Online tan-δ Measurement and Investigation of Insulation Behavior during PD Activity of PCCC in Mercaptans Contaminated Transformer Oil

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***Abstract*— Paper–oil insulation is widely used in transformers. It is reported that during life cycle of transformer, paper and pressboard insulation undergo deterioration because of increase in sulphur content in transformer oil. The reactive sulphur which forms copper sulfide and its deposition in paper-oil insulation system of in-service transformers results in degradation of insulation. The paper covered copper conductors (PCCC) in such oil medium leads to insulation failure. This paper presents tanδ behavior of insulation property of PCCC in transformer oil with reference to formation and migration of Mercaptans sulfur with online tanδ measurements.**

Index Terms: PCCC, Sulphur corrosion, tanδ, paper-oil insulation, Mercaptans sulphur.

Introduction

The reliability of power transformers is normally high and their expected life time typically exceeds 30 years. A recent observation of premature transformer failures in the field caused by copper sulfide deposition has raised a large interest in the power industry [1,2]. The importance of sulfur and its compounds, which concerns the quality of mineral insulating oil, is well recognized and the amount of sulfur contained in typical insulating oil may range from 0.001 to 0.5%. Also it has been recently reported that number of HVDC transformer failures are attributed to the presence of high content of Mercaptans sulfur in oil. The Mercaptans sulfur reacts with the copper conductor and forms copper sulfide on the surface. These become the sites for initiation of partial discharges causing damages to the layers of paper in contact with the conductor. The copper sulfide thus formed also migrates to other layers of paper in contact with the conductor and causes reduction in insulation resistivity [3]. Since copper sulfide is conductive, it affects the voltage distribution leading to surface discharges which results in degradation of paper insulation leading to breakdown of insulation [4]. As per the literature, Mercaptans sulfur can attain concentration upto 100ppm in transformer oil [5]. Tanδ can be a measure of imperfection in dielectric material and its higher value can indicate presence of contaminants [6]. Normal ageing of an insulating material will cause the dielectric loss to increase and contamination of insulation by moisture or chemical substance may cause losses to be higher than normal [7]. The dielectric diagnostic methods most commonly used in industry are the dissipation factor (tanδ) and capacitance measurements at power frequency. The variation of tanδ provides useful information about the insulation quality [8]. The paper presents a technique for on-line tanδ measurements along with PD studies for the following reason:-

1. It may be possible to determine the instants of time at which significant copper sulfide migration takes place:
2. It can also reveal information for understanding the change in capacitance and resistance which occurs due to copper sulfide migration:
3. Computed tanδ values can reveal deterioration of insulation including due to copper sulfide migration.

It is well known that PD activity produces a permanent or quasi-permanent trapping of charge on the surface because of the presence of PD-generated surface charges. The electric field in the gap [example between the paper layers] and around the solid dielectrics will be modified. This phenomena will affect subsequent PD pulses, along with the deterioration effect in insulation including that occurring due to release of the copper sulfide in the transformer oil with Mercaptans. Therefore, simultaneous studies of PD and tanδ are interesting to observe change in PD and tanδ behavior and to attempt correlation with change in the PCCC samples placed in transformer oil.

Sample Preparation

A conductor-insulation, PCCC sample in a pigtail arrangement was prepared to simulate an equivalent electric field condition of a transformer winding in the laboratory, the PCCC also known as paper-oil insulation is configured in pigtail arrangement [9]. Two copper conductors each of 9mm width, 3.5mm thickness and 130mm length are used to prepare the samples. A representation of the developed pig-tail model is shown in Figure1, which has three portions namely, straight portion of length 100mm at the center along with two bend portions of 15mm on either side making an angle of 30^O with the horizontal. These conductors are wrapped with 3 layers of kraft paper insulation of 0.055mm thickness.

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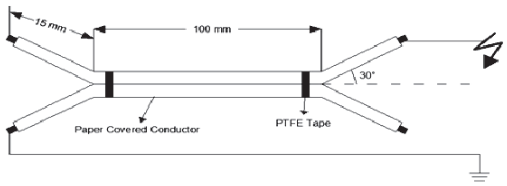

Figure 1: Pig-Tail Configuration of Sample.

