International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 13 (2015)

Polarization and Depolarization Current Measurement – An Effective Technique for Detection and Analysis of Mechanical Displacement of Transformer Windings

S. Natarajan[1] , S. Venkatesh[2], R.Rajesh[3], and S. Mohamed Ghouse[4]

Department of Electrical and Electronics Engineering, School of Electrical and Electronics Engineering, SASTRA University, Thanjavur- 613401, India.
natraj_1971@hotmail.com[1], venkatsri73in@gmail.com[2], rajeshjim@gmail.com[3], ghouseee@yahoo.co.in[4]

Abstract
Healthiness of a power transformer is very vital in today's developing world for ensuring reliable and quality power supply to consumers. Transformer insulation fails mainly due to ingress of moisture and various traditional methods have been utilized to determine the moisture content in oil. Yet, identification of moisture which impregnates into the paper/ pressboard insulation or mechanical displacements of transformer windings due to accumulated short circuit forces during electrical faults, through a nondestructive technique is still a complex task. Polarization Depolarization Current (PDC) analysis is an emerging and a reliable technique with which these flaws can be clearly identified and can even be effectively discriminated (whether it is in oil or pressboard) while the conventional methods (like Breakdown Voltage Test on oil sample) identify moisture in oil only. In this research study an attempt has been made to develop a simplified insulation model of a transformer and an experimental setup is implemented for acquiring the PDC waveforms of the transformer model at different insulation conditions. The flaws have represented through their possible impacts on the dielectric capacitance and resistance of insulation. Careful analysis of the observed variations in PDC patterns indicate and signify the behavioral changes of the flawed transformer dielectric systems.

1. Introduction

Power transformer is a vital constituent which plays a primary role in effective and reliable power transmission and distribution in a power system. Globally large numbers of power transformers are reaching the end of their design life after several years of continuous service. Replacement of such transformer is neither a realistic nor viable solution since thorough techno economical studies needs to be taken up to ascertain the soundness of the insulation system before arriving at a comprehensive decision. Conventionally a variety of electrical, chemical and mechanical techniques have been in vogue for insulation condition assessment of transformers [1],[2]. Moisture ingress and insulation degradation is a prominent issue pertaining to the insulation healthiness and effective operation of transformers. Another important aspect in transformer insulation which is disregarded though unintentionally, is the physical displacement of windings either due to initial transportation during installation or due to the continuous electrical and thermal stresses that are inherent in the power system. Detection of such displacements in winding without dismantling and analyzing the transformer is a difficult task. Polarization and Depolarization Current (PDC), an emerging non destructive testing technique, generally used to assess the moisture content in the oil and solid insulation of a transformer[3],[4],[5] provides a viable alternative to address the complex aspect of discriminating such winding flaws. The basic principle behind the operation of PDC method is based on the important dielectric property which exhibit electric polarization on application of electric field and depolarization after removal of electric field in the dielectric. The transformer or test specimen can be viewed as a model comprising of parallel combination of R and C elements. The resistance component is modeled for accounting the conduction current path (leakage current) which flows through the lossy dielectric and the capacitive component is modeled for accounting the displacement current that flows through the dielectric as a result of polarization. If the specimen is short circuited after this polarization, depolarization starts and a reverse polarity current flows which is accounted as the action for normalization (reorientation) of the dipoles to their original position.PDC measurement in test specimen configured as coaxial cylindrical lossy dielectric(comprising of a parallel R and C combination) is done by injecting a DC voltage into the test specimen for a considerably time to initiate polarization and isolating the test specimen suddenly from the D.C supply to initiate depolarization. During DC injection, polarization current flows through the object. After the supply is removed and the specimen is shorted onto itself, depolarization starts and gives rise to a discharging current which tends to normalize the dipole positions. Fig. 1 and Fig. 2 depict schematic diagram of measurement and a typical waveform during PDC analysis [6],[7].

