Electric Power Systems Research 78 (2008) 1819–1825

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Short communication

Partial discharge study in transformer oil due to particle movement under DC voltage using the UHF technique

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ARTICLE INFO

Article history:
Received 31 July 2007
Received in revised form 21 December 2007
Accepted 21 March 2008
Available online 5 May 2008

Keywords:
Partial discharges
UHF sensors
Transformer oil
Converter transformers
Insulation
Condition monitoring

ABSTRACT

Converter transformers are one of the key components in high voltage DC power networks. The insulation of these transformers is stressed by both AC and DC voltages. Therefore, AC and DC voltage tests are routinely applied during factory tests to verify the performance of the insulation structure. Partial discharges in an insulation system are incipient discharges that can damage materials and may eventually lead to complete failure of the insulation system during operation. Recently it has been shown that monitoring such discharges formed under AC stress is feasible using Ultra High Frequency (UHF) measurement technique and that there is a reasonable correlation between the partial discharge magnitude and the amplitude of the UHF signal generated by partial discharges. However, the partial discharge activity under DC voltages is not fully understood. This paper describes a study using the UHF technique to improve our understanding of particle-induced partial discharge activity under DC voltages in mineral oil insulation. UHF signals generated due to conducting particle contamination in transformer oil under AC and DC voltages are compared and analyzed. A method for distinguishing particle discharges in regions of high or low electric field stress is proposed based on frequency-domain analysis of the measured UHF signal.

1. Introduction

High voltage DC power transmission networks are becoming more widespread and converter transformers are key components of these systems. Mineral insulating oil plays a major role in power transformers, acting both as insulant and coolant. The increasing use of large converter transformers means that it is important to ensure that the insulation systems for this type of plant are reliable.

The performance characteristics of converter transformer insulation are verified by carrying out routine tests in the factory, including AC voltage withstand test, DC voltage test, polarity reversal test, etc. [1,2]. The DC voltage test is severe compared to AC voltage test because movement of conducting particles towards HV conductors can be sustained in a single direction in contrast with their more erratic motion in an AC field. Under certain conditions, DC voltages could initiate the process of degradation and lead to earlier failure of a transformer. At present, the routine DC tests have limitation to measure the incipient discharges, if the electrical noise in the ambience is high. It is also recommended in standard to use ultrasonic technique to classify the partial discharges from the noise [1]. Adoption of UHF technique for identification of partial discharges under DC voltage test in transformer is at infancy stage. Therefore, a potential diagnostic opportunity is being missed.

The presence of even a minor defect in the insulation structure, under normal operating voltages can create local field enhancement causing partial discharges such as corona/surface discharges. The defect may be a due to protrusion from the winding or due to floating conducting/non-conducting particles present in the transformer oil. The non-conducting defect would typically be fibre dust from the press-board or paper insulation surfaces. Conducting defects may be particles in the transformer oil introduced during manufacture/maintenance or from wear and tear of metal parts within the oil cooling system during operation. If the level of contamination is high, under the DC test contaminated particles may align in the direction of electrical field helping to bridge part of the windings or instigate a short circuit from an HV component to earth. Krins et al. [3] observed that a conducting particle affects the breakdown strength of the oil more than the insulating particle. Some literature is available dealing with particle initiated breakdown in transformer oil under AC and DC voltages [4,5] but further research is essential to understand the polarity of the applied voltage on partial discharge formation due to particle movement.

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doi:10.1016/j.epsr.2008.03.022

Birlasekaran has studied particle movement in transformer oil under AC and DC fields both theoretically and by experimental study [6,7]. He concludes that under DC voltages, conductive particles transport charge by contact with electrodes and observed the discharge current in the form of a fast rising current pulse and slowly increasing displacement current [7]. Dascalescu et al. [8], studied particle movement in insulating fluids and concluded that the vertical amplitude of particle bounces increases with electric field up to the point at which micro-discharges occur between the particle and the electrode of opposite polarity.

In addition to the conventional IEC60270 [9] measurements, methods for identification of partial discharges include optical techniques (characterising the light emanating from discharges), detecting acoustic emissions, chemical methods (such as fluorescence measurement, dissolved gas analysis or high performance liquid chromatography) and by radio frequency measurement [10–13].

When PD current pulses involves rise and fall times of a nanosecond or less, signals in the Ultra High Frequency (UHF) range (300–3000 MHz) are excited [13,14]. The UHF technique for partial discharge identification in transformers is gaining acceptance due to its high sensitivity and good signal to noise ratio [13]. Considerable research activity has been carried out on PD activity in transformer oil insulation, e.g., [15,16]. Measurements have indicated that the UHF signals radiated by partial discharges propagate at the speed of light in oil gets attenuated by a factor of square root of dielectric constant of the liquid ($\sim 2 \times 10^8\ \mathrm{m\,s^{-1}}$) and are attenuated by about 6 db per 10 m of travel [17]. Judd et al. [18,19] has provided an extensive review on partial discharge monitoring in transformers using the UHF technique, where details of the sensors, signal interpretation and the applicability of the technique in a practical situation can be found. Jongen et al. [20] carried out studies on partial discharge activity in transformer oil under AC voltages and concluded that phase-resolved UHF signals can help to classify the type of PD source. Meijer et al. studied partial discharge activity in transformers using UHF technique and concluded that noise free phase-resolved partial discharge patterns could be obtained using the narrow band UHF technique [21].