EHV grade transformer oil procured in a single batch was used for experiments in batches, a quantity of 2-MBT mercaptans sulphur was added to achieve 50ppm and 100ppm contamination level in transformer oil to create sulphur contaminated oil for experiments. This oil and the dry PCCC samples were treated suitably for removing moisture. The dry PCCC samples with due precaution were later immersed in oil for obtaining oil impregnation PCCC samples for experiments.

PD Experimental setup with on-line tanδ measurement

A straight detection PD experimental setup is shown in Figure2. The test voltage from 100kV, 10kVA testing transformer was discharge free upto 70kV. The experiments are performed in a Faraday cage where the background noise is less than 2pC. The PD pulses appearing across the measuring impedance are amplified with a wide band detector and is fed to a data acquisition system developed using NI PCI-5154 card having sampling rate of 2G samples/sec and bandwidth of 1GHz. For on-line tanδ measurement, the scaled down applied voltage and current through the sample were acquired with 16 bit NI-ADC together with PD pulse data acquisition. The acquired applied voltage signal was also used as reference for phase resolved PD measurement.

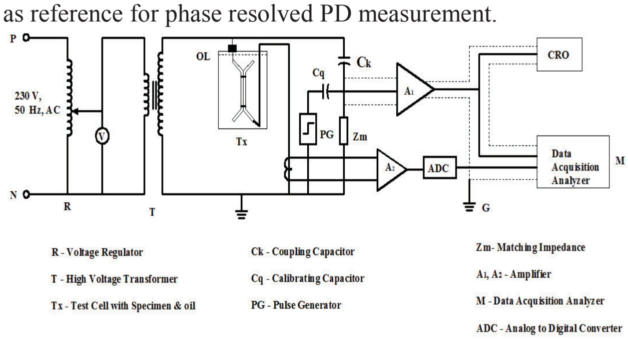

Figure.2: BLOCK DIAGRAM OF PD MEASURING SYSTEM

Experiments were performed with oil impregnated PCCC samples placed in an uncontaminated oil and in 50ppm and 100ppm 2-MBT Mercaptans sulphur 50ppm and 100ppm contaminated oil. Tanδ values were computed from phase difference measurement between applied voltage and current signals. Also values of capacitance and resistance were computed from tanδ values.

Results and Discussions

a. PD Inception and Extinction characteristics.

Figure 3 shows PD inception and extinction voltage characteristics with treated (un contaminated transformer oil) and with Mercaptans sulfur added in the treated transformer oil (contaminated transformer oil). The PD inception and extinction voltages are observed to be lower in PCCC samples placed in sulphur contaminated oil to that observed in the uncontaminated transformer oil. The reduction in inception voltage is 13.8% and 19.4% for 50ppm and 100ppm Mercaptans contaminated oil respectively. Similarly the extinction voltage is 17.14% and 22.85% lower for samples in 50 & 100ppm Mercaptans contaminated oil.

b. Online tanδ Measurement

The variations of tanδ value for samples in treated (uncontaminated) transformer oil, 50ppm and 100ppm Mercaptans contaminated transformer oil are shown in Figures 4 to 6 respectively. It is observed that the time taken for change in tanδ values in contaminated transformer oil is less compared to that for the treated transformer oil. The change in tanδ between initial and final values during experiments and the %change of tanδ calculated between treated and contaminated oil are shown in Table I.

