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Research Article

A Comparative Study of Partial Discharge Pulse Time Characteristics of paper Insulation Impregnated with Mineral Oil, Natural Ester and Synthetic Ester Oil

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Abstract: Measurement of partial discharge (PD) is one of the common methods for investigation of insulation behaviour in solid, liquid and composite dielectric materials. Power transformer insulations is a composite dielectric material consists of Kraft paper wound on the copper conductor and impregnated in petroleum based mineral oil (MO). Nowadays biodegradable natural ester (NE) and synthetic ester (SE) are used as replacement to mineral oil because of its higher breakdown strength and environmental benefits. PD defects in the transformer Insulation winding impregnated in natural and synthetic ester liquid need to be investigated to determine life expectancy of insulation compared to mineral oil. In this paper Partial discharge measurement are carried out as per guidelines of IEC60270 by modelling transformer insulation as Pigtail specimens and impregnating in MO, NE, SE oils. Generally PD data are represented in Phase resolved partial discharge technique and interpreted as phase-charge-number to determine insulation behaviours. In this paper an alternative PD representation which includes PD pulse time characteristics and its phase position are measured. Analysis is carried out on intra-cluster distribution, the pulse data were arranged to give phase- time- number of distribution. The results obtained are a useful tool for PD diagnosis, from the experimentation it is observed that Intra-cluster pulse distribution time is higher in ester oil compared to mineral oil indicating superior replacement for transformer insulating liquid.

Keywords: Partial Discharge, Pigtail specimen, mineral oil, natural ester oil, synthetic ester oil, PTN Distribution

1. Introduction

Partial discharge (PD) is a localized breakdown of insulation. Detection, measurement and analysis of PD are routinely performed for solid, liquid and composite insulating materials to know the magnitude of pulse, its phase, Number of pulses and other parameters. Also previous studies reviewed that PD phenomena is a stochastic behavior [1 - 4]. Computer based analysis of partial discharge records magnitude of charge and time instinct of pulses. Many techniques are employed to understand results obtained such as stochastic nature of PD, discharge mechanism (glow discharge), Finger print analysis which includes PQN pattern analysis and other measurement technique defined with standard systems [5].

Insulation is the most critical and important component of power transformer. Commonly used insulation materials are paper or press board and insulating oil [6]. Kraft paper is made from cellulose pulp can be used in high temperature because of its good thermal stability [7]. petroleum based mineral oil is normally used as liquid insulation for transformer from more than 75 years[8] and even now because of wide availability and less cost. However in recent year with concern over ecology, fire resistance ester based oils are preferred over mineral oil. With growing research over ester liquid, natural ester and synthetic ester can be used as promising insulating

medium in transformers. These oils provide high fire resistance, low viscosity, environmental friendliness, higher breakdown strength and high PD inception voltage compare to mineral oil [9].

The PD measurement system captures PD Burst of pulses with continuously changing magnitude and time with respect to applied voltage change in cycles. Pulse sequence can be grouped as burst data over a time interval. A cluster of pulse can be represented with respect to time with intra-cluster representation as shown in figure.1 [10]

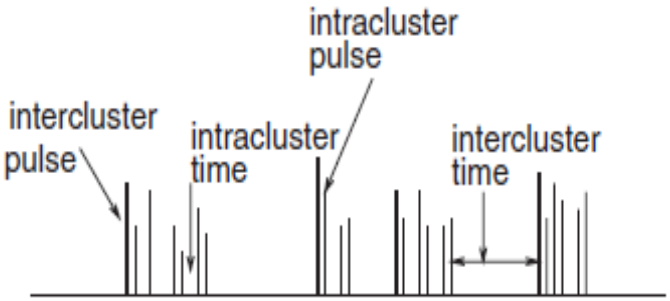


Figure 1 cluster representation of PD Data

Phase-time-Number (PTN) Also known as φ-t-n distribution has time interval between pulses with respect to phase of occurrence. These distribution is phase resolved time interval analysis, which involve obtaining nth pulse in a sequence with change in time interval represented as delta 't' (Δt). φ-t-n distribution gives threshold time interval value to pulse sequence[11].

