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Power Distribution Transformer Insulation Assessment for Prevention of Potential Failure to Enhance Power Quality

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ABSTRACT
This research provides dielectric assessment of power distribution transformer overall insulation integrity with breakdown voltage and partial discharge test as an important aspect of detecting insulation defects as well as problems relating to poor design in high voltage transformers. Knowledge of the conditions under which different types of decomposing activities are likely to occur, measures are taken to ensure against premature system failures resulting to insulation defects. A non-destructive partial discharge measurement introduced along with phase-resolved partial discharge pattern were analyzed to establish the condition of a high voltage electrical transformer insulation system. This research work gives an in-depth assessment of dielectric insulating oil and partial discharge measurement technique to investigate transformer insulation integrity so as to ensure system reliability for improved power quality. Despite the high BDV value of 77.9kV, it still recorded a 73.58pC on injecting a 19.00kV RMS for 500kVA/33, 0.415kV. Results obtained in this research work clearly demonstrate that notwithstanding the impact of dielectrics strength on transformer oil as regards insulation, confirmed that elevated breakdown voltage test value does not completely guaranty good insulation nor detect defects such as bubbles, cavity and voids that occurs within the high voltage transformers insulation. However, partial discharge measurement with MPD/MI software reveals all forms of insulation problems including design errors, thereby increasing transformer optimization and reducing down time. This technique is used to determine if partial discharges are occurring above a certain value when predetermine voltage is applied on the system.
Keywords: Insulation assessment, Failure prevention, Partial discharge, Transformer, Power improvement

1. INTRODUCTION

Distribution transformers are very crucial in deciding the power flow in a large power systems when implementing the installation of an electrical transformer, several tests are conducted to determine the electrical, mechanical and thermal suitability for the system where they will be applied and used. In recent development of electrical power systems, power plant capacity growth has been a major achievement in the power industry. This power is conveyed at a voltage higher than the generated voltage with the consideration of losses along the line, to lessen the force misfortune along the transmission lines, the high voltage transmission is done at low current. However, for this reason, transformers are generally utilized in the electricity distribution subsector. The motivation behind power distribution transformers is to lessen the essential voltage of the electrical circulation framework to a use voltage that serves the consumer [1], [8], [13].

Transformer has no moving parts, aside from the tap transformers, cooling fan and siphon engines. Thus, it cannot easily breakdown like other rotatory machines. Utilizing considerable protection against copper winding, laminated core and other significant parts, transformers are designed to endure endlessly.

However, insulation materials for most part produced using cellulose materials regularly get weakened from the impact of temperature, oxygen, moisture, heat and electrical stresses that affect the insulation condition of transformers [7]. However, various distribution transformer failures in recent past lead to power supply disturbances and has acquired much attention from electrical engineers. Different preventive, predictive and spontaneous assessment techniques has been designed to eliminate or at least minimize the failure failures [2].

II Literature Review

The insulation system of a transformer undergoes ageing due to transformer operating conditions. Thermal, electrical, and chemical stresses act on the insulation system during operation of the equipment to cause an irreversible change in the properties of the insulation system. Such ageing stresses may cause either intrinsic or extrinsic degradation of insulation materials. In most insulation systems, extrinsic ageing predominates because of the presence of imperfections and contaminants. The solid insulation and mineral oil form an inseparable insulation system in a transformer [3]. Cellulose-based insulation and mineral oil used in transformers degrade with time. The degree of insulation ageing depends on thermal, electrical, chemical, and mechanical stresses within the transformer. The temperature of the oil–cellulose insulation plays a major role in influencing the mechanical, chemical, and electrical properties of the material. The temperature of the insulation depends on the loading pattern of the transformer and on ambient operating conditions. Hence putting up measures to deal with issues of insulation defects cannot be over emphasized [1], [7], [8]. It is therefore important to undertake a study in this crucial aspect to prevent uncontrollable system outages. Partial discharge as a veritable tool as an assessment apparatus for high voltage insulation appraisal test [4]. The test arrangement includes gathering of electrodes for the production of artificial partial discharge sources mostly acquired in high voltage electrical equipment with the test arrangement designed such that the crack, cavity or void can be adjusted to modify the discharge characteristics for example the inception voltage, amplitude, repetition rate, and so on. Accordingly, the testing interface has an asymmetrical and radial arrangement of the partial discharge sources around the coupling capacitor of the measurement system which assists with lessening the impact on the measuring circuit of the measurement [5], [13].

