Chapter 14

Detection and Location of Partial Discharges in Transformers Based on High Frequency Winding Responses

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ABSTRACT

Localized breakdowns in transformer windings insulation, known as partial discharges (PD), produce electrical transients which propagate through the windings to the terminals. By analyzing the electrical signals measured at the terminals, one is able to estimate the location of the fault and the discharge magnitude. The winding frequency response characteristics influence the PD signals as measured at the terminals. This work is focused on the high frequency range from about tens of kHz to a few MHz and discussed the application of various high-frequency winding models: capacitive ladder network, single transmission line, and multi-conductor transmission line in solving the problem.

INTRODUCTION

Electrical insulation plays a critical role in the working of high-voltage power equipment. Equipment failure is often caused by complete breakdown (short circuit) of the insulation. This in turn is often the consequence of gradual, cumulative and damaging effects of partial discharges (PD) on the insulation over the years. The occurrence of partial discharges is indicative of some localized faults or defects within the insulation structure of the equipment. In transformers in particular, such localized defects often originate from a certain location within the transformer winding. High electron energies produced from the discharge will cause physical damage and chemical changes to the insulating materials (e.g. transformer oil, cellulosic materials such as Kraft paper, pressboard) at the discharge site. In general, the higher the magnitude of the discharge and its rate of occurrence would cause more severe degradation to the insulation. By detecting the PDs, measuring their (apparent)

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magnitudes and locating their source, a more accurate assessment of the transformer insulation condition can be made and any necessary repair can be quickly carried out.

PDs are transient events of a stochastic nature, producing electrical current pulses of very short duration. Each discharge pulse contains a certain amount of energy and this energy is dissipated in various forms. Consequently, this gives rise to a number of different PD detection methods. The direct method is by measuring the electrical current associated with the PD pulses. Other methods are indirect and based on measurements of electromagnetic waves radiation (light, and HF/VHF/UHF waves), audible and ultrasonic pressure waves, the increase in gas pressure, chemical reactions and by-products, heat, etc. Very often, it is unlikely that a single diagnostic method is able to provide a reliable assessment of the insulation condition because of the limitations of the detection method. For example, the acoustic method using piezo-electric sensors is often used in practice because it can be easily carried out on-line and it is less susceptible to electrical interference. However, the location accuracy is often poor due to the complex nature of the acoustic signals. These signals travel from the PD source to the sensor via many paths with different propagation velocities. Further complications can arise due to the effects of signal attenuations, reflections, refractions, mechanical noise or reverberations, and the presence of solid barriers inside the transformer (core, windings, structural supports).

With distributed impedance plant items such as transformers or rotating machines, a PD results in a current impulse injected into the winding at the position where the fault occurred. This electrical signal then propagates along the winding before it reaches the main terminals and thus can be measured. The electrical method for PD detection/location involves the use of appropriate sensors installed at the two terminals of the winding. A convenient and non-intrusive approach is by high-frequency current transformers (HF-CTs) clamped around the neutral-to-earth connection and the HV bushing tap point. By analyzing the signals picked up at the two winding ends, it is then possible to (i) determine the location of the PD source, and (ii) estimate its original magnitude at the source. To achieve this requires accurate modeling of the transformer winding and its effect on the PD pulse propagation. Different windings (physical dimensions, choice of materials used, winding arrangement) will result in different equivalent circuit configurations and thus give different responses.

The transformer winding electrical characteristic is very much frequency dependent. Further complications arise because the characteristic of the PD signal itself varies considerably. There are many different possible insulation failure mechanisms. Examples of common defects in power transformers that can generate PDs are de-lamination, voids in solid insulation, floating bubbles in oil, moisture, surface tracking, bad connection, free/fixed metallic particles (Bartnikas, 2002). At its source, PD current pulses have very short duration, i.e. impulse-like. The rise time and pulse width are strongly influenced by the physical characteristics at the discharge site. In general, the frequency contents of PD signals spread over a wide frequency range from DC up to hundreds of MHz with a non-uniform amplitude distribution. These different frequency components will propagate through the winding and experienced different attenuation/dispersion effects before reaching the terminals. Thus the resultant signals as measured at the terminals would be significantly distorted as compared to the original PD pulses at the source.

This chapter will discuss the application of various high-frequency winding models for the purpose of predicting the PD signals as measured at the main winding terminals. Here, the term ‘high frequency’ is used to refer to the frequency range from about tens of kHz to a few MHz, and the winding models considered are obviously distributed

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