2. TEST SPECIMEN:

Transformer Insulation winding is modeled as pigtail specimen. It mainly consists of two rectangular shape copper strips attached back to back with a bend of 30̊ on either side so as to represent transformer winding. Three layers Kraft paper is wound on the copper conductor and impregnated in oil insulation [12]. Pigtail model representation is shown in figure 2.a and actual picture of specimen inserted in oil is shown in Figure 2.b. For impregnation with mineral oil, natural ester oil, and synthetic ester oil, three separate test cell setups were developed. One end of the specimen is connected to High voltage (HT) supply and another end is connected to ground.

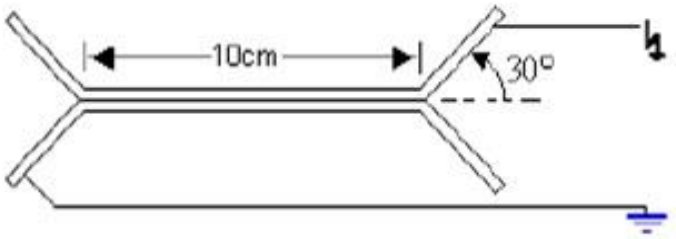


Figure 2.a Pigtail model of specimen

Figure 2.b Test setup

3. PD MEASURING SYSTEM:

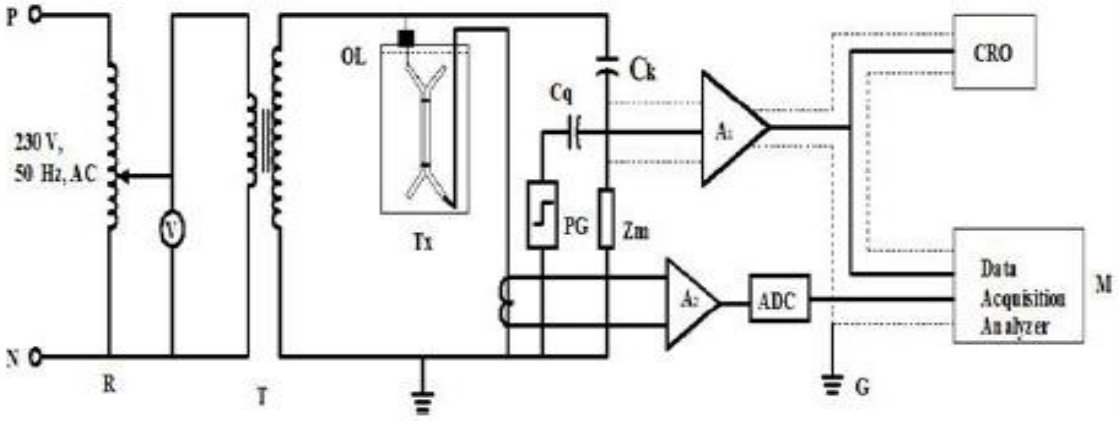


Figure 3: PD Measuring circuit

Straight Partial discharge detection technique is used as per IEC60270 in experimentation [13]. Figure 3 shows the block diagram for PD measurement circuit and figure.4 show laboratory setup. All the equipments are housed in faradays cage/shielded chamber to prevent outside interferences. 100kV PD free transformer is used to generate High voltage; 1000pF coupling capacitor free from PD is used in the experimentation to couple PD pulse to RLC parallel circuit. High voltage is applied to one end of the test specimen another end is grounded. High speed 1 GHz digitizer is used to capture pd pulse and using special designed NI labview software PD data are represented in PRPD patterns for analysis [14 -15]

Figure 4: Laboratory Experimental setup
1. Input Control unit 2.HV Transformer
3. Coupling Capacitor 4.Oil-specimen test cell
5. Oscilloscope 6.Digitizer PC

Figure 4: BDV TEST SETUP

4. RESULTS AND DISCUSSION

The experimental results are discussed in three steps;

1. Break down voltage of MO, NE and SE Oils;
2. PD Inception and Extinction voltages of pig-tail specimens impregnated with MO, NE AND.
3. Analysis of Partial discharge PD Signals

4.1 BREAKDOWN VOLTAGE VALUE

Breakdown Voltage test is carried out to determine oil strength to withstand AC Voltage stress. The test is carried out as per IEC 60156 [16]. Spherical electrodes are mounted in a horizontal axis with 2.5 mm gap in a glass cell as shown in figure 5. Input voltage is raised at the rate of 2kV/sec until breakdown occurs. Initially mineral oil is poured to glass cell. The breakdown voltage obtained for mineral oil, natural ester oil and synthetic ester are tabulated as shown in table.1. Average breakdown voltage of mineral oil is 32kV, Natural ester oil it is 66kV and synthetic ester oil 72kV. Viscosity of ester oils are higher compare to mineral oil and hence conducting particle movement in ester oil are slower compare to mineral oil results in higher breakdown voltage [17].