1.2 Chemical Detection Method

Partial discharges can be detected chemically as long as the current steamer across the void can breakdown the surrounding materials into various substance parts. The two primary substance test performed by high voltage transformers manufacturing organizations today are high performance liquid chromatograph (HPLC) and the predominant dissolved gas analysis (DGA) [9], [8] . Chemical estimation methods are consequently not appropriate for continuous checking in light of the fact that it doesn't give any data about the situation of the PD or the degree of harm done to the insulation. Another know chemical test is the DGA (Dissolved Gas Analysis) test which identifies accumulated deposit of gases produce by the breakdown of mineral oil in the transformer, which disintegrate once again into the oil. Subsequently, causing insulation vulnerability because of different impurities in the mineral oil [2], [6], [13].

1.3 Electrical Detection Method

Electrical identification approach is usually utilized and generally well known technique for estimating partial discharge in high voltage power hardware. The electrical detection technique as the most famous method for partial discharge measurement in transformers [11]. This method centers around catching the electrical pulses initialed by current steamer in the void, these pulses are sustained for single nanoseconds which suggests an exceptionally short duration of pulses span and have quantifiable frequency components in excess of 1MHz [13]. The pulse shape, its corresponding phase location within the AC pattern of the HVT, and the signal intensity all lead to information about the kind of partial discharge fault and the severity of defect in insulation. Electrical estimations are divided into two distinct classes, direct probing and RF emission testing [8], [12]. The direct test approach necessitates that the capacitive couplers be connected with the phase terminals of the transformer.

1.4 Dielectric Breakdown in Liquid Insulation

Insulation breakdowns are generally brought about by partial discharge activities, these phenomena most occurs in the weak region of an extended insulating system [7], [10]. Liquid Insulation is generally utilized in high voltage electrical hardware like transformers, circuit breakers, Reactors, Ring Main Unit (RMU), and so forth. In transformers, the dielectric is used to provide required insulation between the active parts of the transformer just as the grounded parts, it likewise discover an application in heat transfer from the transformer to the environment subsequently giving a cooling impact. In electrical breaker switch it likewise gives insulation to the active parts and the grounded parts, here the liquid dielectric is utilized to extinguish arcs created around the breaker contacts. The liquid dielectric is mainly gotten from petroleum products [2], [8], [13].

III. MATERIAL AND METHOD

Materials

The following materials were used for the experimental demonstration of the reliability evaluation of power distribution transformer prevention of potential failure for improved power quality

(i) MPD 600 acquisition kit/ charger unit, (ii). Measurement calibration kit, (iii). Overload impedance measurement, (iv). Capacitive measurement sensor (v). Fiber optic bus controller