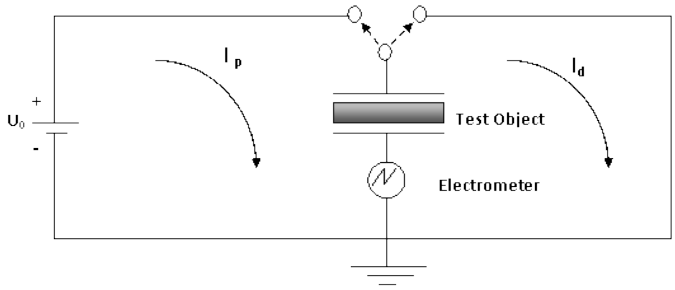


Fig.1: Schematic diagram for PDC measurement

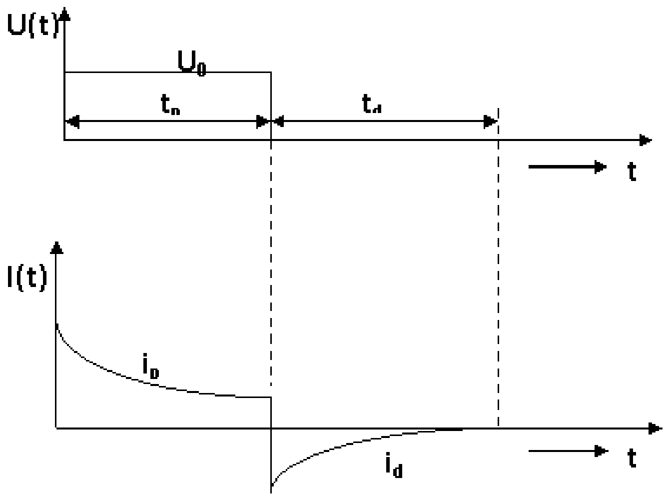


Fig.2: Typical PDC waveforms

In the research study, attempts have been made for implementing a test and measurement setup to perform PDC analysis on fabricated laboratory models that replicate the dielectric system of a transformer. In the modeled system developed for our investigations, the insulation system and fabrication arrangement comprises coaxial insulation cylinders with windings over them, the winding position being deliberately modifiable to change the dielectric capacitance of the system.

It is evident that the change in capacitance of a coaxial cylindrical capacitor can be obtained with variation in distance of between cylinders (i.e. radial displacement) or change in the overlapping area of the cylinders (i.e. axial displacement).

In this research, to simulate a mechanical radial displacement oriented fault, which is represent able by a change in capacitance between cylinders and to observe its subsequent effect on PDC Waveforms, the overlapping area of the cylinders is kept fixed while, the spacing between them is varied deliberately by moving the inner cylinder (radial movement). The Subsequent variation in the value of capacitance will have a direct bearing on the nature of PDC waveforms. Careful Comparison of the PDC waveforms of test specimen obtained before and after such artificially induced winding displacements and detailed analysis of changes in PDC waveforms can be capitalized to ascertain condition, the degree of healthiness of the transformer insulation.

2. Test Setup for PDC Experimentation and Analysis:

The major components for the test arrangement comprises (1)500V D.C source, (2) a fast acting controllable switch (3) sample Under Test (4) measuring resistance and (5) Digital Storage Oscilloscope (DSO). In this study, the test sample consists of coaxial metallic cylinders wherein oil (paraphine) is filled between the coaxial cylinders. A Cockroft- Walton Voltage Multiplier circuit, which has been indigenously developed by the authors of this research in High Voltage Laboratory of SASTRA University, provides an reliable and low ripple d.c. output voltage in the range 200V- 5KV. In this study an output voltage of 500VD.C is utilized. The transformer model comprising the two coaxial cylinders represents the short circuited primary winding and the short circuited secondary windings of the transformer while the oil between the cylinders signifies the lossy dielectric media. Thus the model looks like a cylindrical co-axial capacitor.

The equivalent circuit representation of the transformer may be modeled as a lumped resistor 'R'(resistance of the insulation accounting conduction current flow between the high voltage and low voltage windings) in parallel with a lumped capacitor 'C' (capacitive of the dielectric between the windings accounting polarization and depolarization currents). Fig. 3 shows the schematic layout of the test setup implemented for PDC measurement and analysis.

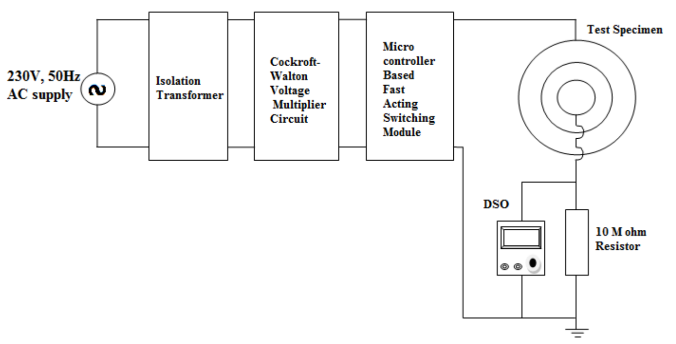


Fig. 3: Schematic Test Setup for PDC Analysis

The principal constituents of the Cockroft-Walton multiplier DC voltage source which provides the test voltage comprises (1) an isolation transformer, (2) diodes for rectification and (3) capacitors. The capacitors are implemented in two columns called oscillating column and smoothening column. Fig. 4 indicates a snapshot of the test setup developed for the experimentation and analysis.