Figure 5: BDV TEST SETUP

Oil/Trails	1	2	3	4	5	6	7	8	9	10
Mineral Oil (MO)	31	32	32	29	32	30	32	32	32	32
Natural Ester (NE) oil	60	66	66	68	65	66	66	66	66	66
Synthetic Ester (SE) oil	70	72	72	72	72	72	72	72	72	72

Table 1: Breakdown voltage Value in kV

4.2 INCEPTION AND EXTINCTION VOLTAGE: The voltage at which ionization and partial discharge starts in the insulation with rise of input voltage is the Inception voltage and the voltage at which PD exit with reduction of input voltage is referred as extinction voltage. Results obtained for inception and extinction voltage in pigtail specimen impregnated in different insulating oils are tabulated as shown in table.2.

	Inception voltage	Extinction Voltage
Mineral Oil	2.7	2.5
Natural Ester oil	3.2	3.0
Synthetic Ester oil	3.5	3.3

Table 2: Inception and Extinction Voltage

4.3 Phase Resolved Partial Discharge (PRPD) Results

PD is a random process; In order to obtain meaningful data, PRPD patterns are widely used popular measurement technique to define PD distributions [18]. Partial discharge pulses are grouped by their phase angle of applied voltage. The profile of Phase-Charge, Phase-Number, Phase-charge-Number provides information of defects in insulation due to PD. The PD pulse count, time characteristics with respect to its phase position were arranged to give phase-time distribution number in Pigtail specimen impregnated in mineral oil, natural ester oil and synthetic ester oil.

4.4 PHASE-CHARGE-NUMBER (PQN) PATTERN:

Pulse sequence information received from partial discharge data acquisition system can be seen as continuous pulses with different time interval and magnitude over the frequency of applied input voltage. Theses pulses can be grouped based on time interval. The change in time is referred as delta 'T' measured in micro or msec [19].

φ-t-n experimental data obtained for all the oils is compared in terms of following parameters

i). Phase angle in Deg vs Time (PT)

ii). Time vs No. of counts (TN)

iii) Phase vs Time vs No. of counts (PTN)

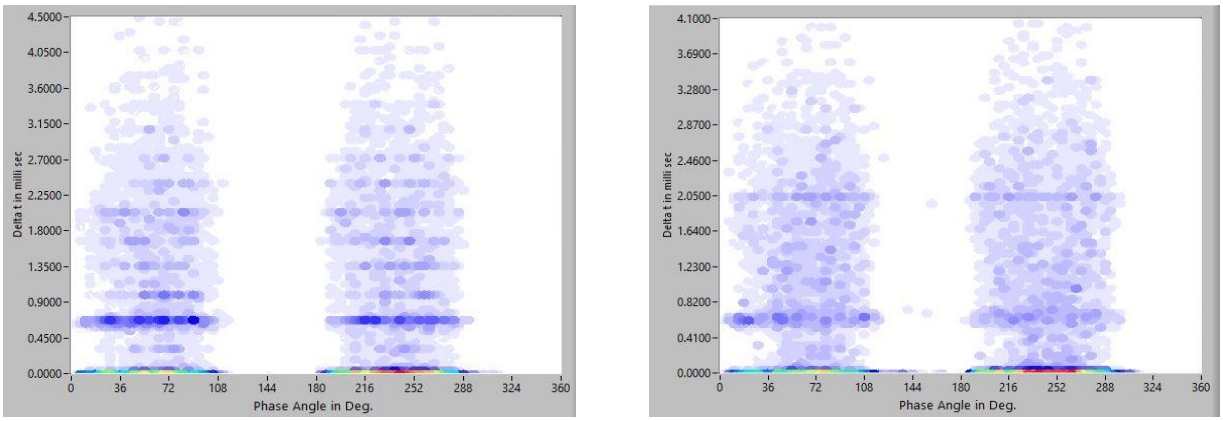
4.4.1 PHASE VS TIME (PT):

Figure 6, figure 7 and figure 8 shows graph of Phase angle vs Inter cluster pulse time in milli sec for pigtail specimen impregnated in mineral oil, natural ester oil and synthetic ester oil at the start of experiment and end of experiment respectively.