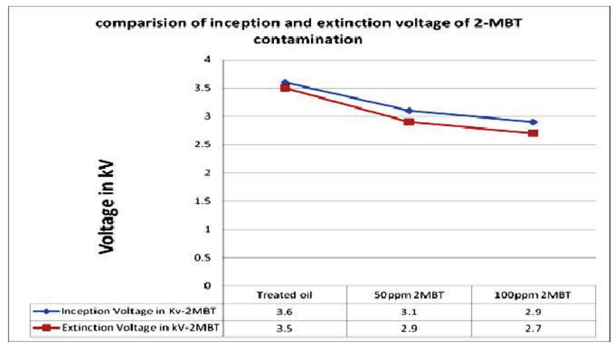

Figure.3. Variation of Inception and Extinction voltage

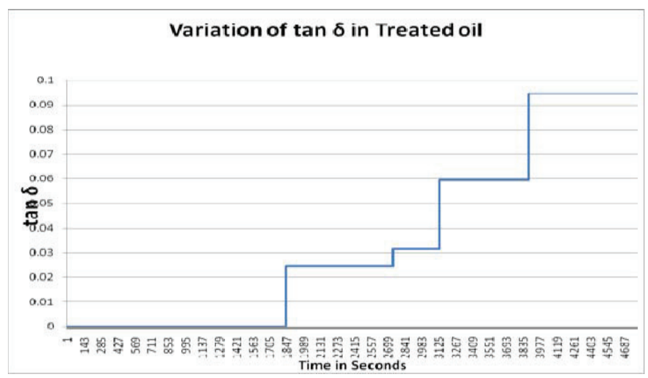

Figure.4: Variation of tan-δ with time in treated oil

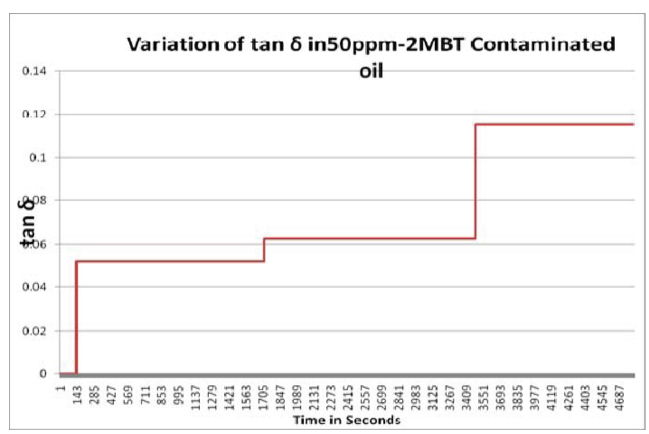

Figure.5: Variation of tan-δ with time for 50ppm 2-MBT contaminated oil

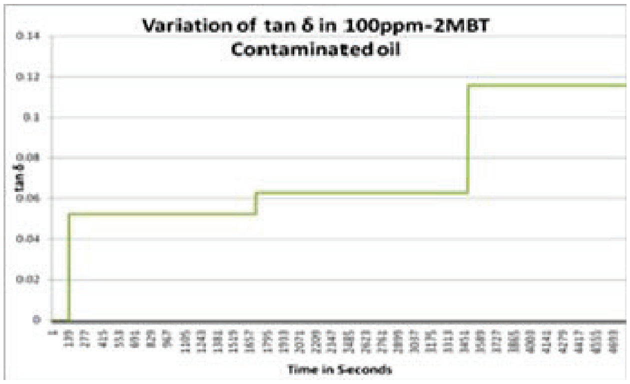

Figure.6: Variation of tan-δ with time for 100ppm 2-MBT contaminated oil

In all the experiments performed, tanδ exhibits step change with time where each step change may occurs due to the release of copper sulfide and deleterious effect of PD. It is observed from Figure 4 that the change in tanδ in a PCCC samples placed in treated oil occurs at 1847 sec onwards and its value changes from 0.022 to 0.0944. However for a PCCC samples placed in 50 ppm and 100 ppm Mercaptans contamination levels, the change in tanδ values are observed from 143sec and 139sec onwards respectively as shown Figures 5 and 6.

Table I: change in tan-δ of pig-tail specimen with oil

Type of oil	Time of occurrence (seconds)	Change in tanδ values		%change of tanδ
		Initial	Final	
Treated oil	1847	0.024439	0.094527	---
50ppm 2-MBT contaminated oil	143	0.052125	0.11507	53.11
100ppm 2-MBT contaminated oil	139	0.052172	0.115586	53.15

c. Change in capacitance of the PCCC

The variations of capacitance value is calculated in treated transformer oil, 50ppm and 100ppm Mercaptans contaminated transformer oil are shown in Figures 7 to 9 respectively. The change in capacitance between initial and final values during experiments and the %change of capacitance are calculated for treated and contaminated oil and shown in Table II.