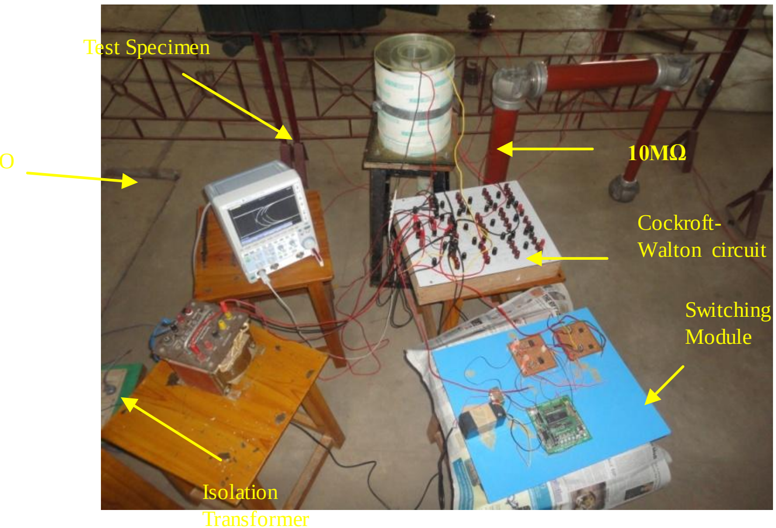


Fig.4: Photograph of the experimental test setup

Insulated Gate Bipolar Transistor (IGBT) is utilized as a fast acting switch in the switching module developed for obtaining the PDC characteristics. A microcontroller based triggering schedule is implemented for turning ON and OFF the IGBTs. The output from the microcontroller is either 0V or 5V indicating 0 and 1.Since 5V output is incompatible and inappropriate to turn ON the IGBT (IGBT is turned ON at 12V), a driver circuit is implemented. The driver circuit amplifies the output from the microcontroller and converts the 5V output into 12V output. Fig.5 shows the driver circuit implemented in this research study.

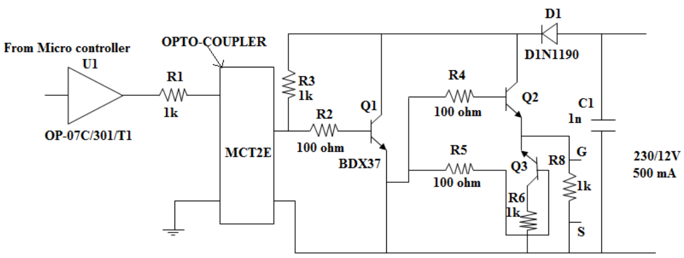


Fig. 5: Driver Circuit for Triggering IGBT

The driver circuit consists of an opto-coupler and a Darlington amplifier. The main purpose of the opto-coupler is to transfer a signal from one part of a circuit to another part which is at different voltage levels without making ohmic contact. Darlington amplifier consisting of two BJTs connected in such a way that the current amplification provided by the first transistor Q1 is again amplified by a second transistor Q2 thus ensuring higher current gain. Further, the availability and use of the integrated version results in optimal and effective utilization of space requirement (as they utilize a common shared collector). The output of the driver circuit is given as input to trigger the IGBT [12],[13]. Fig. 7 displays a photograph of the switching module designed and implemented in this research.