TYPE OF OIL	Intra pulse time record at the start of experiment in msec	Intra pulse time record at the end of experiment in msec
Mineral oil	4.5	4.1
Natural Ester oil	7.7	6.9
Synthetic Ester oil	8.8	7.5

Table 3: Intra-cluster pulse duration at start and end of experimentation

For mineral oil delta t is 4.5mili sec, for natural ester oil delta t is 7.7mili sec and for synthetic ester oil delta t is 8.8mili sec. comparatively synthetic ester has almost double the value compare to mineral oil also natural ester oil value is more than mineral oil at the start of experiment. Towards the end of experiment delta t value for MO, NE and SE oils are 4.1, 6.9 and 7.5 msec respectively. In comparison to mineral and natural ester oil, synthetic ester oil has a longer intra cluster pulse time. The intra cluster time is usually high when the oil is new and unused, but it decreases over time and due to contamination, indicating a loss of insulation strength. [18]. Intra-cluster time is low in mineral oil, indicating that the interval between subsequent pulses is short. This results in increase in pulse repetitive time, which causes early insulation breakdown and a reduction in insulation life [21]. From figure 6, 7 and



8 it is observed that magnitude of pulse distribution is high in mineral oil compare to ester oils. Intra cluster pulse distributions are seen over entire time range over the phase.

Figure 6: Phase angle vs time variations at the start of Experimentation and end of experiment for pigtail specimen impregnated in Mineral oil (MO)

Figure 7: Phase angle vs time variations at the start of Experimentation (a) and end of experiment (b) for pigtail specimen impregnated in Natural ester oil (NE)

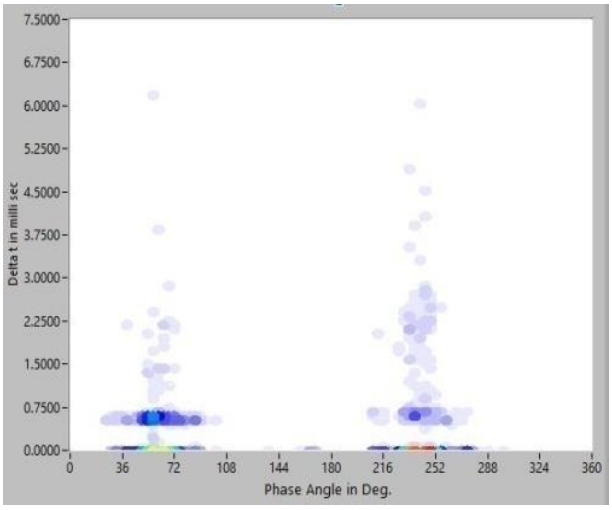
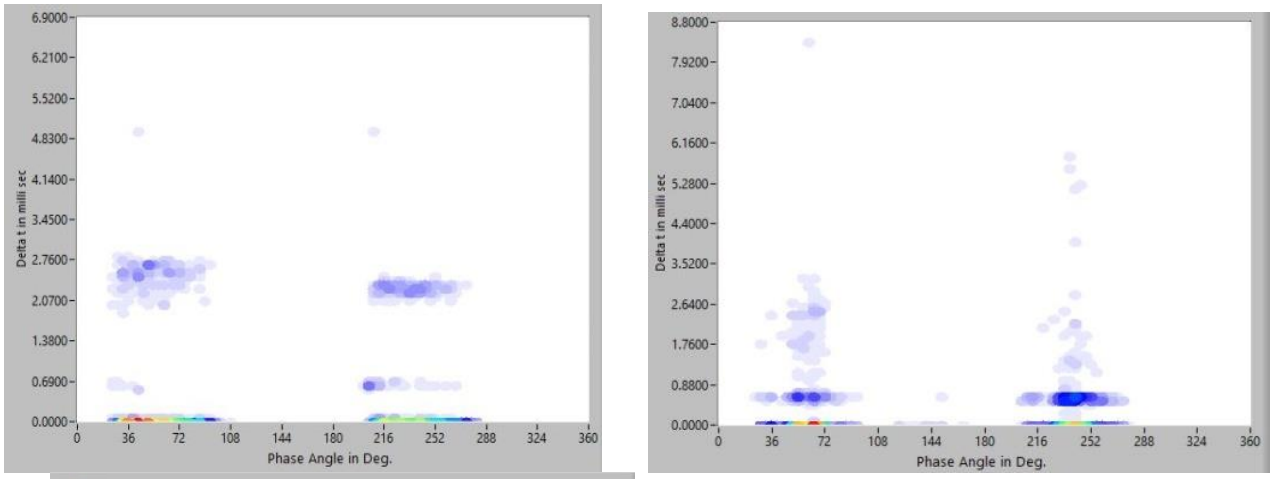
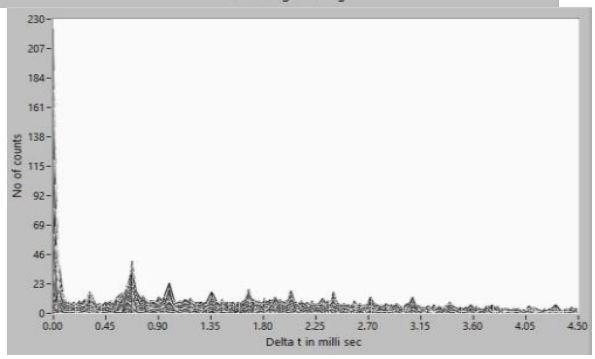