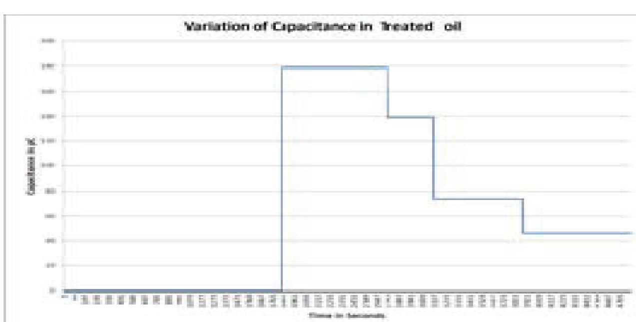

Figure.7: Variation of capacitance with time in treated oil

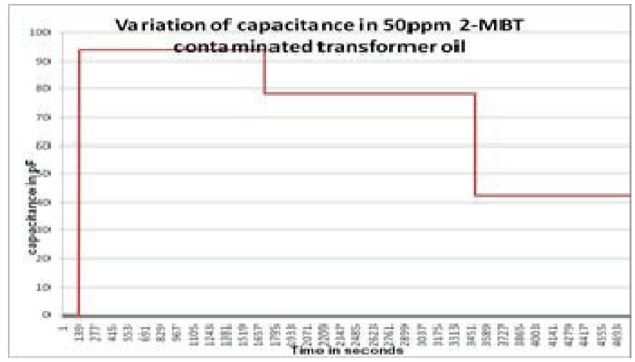

Figure.8: Variation of capacitance in time for 50ppm 2-MBT contaminated oil

In all the experiments performed, the change in capacitance is in accordance with tanδ behavior. It is observed from Figure 7 that the change in capacitance for a samples in treated oil occurs at 1847 sec onwards and its value changes from 178.89 pF to 46.44487. However in 50 ppm and 100 ppm Mercaptans contamination levels, the change in capacitance values are observed from 143 sec and 139 sec onwards respectively and its value reduces to 93.6276 and 106.034 pF at starting respectively. The capacitance reduction accounted to 47% in 50ppm and 40% in 100ppm contaminated transformer oil compared to treated transformer oil.

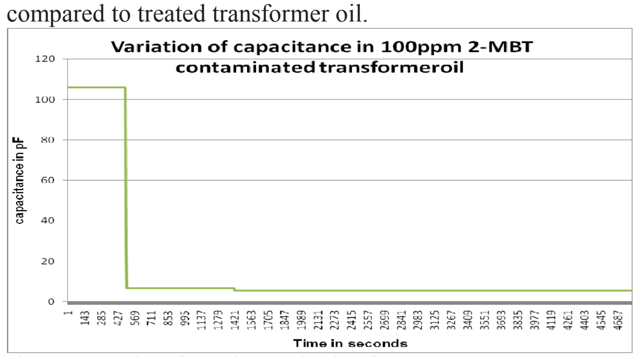

Figure.9: Variation of capacitance with time for 100ppm 2-MBT Contaminated oil

Table II: change in capacitance of pig-tail specimen with oil

Type of oil	Time of occurrence	Change in capacitance in pF		%change of capacitance
		Initial	Final	
Treated oil	1847 sec	178.8972	46.44487	---
50ppm 2-MBT contaminated oil	143 sec	93.6276	42.63278	47.66
100ppm 2-MBT contaminated oil	139 sec	106.034	5.58482	47.66

d. Change in resistance of the PCCC

The variations of resistance value is calculated for a PCCC samples placed in treated transformer oil, 50ppm and 100ppm Mercaptans contaminated transformer oil are shown in Figures 10 to 12 respectively. The change in resistance between initial and final values during experiments and the %change of resistance are calculated for treated and contaminated oil and shown in Table III.

The change in resistance is in lieu with tanδ behavior. It is observed from Figure 10 that the change in resistance in treated oil occurs at 1847 sec onwards and its value changes from 7.28GΩ to 7.248GΩ. However in 50 ppm and 100 ppm Mercaptans contamination levels, the change in resistance values are observed from 143sec and 139sec onwards respectively and its value reduces to 6.498 and 6.6GΩ at starting respectively. The resistance reduction accounted to 10.74% in 50ppm and 10.74% in 100ppm contaminated transformer oil compared to treated transformer oil. It is observed that the resistance change in a PCCC samples placed in contaminated oil is % change wise small compared to that placed in treated transformer oil.