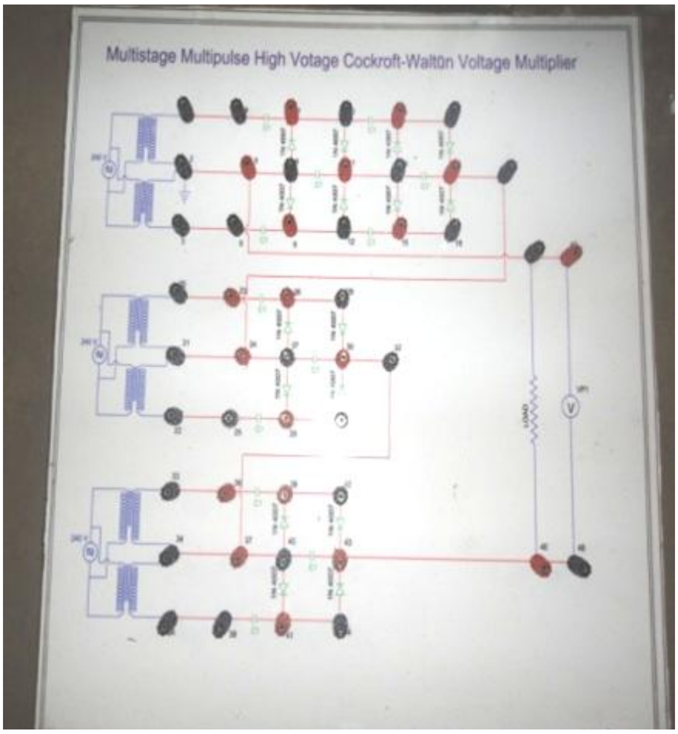


Fig.6: Cockroft–Walton Voltage Multiplier

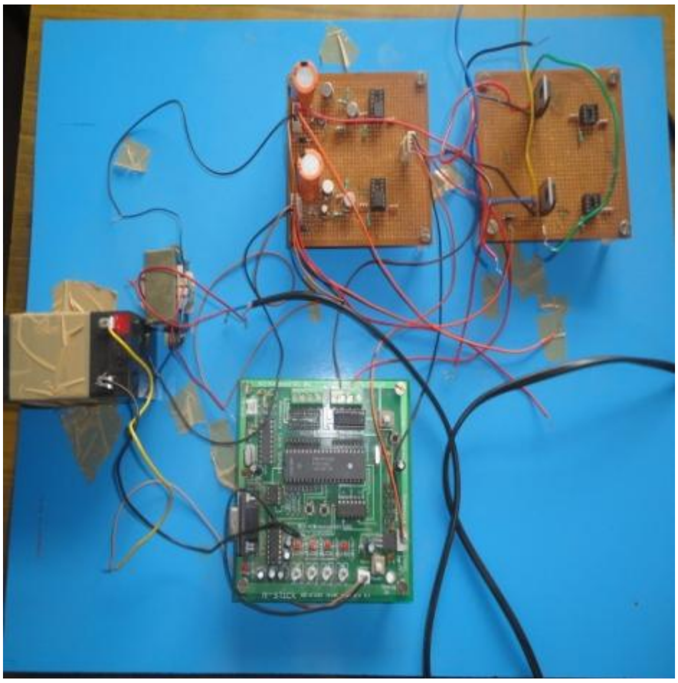


Fig.7: Electronic Switching Module

3. PDC Analysis of Test Specimen with Different Configurations

The fabricated laboratory test specimen comprises a coaxial cylinder with outer and inner cylinders fixed rigidly to a base acrylic support as shown in Fig. 8 and Fig. 9.

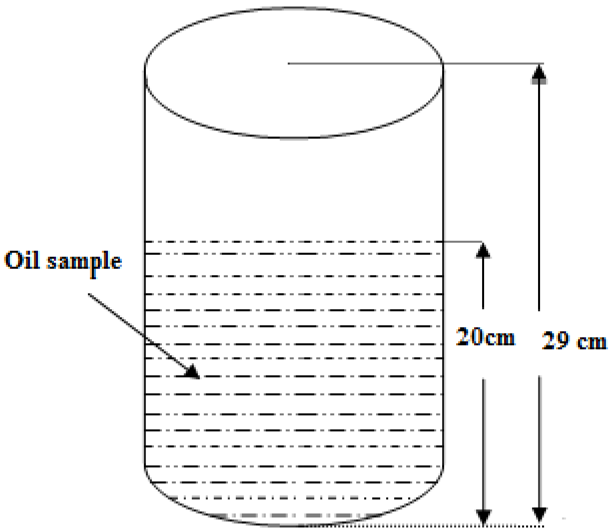


Fig.8: Front view of test specimen

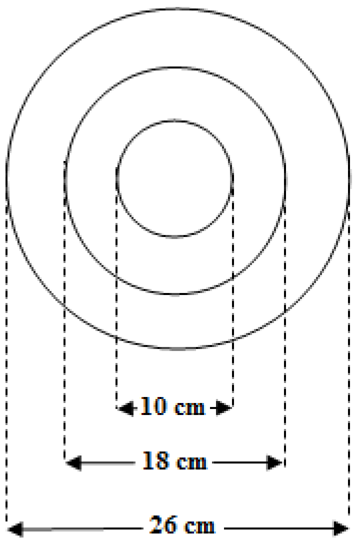


Fig.9: Top View indicating coaxial cylinder dimensions

Fig. 10 and Fig. 11 display the snapshots of the fabricated coaxial cylinder with oil filled between the cylinders.