Figure 8: Phase angle vs time variations at the start of Experimentation (a) and end of experiment (b) for pigtail specimen impregnated in Synthetic ester oil (SE)





impregnated in mineral oil, natural ester oil and synthetic ester oil at the start and end of experiment respectively. In mineral oil, bursts of pulses can be seen throughout the intra cluster duration, in natural ester oil, two dominant clusters can be seen, whereas in synthetic ester oil, one cluster pulses with a large magnitude was shown at the beginning.

4.4.2 DELTA TIME VS NUMBER OF COUNTS (TN): : Figure 9, figure 10 and figure 11 equivalent representation in terms of Time vs Number of counts of pigtail specimen

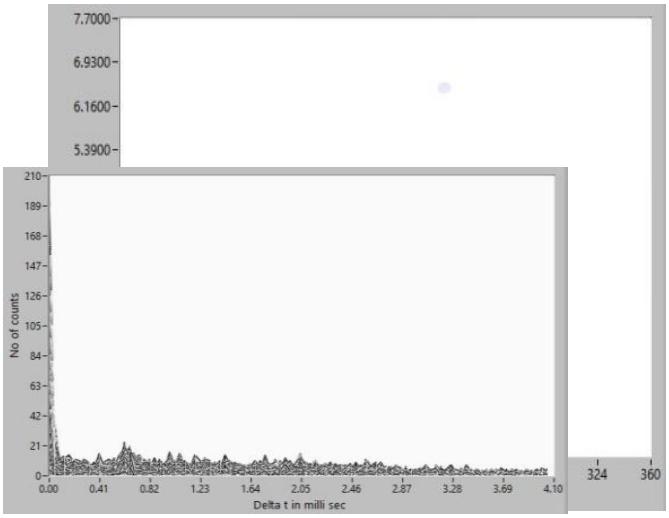


Figure 9: Time vs Number of counts at the start of Experimentation (a) and end of experiment (b) for pigtail specimen impregnated in Mineral oil (MO)

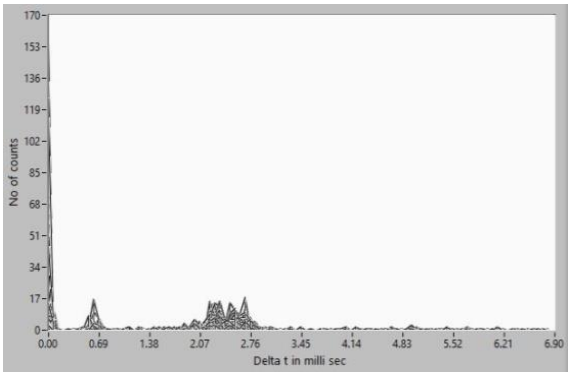


Figure 10: Time vs Number of counts at the start of Experimentation (a) and end of experiment (b) for pigtail specimen impregnated in Natural ester oil (SE)