Table III: change in resistance of pig-tail specimen with oil

Type of oil	Time of occurrence	Change of Resistance in GΩ		%change of Resistance
		Initial	Final	
Treated oil	1847 sec	7.28	7.248	---
50ppm 2-MBT contaminated oil	143 sec	6.498	6.453	10.74
100ppm 2-MBT contaminated oil	139 sec	6.6	6.582	10.74

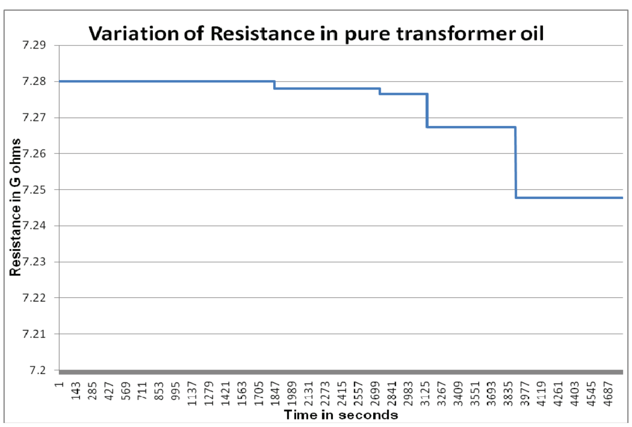

Figure.10: Variation of Resistance with time in treated oil

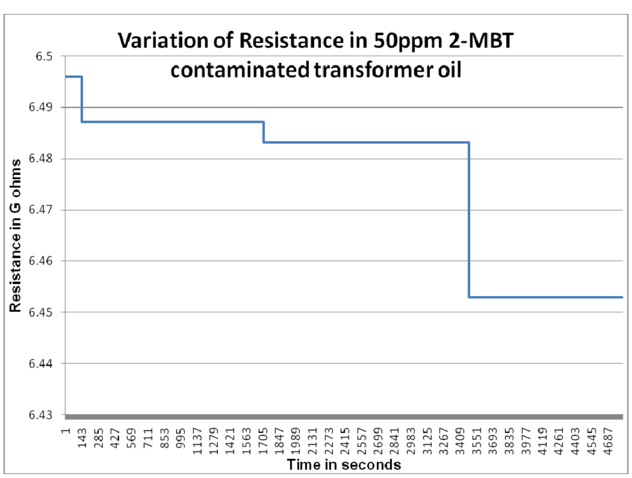

Figure11: Variation of Resistance with time for 50ppm 2-MBT contaminated oil

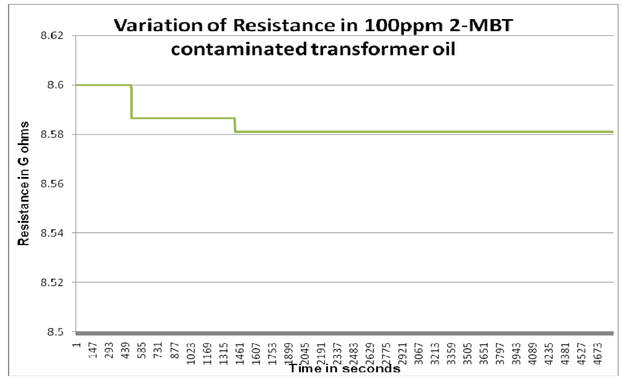

Figure12: Variation of resistance with time for 100ppm 2-MBT contaminated oil

CONCLUSIONS

In order to understand the effect of Mercaptans sulfur on behavior of insulating samples. Insulation properties is studied with PD. tanδ, capacitance and resistance obtained with experiments. Some of the important observations of the study are:

1. The tan-δ change is observed as a step change during continuous application of electrical stress on the PCCC sample in transformer oil:
2. The contamination levels has increasing negative effects-on the performance of the PCCC samples in oil.
3. The insulation deterioration occurs due to the presence of Mercaptans and space charges created due to this.

Further work in correlating acquired PD discharge magnitude and phase distributions, along with acquired tanδ values with the PCCC sample is in progress.

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