Fig.10: Photographs of the Test Specimen

The height of the specimen is 29 cm. Aluminum sheets which form a part of the electrodes are used during fabrication of the model. Transformer oil (approximately 3 liters) is filled between outer and inner cylinder to a height of 20 cm. The middle cylinder is free to move axially and radially. Using an LCR meter the capacitance offered by the transformer oil between the outer and inner cylinder is measured. The insulation resistance (IR) withstand values are measured with the aid of a 500V manually operated Megger and for various configurations. It is noted during studies that the IR value was approximately 140MΩ without appreciable difference. The different configurations of the specimen are shown in Fig.11, Fig. 12 and Fig. 13 respectively.

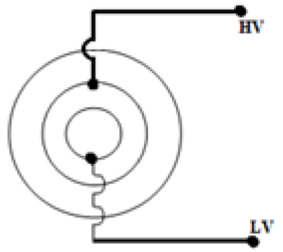


Fig.11: Inner plus middle Electrode Configuration

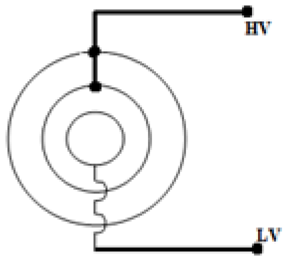


Fig.12: Inner plus middle and Outer shorted configuration

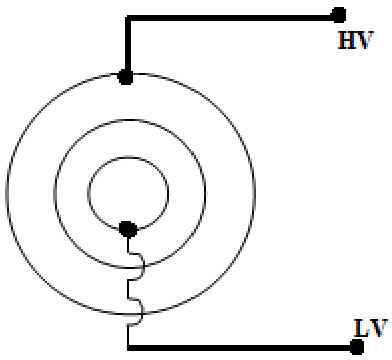


Fig.13: Outer plus inner Configuration

The capacitance values are measured using LCR meter and tabulated in Table 1.

Table1: Capacitance Values of the different configuration of the test specimen

Sl.No.	Configuration of the Test Specimen	Capacitance in pF
1	Between Inner and Outer cylinders	74.5
2	Between Inner and Outer cylinders with Middle cylinder	76
3	Between Inner and Middle cylinders	92
4	Between Outer Shorted with Middle and Inner Cylinders	110

4. Analysis and Inferences

The PDC waveforms are captured using a DSO connected across measuring impedance (say a 10MΩ resistance,). The 10MΩ resistor is connected in series with the specimen and the currents are obtained in the order of nano-amperes wherein the decaying rate depends on the time constant requirements which are captured during studies. The peak value of the current gives information about healthiness of the capacitance [8],[9],[10],[11]. Table 1 describes the various configurations of the coaxial cylinders and the difference in capacitance due to physical displacement and their subsequent influence in the PDC can be seen distinctly from the resultant waveforms. Three configurations of the specimen have been implemented and studies related to the peak currents and the rising and falling slopes of Polarization and depolarization current waveforms have been found to indicate appropriate results.Fig.14 shows the polarization waveform for the configuration comprising inner and outer cylinders.

Fig. 14 indicates the polarization waveform obtained with the DSO for the setup with oil between inner and outer cylinders.

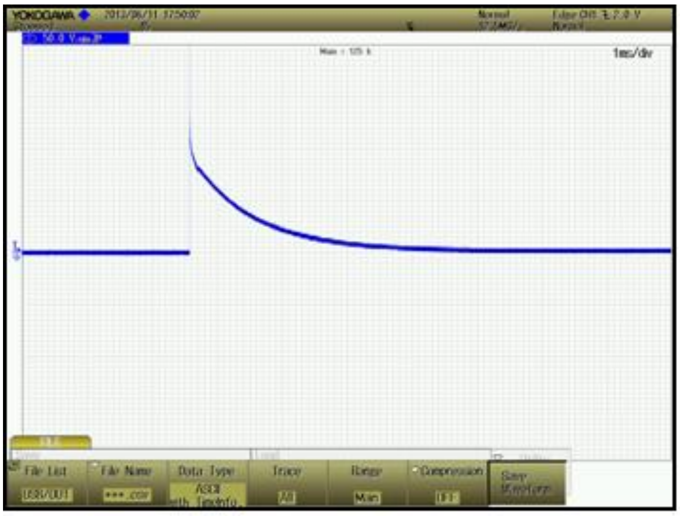


Fig.14: Polarization waveform for configuration comprising of inner and outer cylinders

Fig.15 shows the polarization current waveform for inner and middle cylinder.