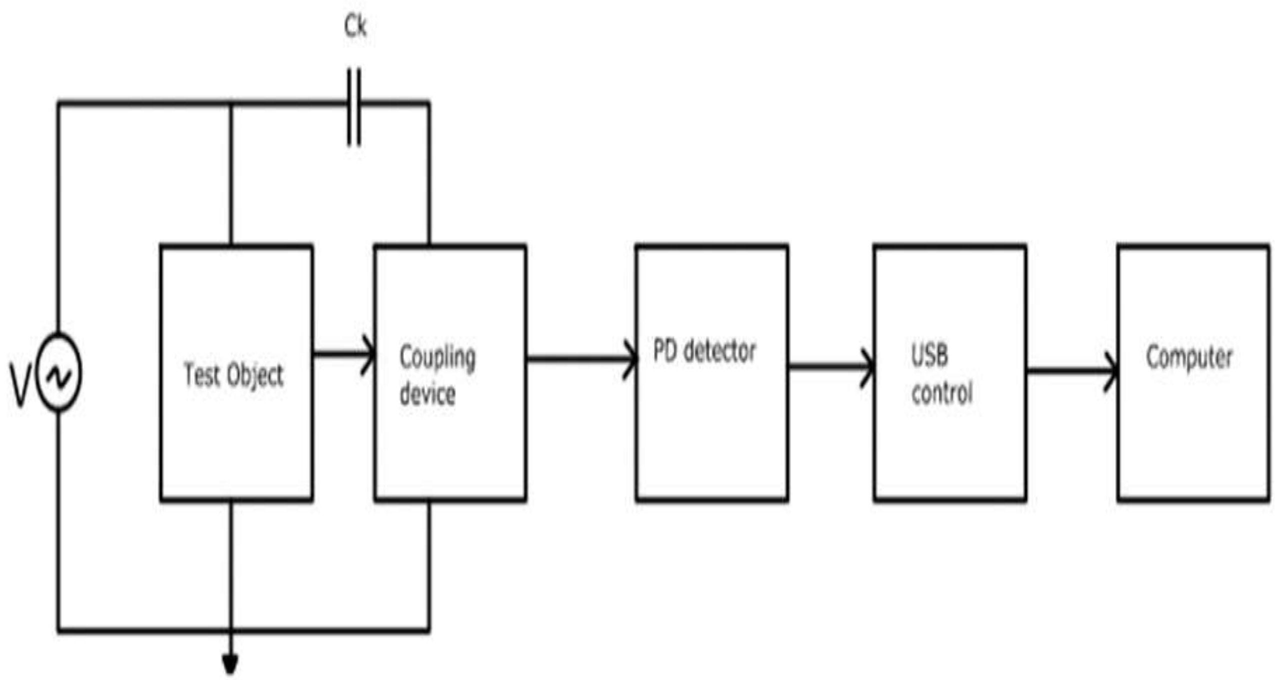


Figure 3.1: Block Diagram of PD Testing Procedure

Method

The various methods adopted in this research are as follows:

i. Simulation of partial discharge activities in distribution transformer insulation using MPD/MI software
ii. The transformer under investigation is calibrated using the omicron calibration gadget CAL542 to fulfill the requirements of IEC 60270
iii. Mathematical modeling using dielectric capacitive bounded cavity
iv. The coupling capacitor with very low inductance, high voltage filter to reduce back ground noise generated from the power supply.

v. The overload protection impedance to synchronize all partial discharge measurement equipment with the test voltage

vi. The MCU 502 fiber optic bus is used to mainly transfer partial discharge signals to the PC through the fiber optic cable to further attenuate interference.

3.1 PD Measurement System within the Test Circuit

To evaluate the fundamental quantities of partial discharge pulses, apparent charge magnitude qi is considered. An efficient measurement procedure ought to be utilized for proper data acquisition for possible analysis, now, it ought to be referenced that under practical condition quite various types of disturbances, for example, background noise are often present in the partial discharge measurement.

Most partial discharge estimation procedures are typically incorporated into the test circuit in accordance with scheme shown in Figure 3.2. The detection circuits beneath has the coupling device, CD and the impedance Zmi as its feedback boundaries for the measurement system. These parameters are likewise positioned at the high voltage terminal provided the test object has one of its terminal earthed. The partial discharge signals are created at the impedance Zmi. The Optical connection is then used to interface the MPD 600 and the MCU 502 to forestall undesirable signs in type of clamor and furthermore to improve the nature of partial discharge signal at the output. The fiber optical link test set-up to the control PC and give total electrical protection and the link association with the MPD 600 is up to 2km long.

Assuming the two terminals are associated along with an external capacitor CK, the charge development inside the series connected insulation links Cb and Cc will likewise be contained in the charge of the external capacitor Ck. The charge developments can be detected as circulating impulse current I (t) in the parallel connected capacitors given as Ck and Ct as contained in Figure 3.2

