Chapter 1

Introduction

1.1 Overview

In the electric machines (e.g. transformer, motor, generator and etc.), the presence of partial discharges (PDs) is often the indication of the degradation of the electric insulation of the power apparatus. The final stage of partial discharge is the electric breakdown, which can lead to catastrophe not only to the electric machines but also to the power system. PDs are generally caused by the aging of the electric windings; and they are small electric charges released from the metallic windings. If the PD explosion happens in the oil-immersed power transformer, it will excite the surrounding fluid medium and therefore induce acoustic waves, which will then propagate through the transformer oil to the transformer tank. To understand the propagation phenomenon and the nature of the PD, deriving the equations for the acoustic wave propagation in the fluid and analyzing the measurements of PD signal are necessary.

The structure of the transformer is often complex, therefore analyzing the mechanism of how the PD's acoustic signals propagate inside the real transformer on a theoretical basis is not possible. So, to understand the PD acoustic wave propagation physics, simplified models need to be obtained. Some works have been focused on modeling the PD formation from a circuit elements (capacitors, inductors) point of view [1, 2]. In [3], the authors reported the experiment of signal attenuation vs. distance using a experiment transformer tank with a pseudo acoustic generator excited by a function generator and the measuring sensors mounted on the transformer tank wall. In order to estimate the original intensity of the initial PDs released from the windings and further determine the severity of the PD activities, we need to derive the acoustic wave propagation model in mathematical form. To achieve that, utilizing well-developed acoustic theory is necessary.

To simplify the derivation the acoustic wave equation in the fluid, we considered only a one-dimensional problem. The sources of the acoustic wave dissipation may be divided into two general categories [4, 5]: (1) those intrinsic to the medium and (2) those associated with the boundaries of the medium. Losses in the medium may be further subdivided into three basic types: viscous losses, heat conduction losses, and losses associated with internal molecular processes. It is proven that the majority of the energy loss in fluid is associated with viscous losses [4, 6]. So only the viscous affect is included as a loss in this work. In addition, without the loss of generality, assumptions of the fluid being adiabatic, homogeneous, and isentropic are made. The harmonic solution of the derived wave equation can then be obtained. The simulation of the solution under water and oil is compared to the laboratory experiment results and they are found to be consistent with each other.

Detection of the PD from onsite or experiment measurement is essential to understand the characteristics of the PD of different devices. PD detection has been used in many power apparatus, such as, gas insulated substation [7, 8], polyethylenes [9, 10], motors [11], stator bars [12], cables [13, 14], power transformers [15-22], etc. Several detection methods have been implemented, e.g. acoustic sensing [12, 17, 19, 22, 23], electrical signal measuring, radio wave measuring [7, 24]. Sometimes, it is not easy to probe the released partial charges by using the electrical measurement; since the noises associated with the operation of the machines and measurement apparatus as well as some outside signals (e.g. EMI, radio, instrument, etc) might couple with the measurement results. Therefore, many attempts have been made to measure the PD signal via acoustic optical sensor [18, 21, 23, 25, 26], since the acoustic optical sensors have the property of the immunity from the electrical signal. In this work, with the cooperation of Virginia Tech Center for Photonics Technology, the in-house designed optical acoustic sensors and the commercial piezoelectric transducers (PZT) were used to measure the PD signals from the Northfleet West SGT3A 500 MVA 400kV/275kV transformer. This is the first time ever reported that the detecting sensors were place inside the transformer. More details on how the fiber optic sensors were fabricated and tested can be found in [20].

Several data sets (see Appendix A) from the on-site measurement allow us to analyze the measured data from both the top and bottom drain valves of the Northfleet West SGT3A 500 MVA 400kV/275kV transformer for possible PD generated acoustic signals. The measurement contain noises mostly from vibration, optical and EMI noises, so we adopted the wavelet-based denoising technique to remove much of the noises, therefore the signal-to-noise ratio is dramatically increased. For PZT measurement results, the PD pulse duration, and amplitude were summarized statistically. In addition, the frequency spectrum of the PD signal from both fiber optic sensor and PZTs were analyzed, and it is found that the PD frequency occurred between 70 kHz to 250 kHz. With the assumption of propagation delay between the PD source and detecting sensors, the calculated delay times with respect to each phase were reported.

1.2 Contribution of the research

This thesis contributes in the following aspects:

- Theoretical derivation of acoustic wave propagation in transformer fluid under ideal condition.

- The theoretical calculation result is compared with simulation and laboratory measurement. They are found to be consistent between each other. This outcome is the first available in history.

- Onsite PD measurement results from fiber optic sensors are analyzed using wavelet-transform-based denoise method. It is proven that such signal processing technique is effective to remove the noise-dominant signal.

- Addition to the previous measurement, some commercial piezoelectric transducer (PZT) were used to catch possible PD signals. The statistics of the signal characteristics are studied in this work.

1.3 Organization of this study

This thesis consists 6 chapters. Chapter 1 introduces some background knowledge and previous works that has been done in PD field. Chapter 2 documented the derivation of the acoustic wave equation, its associated harmonic solution and the comparison of theoretical results with lab experiments. Chapter 3 includes the measurement results from the on-site Northfleet West SGT3A 500 MVA 400kV/275kV transformer. Chapter 4 introduced the wavelet transform, its related denoising techniques and the criteria selection methods. Chapter 5 shows the on-site measurement signal analysis results. Conclusion and suggested future research works are stated in Chapter 6.