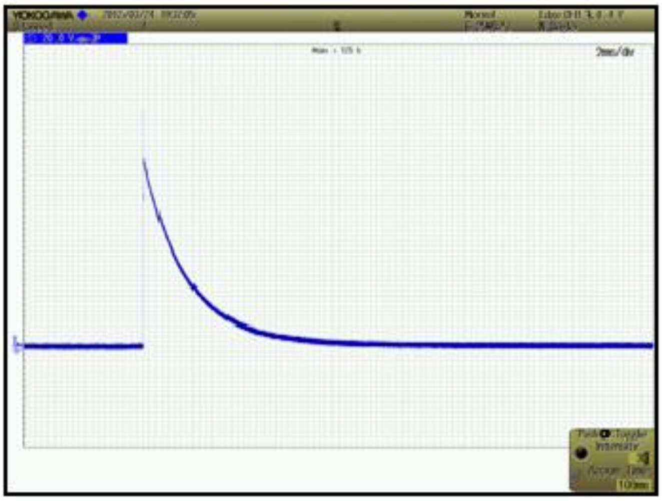


Fig.15: Polarization waveform -for configuration comprising of inner and middle cylinders

Fig.16 shows the polarization waveform for outer and middle cylinders shorted and between inner and shorted arrangement

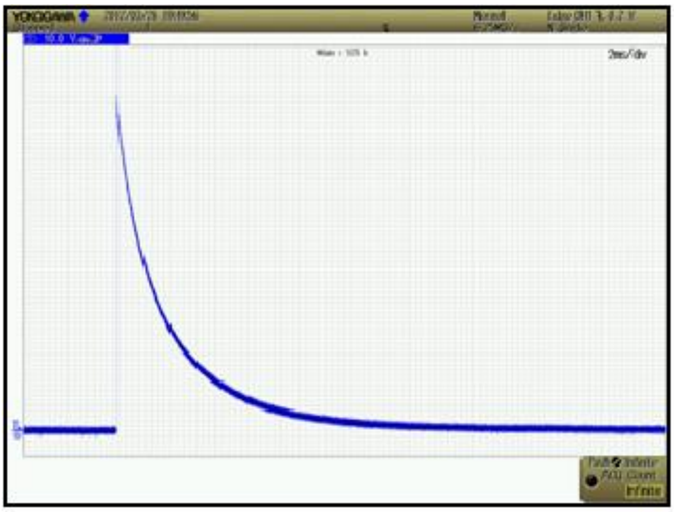
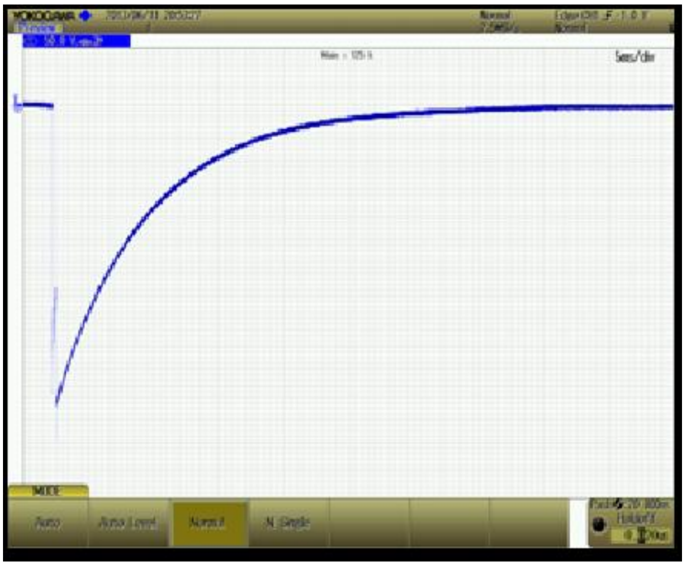
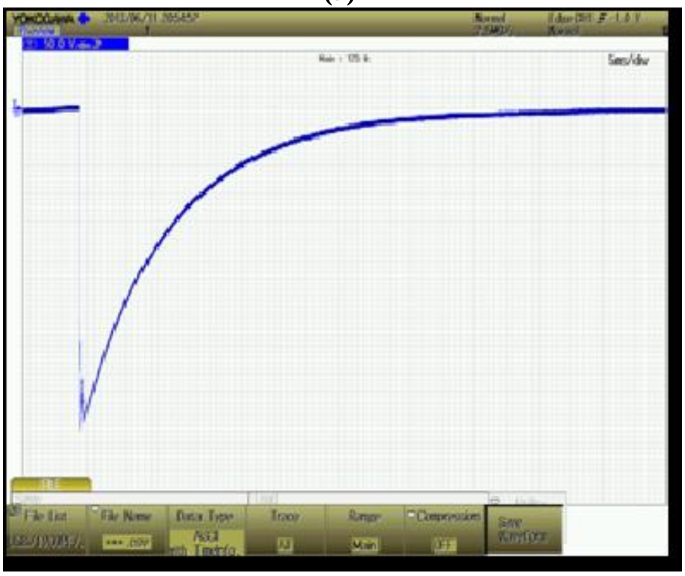


Fig.16: Polarization waveform for configuration comprising of outer shorted with middle and inner cylinders

From the depolarization current waveforms captured for the different configurations, it is inferred that there are no significant variations in the magnitude of peak currents. Fig.17 shows the sample depolarization waveforms for different configurations, comprising of (a) inner and middle cylinders (b) outer shorted with middle and inner cylinders configurations.