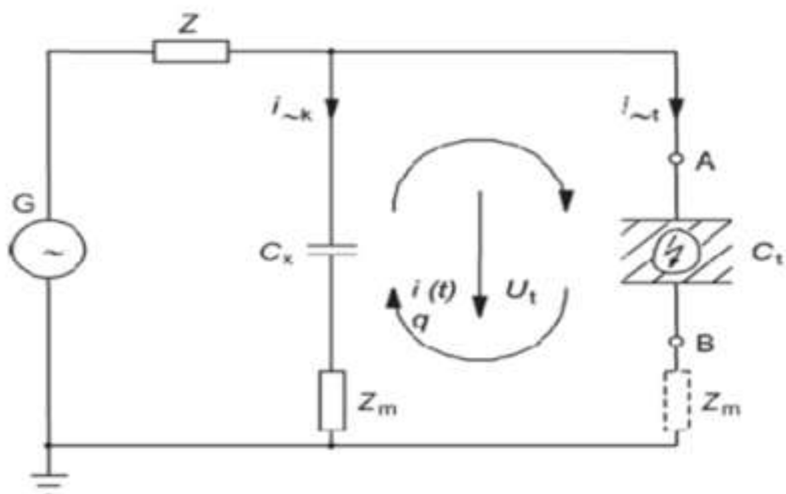


Figure 3.2: Equivalent Circuit for PD Measurement

Ct = Ca Test object capacitance, G = High Voltage AC voltage source, Z = Voltage source connector
Ut = Voltage of parallel connected capacitors, Zm = Measuring Impedance, I (t) = PD current pulse
I-k, t = Displacement current, Ck = Coupling capacitor

All dielectric material has an attributes of dielectric strength, which is maximum value of electric field that it can withstand without breakdown. Assuming the capacitance of any capacitor can be written in type of

C = ƐO ℓ (3. 1)

Where,
C = Capacitance of any capacitor, ℓ = Parallel plate capacitor, Ɛo =Permittivity constant

In which ℓ has the component of the length, For instance, ℓ = A/d for an equal plate capacitor? Faraday's admission was that with a dielectric totally occupying the space between the terminal A and B.
Equation 3.1 becomes

$$C = K\varepsilon_o \ \ell = KC_{air} \quad (3.2)$$

Where, Cair is the value of the capacitance with just air between the terminal A and B.

Recall, the power supply (Battery) guarantees that potential difference V between the terminal A and B will remain constant. At the point when a dielectric material is utilized to show the plate or terminal A and B, the charge q on the plate increases by a factor of K, the excess charge is conveyed to the capacitor plate by the supply. For the situation where there is no supply the charge q should remain air constant when the dielectric separator is embedded, then, at that point, the potential difference V between the terminals reduces by a factor of K. This load of observations are consistent (through the connection q = CV) with expansion in capacitor brought about by the dielectric. Comparing equation (3.1) and (3.2) gives a situation of a region totally filled by the dielectric material of dielectric constant K, all electrostatic conditions containing the permittivity constant Ɛo are to be altered by replacing Ɛo with Kεo. Consequently, the size of the electric field created by a charge inside a dielectric is given by this changed structure:

$$E = 1/(4\pi K\varepsilon o)\ q/r^2 \quad (3.3)$$

Likewise, the expression for the electric field just outside an isolated conductor immersed in a dielectric is given as

$$E = \sigma/K\varepsilon o \quad (3.4)$$

Where K is constant and greater than unity, both of these conditions show that for a proper dissemination of charges, the impact of a dielectric is to weaken the electric field that would somehow or another be available.
Fig 3.8 Equation shows the circuit diagram of cavity in a liquid insulation with an estimated energy in a discharge released by cavity.
The same circuit of fig 3.3 is considered; hence the total capacitance of dielectric framework is given by:

$$C = c_a + \frac{c_b \times c_c}{c_b + c_c} \quad (3.5)$$

$$\Delta v_1 = \Delta v_c \times \frac{c_b}{c_a + c_b} \quad (3.6)$$

$$q_a = \frac{c_b \times c_a}{c_b + c_a} \times Vc \quad (3.7)$$

$$c_b \le c_c \le c_a \quad (3.8)$$

$$q_a = c_b \times \Delta Vc \quad (3.9)$$

The energy in the discharge is calculated by taking different energy before and after the discharge in the capacitance of the cavity

$$w = \frac{1}{2} \times c_c \times (u^2 - v^2) \quad (3.10)$$

$$(u^2 - v^2) = (u - v) \times (u + v) \quad (3.11)$$

Considering the residential voltage in cavity, then voltage across cavity is given by

$$\Delta v_a = u - v \quad (3.12)$$

If residual voltage is not considered and by putting equation 3.11 and 3.12 and 3.10 the following equation is obtained

$$w = \frac{1}{2} \times C_C \times \Delta V_c \times U \quad (3.13)$$

When there is no discharge in the voids and discharge take place at peak voltage, breakdown voltage u is given by

$$u = \frac{C_b}{C_b + C_c} \times v_{peak} \quad (3.14)$$

Combining equation 3.14 and 3.13

$$w = \frac{1}{2} \times C_C \times \Delta_{Vs} \times u \times \frac{c_b}{c_b + c_c} \times v_{peak} \quad (3.15)$$

$$c_b \leq c_c$$

As cavity depth is less than insulation thickness

$$w = \frac{1}{2} \times C_C \times \Delta_{Vs} \times \frac{c_b}{c_b + c_c} \times v_{peak} \quad (3.16)$$

