency techniques employed to measure partial discharge signals related to defect models, and some relations are explored between them, however when using the UHF band methods and related techniques the wave propagation has a major influence on results. Therefore, since the model

* Corresponding author.
E-mail address: R-rostaminia@phdstu.scu.ac.ir (R. Rostaminia).

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structure can impact on the propagated waves any short comings in this model will contribute to errors encountered. To overcome this shortcoming of the models, researches suggested using models having windings similar with the real transformer windings for PD signals investigation [9]. However, these models also have some other shortcomings, i.e. not having a tank or a magnetic core. In a power transformer, core is constructed from steel sheets in a packet form with different width in steps.

The transformer core is one of the main parts of a power transformer which is ignored in past transformer models used for PD studies. As an example in [10], the authors presented a method for localization of PD in a power transformer. In their modeling, the core is simulated by a cylindrical steel shell. In [11], the windings and core are represented in form of a barrier against propagation of PD electromagnetic waves. Therefore, two kinds of barrier, in cylindrical and cubical forms are employed in the propagation paths of EM waves. The effects of this type of core modeling on propagation time and the delay time of EM waves introduced to the receivers and the measuring probes are investigated. In [12], the effects of transformer active part (core and windings) on PD related EM wave propagation is analyzed. However, in none of abovementioned works, the effects of different core structures on PD related EM waves propagation are investigated.

In this paper, the core effects on PD related EM waves propagation is investigated. The PD related EM waves propagation is studied using the Finite Integration Technique (FIT) through application of CST Microwave Studio software. Here, different core structures, such as: the iron packet core with insulation layers in between, the cylindrical steel shell and the cylindrical wooden shell cores are employed in the modeling.

Also, the effects of different thicknesses in windings insulation, and variation of tangent delta of oil insulation (especially for aged oil) are studied. The characteristics of recorded PD signals versus location of measurement probes are studied, where major distortions and oscillations exist on the signal in time domain. Wavelet Transform (WT) is used to differentiate among different designs and be able to explain the results in a better form. Therefore, an important parameter based on the scale of energy is introduced to be used for selection of mother wavelet. At the end, the impact of different core models on propagated PD related EM pulses; in a wide frequency range is discussed.

This paper is organized in the following order: In Section 'Simu lation model and procedures', the transformer model based on different structures for core and windings are presented. In Section 'Wavelet transform', the WT is applied on the measured signal which is used to compare the effects of core model on PD related EM waves propagation of different frequency range. Additionally, in Section 'Wavelet transform', based on application of maximum energy scale coefficients, the mother wavelet is selected. The simulated results and the results of analysis on different core structures are demonstrated in Section 'Simulation results and discussions'; the conclusion of this work is presented in Section 'Conclusion'.

Simulation model and procedures

To investigate the core effects on EM PD waves' propagation, a transformer model is investigated to resemble the real transformer. The electric field distribution of the model is calculated with CST Microwave Studio software using Finite Integration Technique (FIT) on Maxwell's equations. The FIT is a consistent discrete scheme which solves Maxwell's equations in their integral form rather than differential form [13].

The proposed model in CST software is depicted in Fig. 1. Three different cores, the iron packet core, the steel cylindrical shell core and the wooden cylindrical shell core are utilized to analyze the core effects on PD EM waves' propagation of signal. The iron packet core is used to investigate behavior of real transformer core under PD EM wave propagation. In PD studies, generally a steel cylindrical shell type core is used for simulation instead of the iron packet core. Therefore, this kind of core should be verified against a real transformer core. In [14], a transformer model developed by CIGRE transformer working group to investigate the polarization and depolarization current, under different transformer operating temperature. In that model, the wooden cylindrical shell core was utilized as transformer core. Hence, also a wooden cylindrical shell core is substituted for transformer core, to investigate whether this representation of core affect the accuracy of the proposed transformer model in PD EM waves propagation. The specifications of real packet core dimensions are presented in Table 2 of Appendix 1.

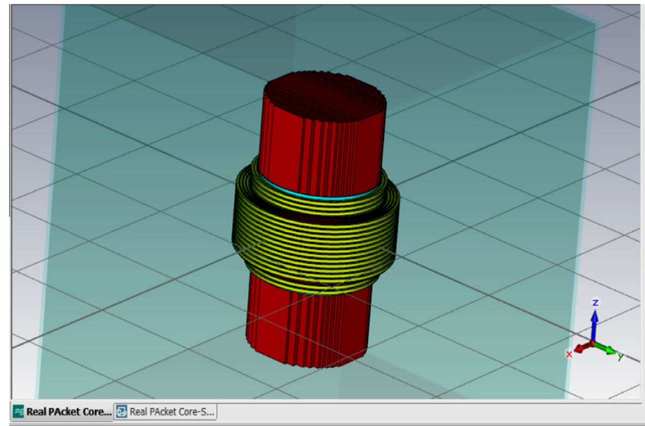

Fig. 1. The Model of Windings and real packet core in CST Software.

As shown in Fig. 1, four layers of low voltage (LV) windings and two layers of high voltage (HV) windings exist in this model. The characteristics and dimensions of these windings and other components of this transformer model structure are shown in Table 3 of Appendix 2 [15]. There are 19 and 12 turns in each LV and HV winding layer, respectively.

For the sake of simplification, minor modifications are applied on this model if compare with a practical power transformer. These simplifications contribute to minor changes in number of layer number, and number of turn in each winding. Due to the some restrictions in hardware employed for simulation, the related dimensions of the model are multiplied by a scale factor of 0.5. The total number of created mesh in the software is about 18,193,000, having 8 GB RAM and 3.4 GHz CPU on the computer; the run time for each simulation was about 26 h.

The PD current wave source is considered to have a normal Gaussian function form as depicted in Fig. 2 [10]. The PD pulse width and current amplitude are reported to be about 1 ns and 1 mA, respectively. In order to evaluate the core effects on propagated PD waves in different directions of transformer space, four electric field measuring probes are embedded in four different positions over the tank wall of the model. The locations of these four probes are depicted in Fig. 3. The probes 1–4 are at (−155,0,0), (155,0,0), (0,155,0) and (0,0,155), respectively. The electric field calculation is performed during 24 ns and the frequency band width of measuring probes is considered 0–3 GHz.

Two possible locations for PD occurrence are considered and studied in this model to investigation the related EM waves' propagation. One position for PD occurrence is considered to be located inside the HV and LV windings insulation, i.e. at (−71,0,0) and another one inside the insulating oil, i.e. at (−95,0,0). The possible