(a)



(b)

Fig.17: Depolarization waveform for the configuration comprising of (a) inner and middle cylinders (b) outer shorted with middle and inner cylinders

In this work the capacitance offered by the test specimen was checked with LCR mete, and for various configurations, it was found to be in the range of 79 to 110 pF. Hence for enabling precise analysis to be carried out from the resultant waveforms (involving higher rising and falling slope portions of the respective Polarization and depolarizing current waveforms), it was decided to add a known capacitor, preferably of a higher value in parallel to the test specimen, so that, the net resultant changes in the capacitance can offer even larger variations in PDC waveforms.
Considering the range of capacitance values, it was decided to use a 140kV, 1200pF capacitor available at HV lab of SASTRA University in parallel with the test specimen and to repeat the test procedure again. The basic idea behind this attempt is that during further analysis, the variations in PDC waveforms will be predominantly seen with higher valued net

capacitances (comprising the internal c of the test specimen and the externally added c, for enhancement). For example variations in capacitances, (in the specimen alone cases) in the range of 80pF to (80+ΔC)pF will not have much of an impact in the waveforms compared to 1280pF to (1280+ΔC)pF(with the enhanced case). Hence an available 1200pF capacitor was connected in parallel with the test specimen and the studies were repeated. The captured waveforms showed remarkable influences in the peak values and slopes of polarization and depolarization current.

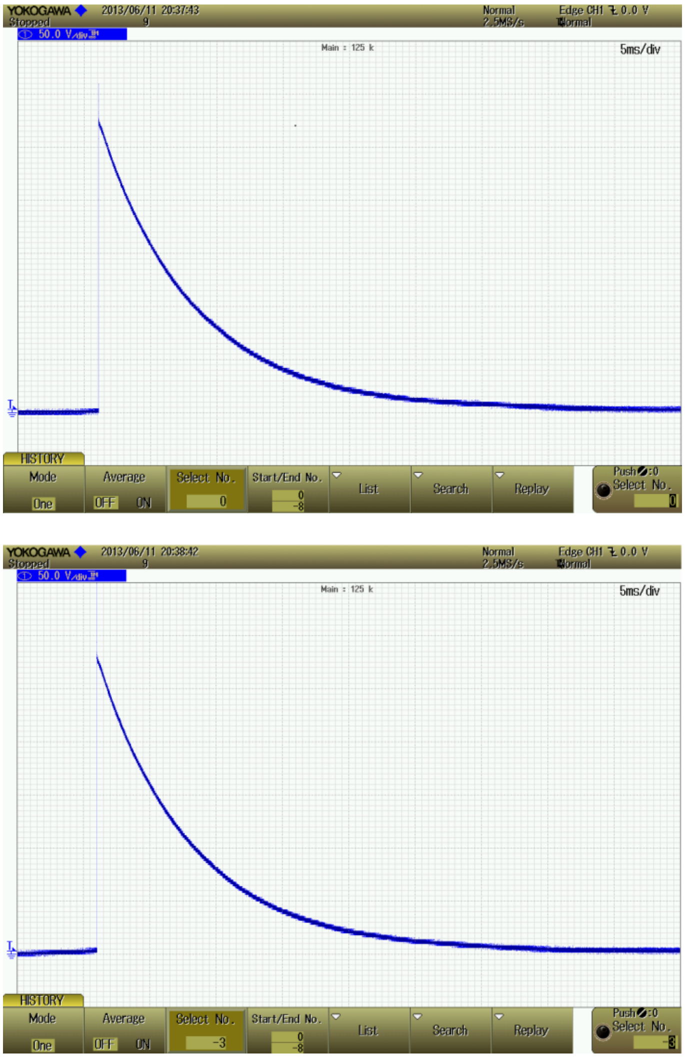


Fig 17.Polarization waveform for the configuration comprising of inner and outer cylinders with 1200pF + specimen in parallel (enhanced capacitance configuration)

5. Conclusions

An indigenous, techno economically feasible approach for discrimination of winding deformation based on experimental arrangement for measurement of PDC waveforms has been attempted using assembled Cockroft-Walton circuit, switching module, a DSO and a measuring resistance. Detailed studies with varying configurations/arrangements, which simulate physical radial winding displacements of transformer models clearly indicate the possibility of discrimination of flaws based on PDC measurement and analysis. Acquisition and analysis of a credible database and related waveforms of PDC measurements for various capacities of transformers will provide a viable solution for comparison with the database to ascertain the soundness of transformer insulation healthiness for meaningful and realistic interpretation.