From equation 3.9

$$W = \frac{1}{2} \times q_1 \times v_{peak} \quad (3.17)$$

Where,

W = Energy stored in a capacitor, Ca = capacitance of weak region or cavity, Cb = Capacitance representing insulation material around cavity, Cc = Capacitance of remaining insulation material, q_1 = Transferred charge, Vpeak = Peak voltage, U = Breakdown voltage, ΔVs = Voltage drop at Vs, ΔVc = Voltage drop across Vc, u = Initial Voltage, v = Final Voltage

IV RESULTS AND DISCUSSION

4.1 MPD/MI Stimulation and Experimental Results

Transformer oil dielectric strength is very important in ensuring reliable operation of power distribution transformer. The test is mainly determined by the presence of contaminate like moisture, acids and other related gasses. It is therefore important to constantly maintain these dielectric properties to always ensuring good transformer insulation condition. Although, dielectric properties in transformer oil decreases with time as well as service condition. However, a more sophisticated means of detecting the oil component and the overall insulation condition of transformer is employed in this work called the partial discharge measurement system. The operation of the MPD 600 monitor are fully computer controlled system. The MPD partial discharge examination system is the obtaining and investigation unit for identifying, recording and breaking down partial discharge occasions in numerous applications

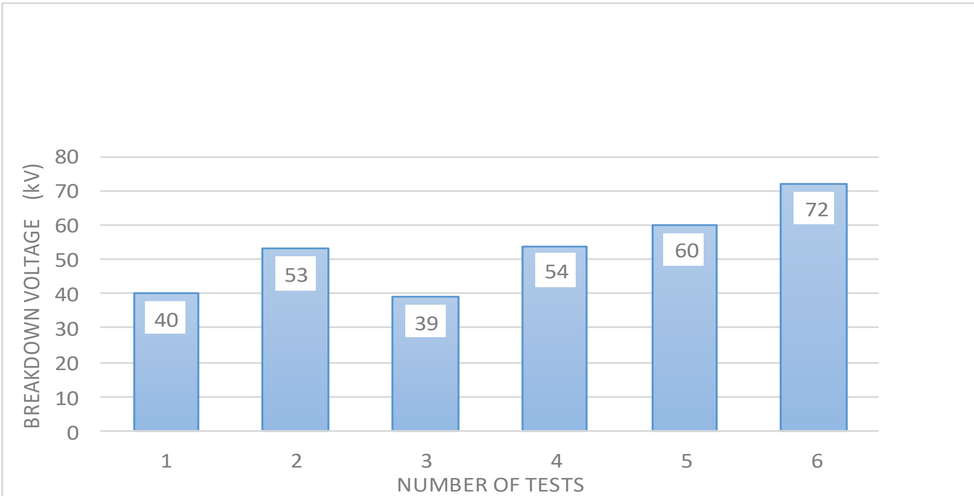


Figure 4.1: Breakdown Voltage Level (kV) at 30^{o}C

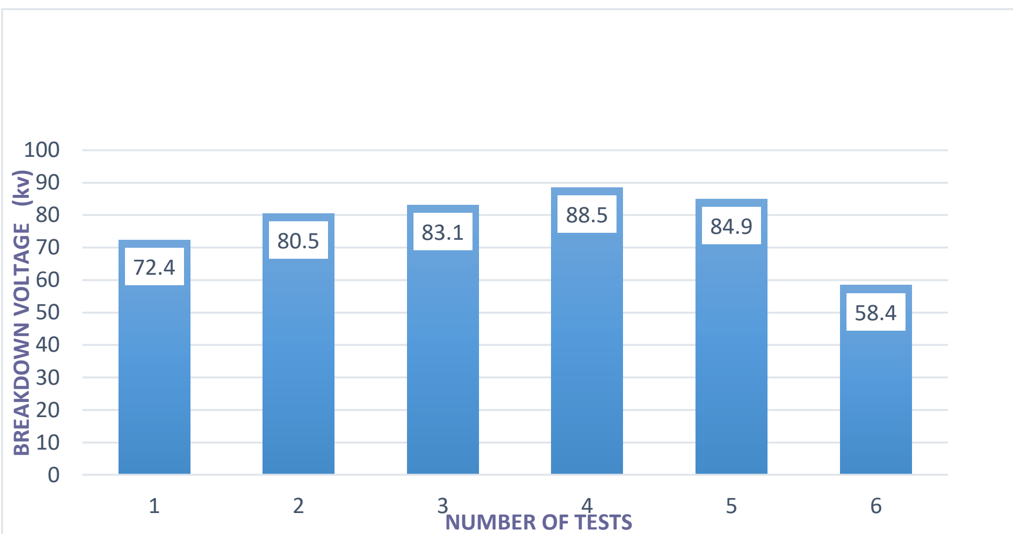


Figure 4.2: Breakdown Voltage Level (kV) at 34^{o}C

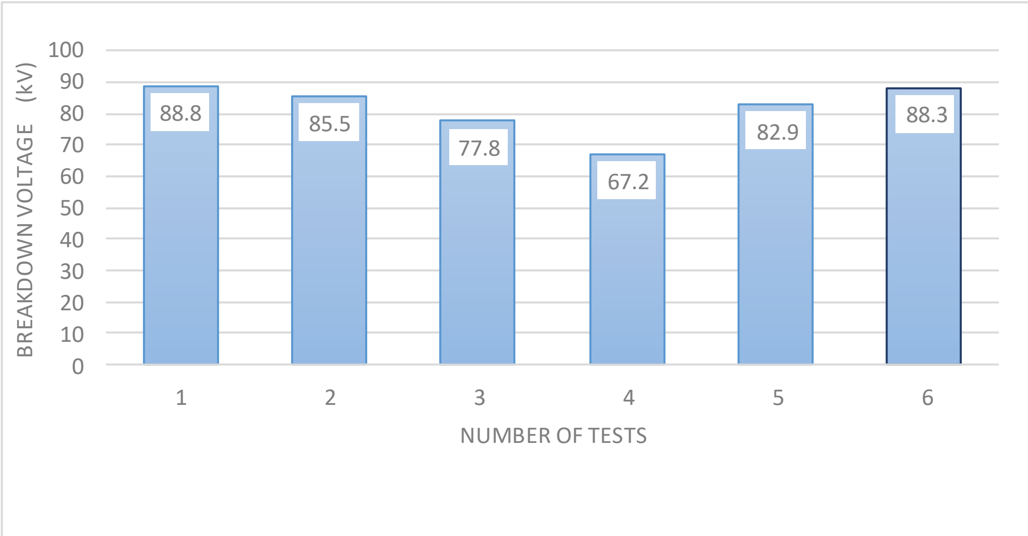


Figure 4.3: Breakdown Voltage Level (kV) at 35^{0}C

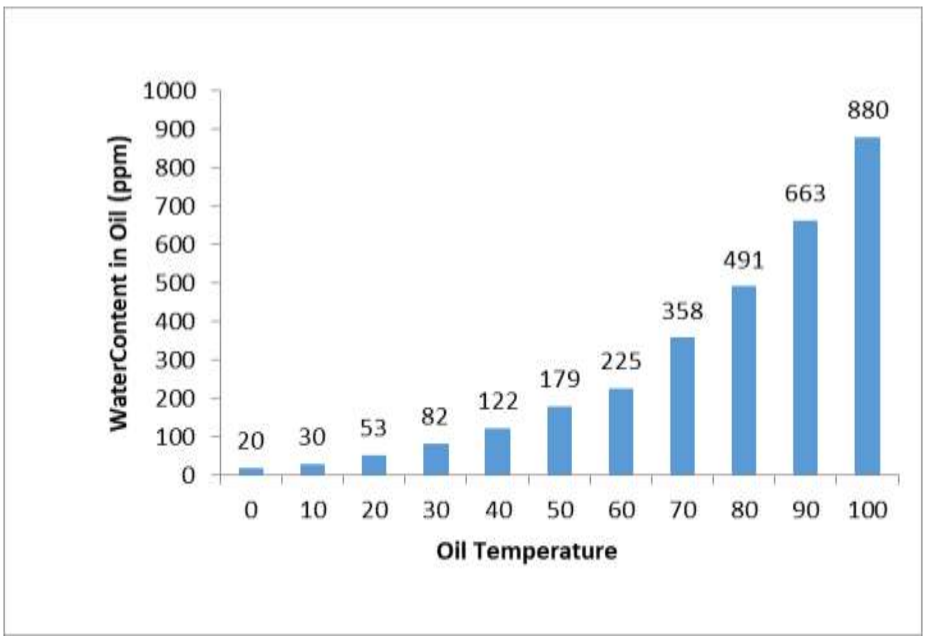
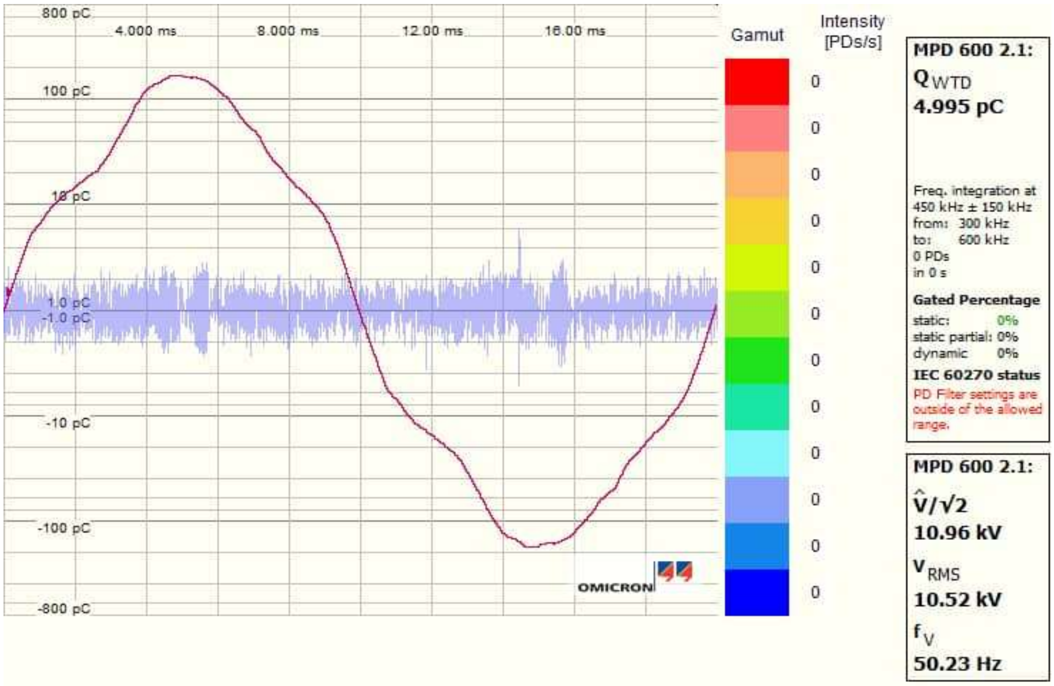


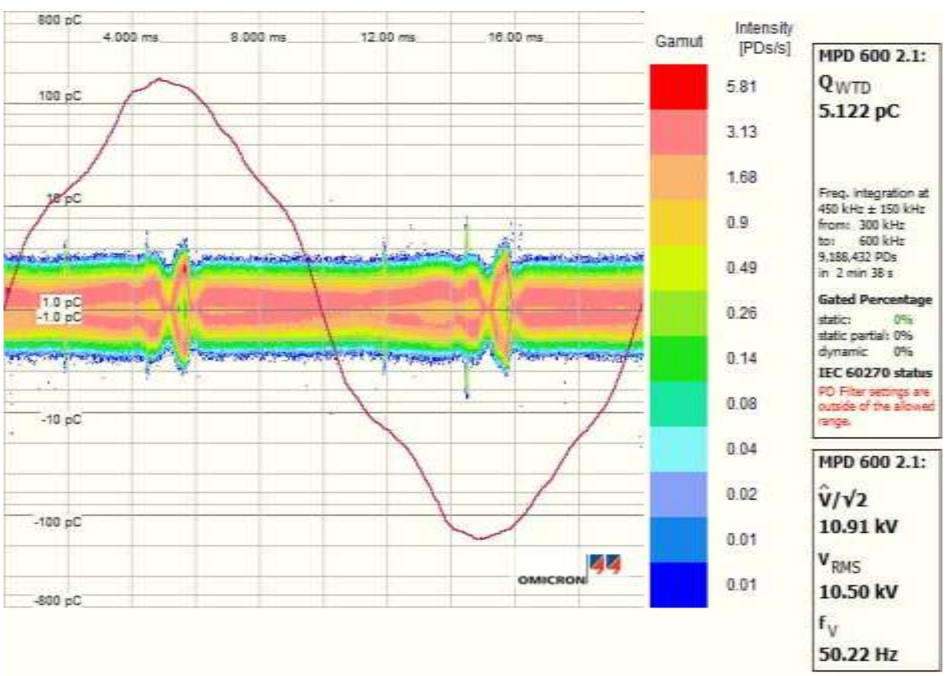
Figure 4.4: Water in Oil Solubility as Against Temperature