The UHF PD detection technique is effectively a tool for Non-Destructive Testing (NDT) and can identify active defects present in the insulation structure during operation. However, its application to transformers in the field as a condition monitoring system is still limited. Further research is needed to lay the foundations for understanding the characteristics of UHF signals generated due to incipient discharges formed under DC voltages to improve confidence for its use by engineers carrying out DC tests on converter transformers. Hence an attempt has been made in the present study to understand the feasibility of applying UHF sensors for identification of partial discharge activity in transformer oil under DC voltages.

2. Experimental

The experimental setup used for the present study is shown in Fig. 1. AC voltages were generated using a test transformer rated at 50 Hz, 1.25 kVA, 0–50 kV. DC voltages were produced using a 0–100 kV, 1 mA supply source. Both applied AC and DC voltages were measured using a high voltage probe (Tektronix model. No. P6015A) connected to digital oscilloscope.

The test cell used in the present work is shown in Fig. 2. It consists of two electrodes in a cylindrical container filled with transformer oil (type L10B reclaimed). The upper electrode was spherical and the lower one was a slightly concave dish to contain the particle. The gap between two electrodes maintained at 15 mm. A small aluminium ball of diameter 2.5 mm was placed in the concave lower electrode while the high voltage was connected to the top electrode. In the present study, the AC and the DC voltages were increased at a rate of 300 V/s up to the required test voltage level. In the present study the conventional PD measurement is adopted and an attempt has been made to correlate the produced UHF signal with partial discharge magnitude.

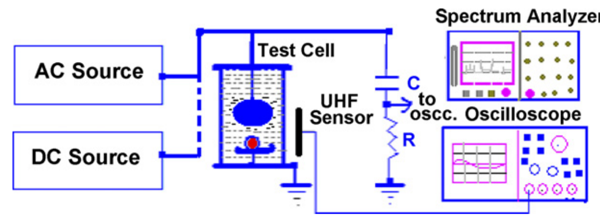

Fig. 1. Experimental setup.

To measure the PD current, adopting conventional technique, a standard coupling capacitor of 50 kV, 1000 pF in series with a measurement impedance of 150 Ω was connected across the test object. PD pulses developed across the impedance were measured using an oscilloscope. To improve the sensitivity of PD measurement in terms of pulse shape and magnitude, a low-noise amplifier (Hewlett Packard 8447D amplifier) was added at the output of the detector circuit. The amplifier used in the circuit had a bandwidth of 1300 MHz and the voltage gain of ×20. To eliminate interference from UHF signals on the capacitively coupled current pulse measurement, a low pass filter with a cut-off frequency of 5 MHz (mini circuit, BLP 5+ LP filter) was placed before the amplifier, resulting in a bandwidth of 0.3–5.0 MHz for the conventional PD detection part of the circuit. This circuit was then calibrated using a commercial PD calibrator (Lemke Diagnostics GmbH-Model LDC-5) in the range 5–500 pC to inject known levels of charge.

The UHF sensors used for partial discharge detection must have broadband response, the reason being the frequency content of signals from a PD varies depending on its location and the signal path.

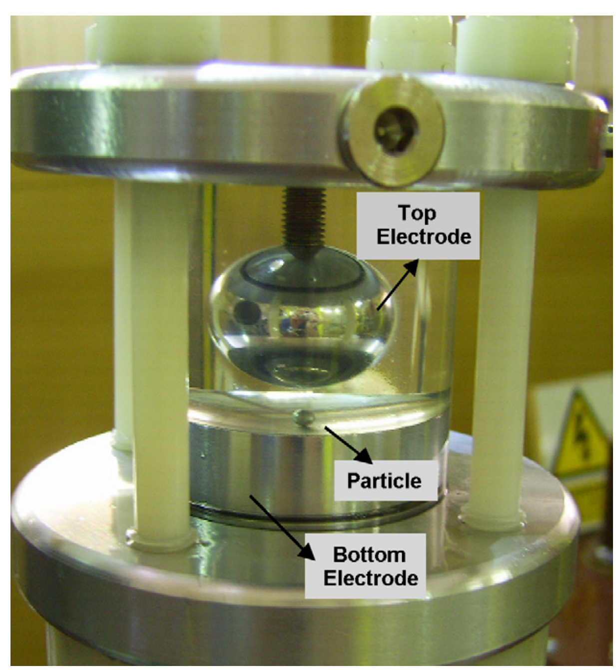

Fig. 2. Photograph of the test cell.