Acknowledgement

The authors of this work are extremely grateful to Prof.R.Sethuraman, Vice- Chancellor, SASTRA University, Dr. S. Vaidhyasubramaniam, Dean- Planning and Development, SASTRA University and Dr. S. Swaminathan, Dean- Sponsored Research and Director- CeNTAB, SASTRA University for the support and motivation extended to them during the course of the research. The authors are also grateful to Dr. B. Viswanathan, Dean/SEEE of SASTRA University for the motivation and many useful suggestions. The authors of this research work would like to thank Mr. M. Balasubramanian, Asst. Professor/SEEE, SASTRA University for extending the facilities created by Research and Modernization Fund (RMF) Grant, Project No. 10 for carrying out this work.

References

[1] Tapan K. Saha and PrithwirajPurkait, "Investigation of Polarization and Depolarization Current Measurements for the Assessment of Oil-paper Insulation of Aged Transformers" IEEE Transaction on Dielectrics and Electrical Insulation, Feb 2004.

[2] Tapan K. Saha "Review of Modern Diagnostic Techniques for Assessing Insulation Condition in Aged Transformers", IEEE Transaction on Dielectrics and Electrical Insulation, Oct 2003.

[3] R. Malewski, J. Subocz, M. Szrot, J. Plowucha and R. Zaleski "Condition assessment of medium power transformers using diagnostics methods: PDC, FDS, FRA to support decision to modernize or replace service-aged units", CIGRE 2008.

[4] A. Küchler , T. Leibfried, B. Breitenbauch, J.J. Alff , V. Der Houhanessian , W.S. Zaengl, "Transformer Insulation Diagnosis by Polarization and Depolarization Current Analysis", September 2003.

[5] T. K. Saha, M. Darveniza, Z. T. Yao, D. J. T. Hill, and G.Yeung, ''Investigating the Effects of Oxidation and ThermalDegradation on Electrical and Chemical Properties of PowerTransformers Insulation'', IEEE Trans. Power Del., Vol. 14, pp.1359_1367, 1999.

[6] U. Gafvert, ''Condition Assessment of Insulation Systems: Analysis of Dielectric Response Methods'', Nordic Insulation Symposium. NORD IS 96. Norwegian Univ. Sci. & Technol., Trondheim, Norway, pp. 1-19, 1996.

[7] C. A. Bozzini, ''Transformer Ageing Diagnosis by Means of Measurements of the Degree of

Polymerization- Results of New Experiments'', CIGRE, Paris, France, Paper No. 12-08, 1968.

[8] U. Gafvert, L. Adeen, M. Tapper, P. Ghasemi, and B. Jonsson,''Dielectric Spectroscopy in Time and Frequency Domain Appliedto Diagnostics of Power Transformers'', Proc. 6th International Conference on Properties and Applications of Dielectric MaterialsICPADM., Vol. 2, pp. 825_830, 2000.

[9] Dielectric Response Methods for Diagnosis of Power Transformers CIGRE Task Force 15.01.09, 2002, Electra no. 202.

[10] W. S. Zaengl, "Applications of dielectric spectroscopy in time and frequencydomain for HV power equipment," *IEEE Electrical Insulation Magazine*,vol. 19, no. 6, pp. 9–22, Nov./Dec. 2003.

[11] T. Leibfried and A. J. Kachler, "Insulation diagnostics on power transformersusing the polarisation and depolarisation current (PDC) analysis,"in *Proceedings of Conference Records IEEE International Symposium on Electrical Insulation*, 2002,pp. 170–173.

[12]. Amit Kumar, J. Rattan, R.N Sharma, and SushilChauhan," Investigation of Polarization and Depolarization Current for Evaluation of Moisture in Oil-Pressboard Insulation", *International Journal of Computer and Electrical Engineering, Vol. 3, No. 6, December 2011*

[13] M.A. Mazidi& Janice GillispieMazidi, "The 8051 Microcontroller and Embedded Systems", Pearson Education Inc., 2000.