The Figure 4.4 shows vividly distribution of transformer oil temperature rise versus water content in oil (ppm), gradual rising formation (see Table 4.4 in appendix – D



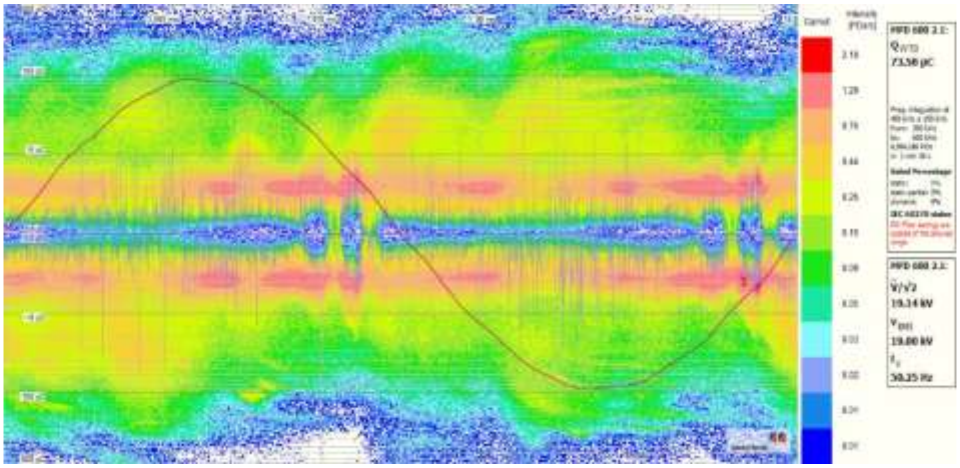
4.995pC at 10.52kV

Figure 4.5: PRPD Pattern Measured on 500kVA



5.122pC at 10.50kV

Figure 4.6: PRPD Pattern Measured on 500kVA



73.58pC at 19.00kV

Figure 4.7: Failed PRPD Pattern Measured on 500kVA

V CONCLUSION

The purpose of this investigation was to measure the insulation disorder in 500kVA transformers to determine its ability to withstand electrical stress. The main purpose of this research is to proffer solutions to the recurring breakdown problems of power distribution transformers via breakdown voltage and partial discharge test of 500kVA transformers. I therefore decided to examine a couple of failed transformers as to know if they meet required standard insulation demand. In order to fulfil this aim, I used a 500kVA transformers as a sample to validate the efficacy of the phase-resolved technique and the dielectric composition used to inspect the transformer reveals that partial discharge measurement has the ability to completely detect the overall insulation defect that may not be revealed through other testing methods.

Following a thorough evaluation of the insulation of the 500 kVA transformer using the phase resolved technique, it was found that few of the transformer with appreciable BDV test values were healthy up to 10kV and the transformer's users could carry out all essential tests efficiently to avoid unwanted failures. When compared to other methods such as the acoustic method and Dissolved Gas Analysis, the phase-resolved approach was acceptable for measuring fault in transformers insulating medium since it can quickly detect the different PD faults and their localization.

In light of the above, the previously held beliefs about the state of the 500kVA transformer in some of the results sampled were in perfect condition. Some other results shown above proofs that the transformer insulation condition has been altered, while displaying a very high Pico column value way above the acceptable criteria according to IEC 60270. The functioning/durability of a transformer primarily depends on the nature of their insulation integrity.

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