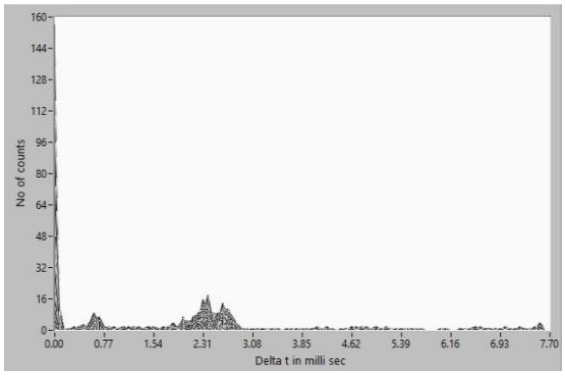
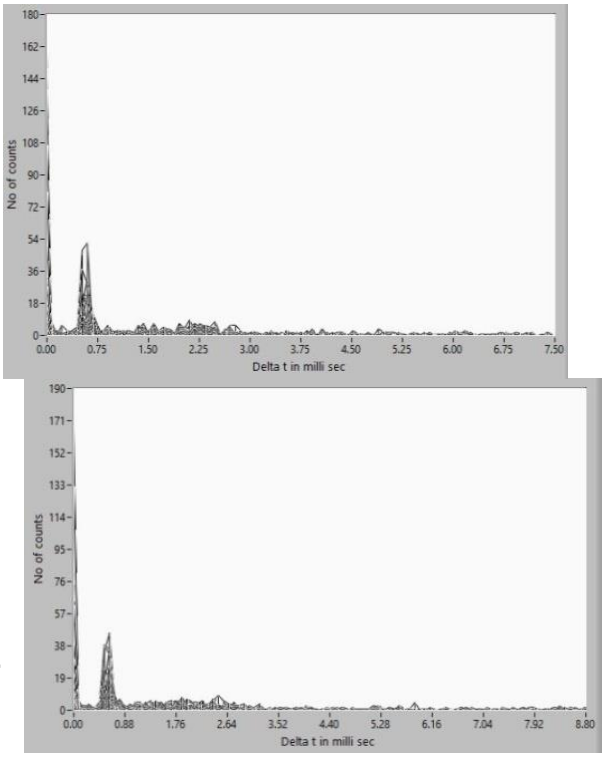
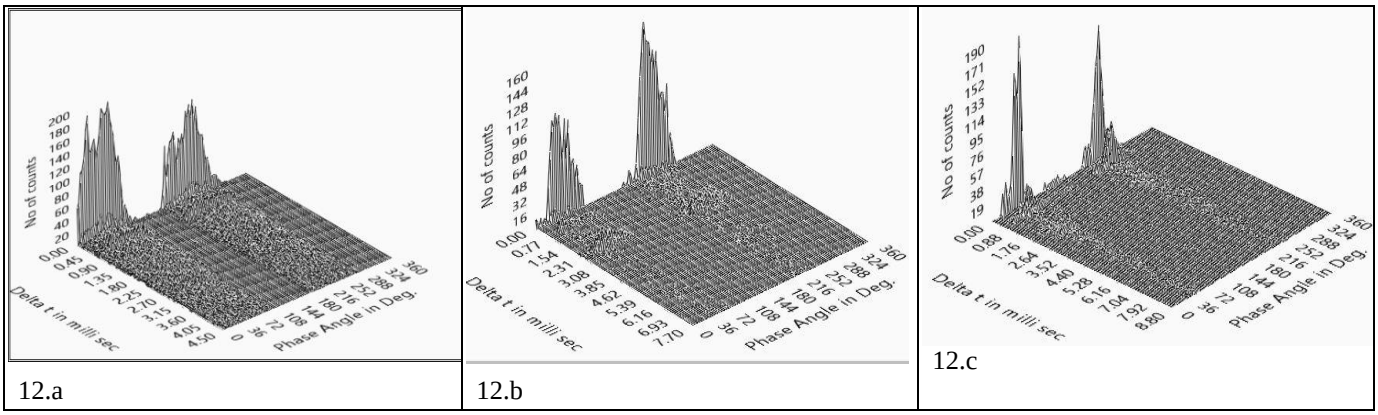


Figure 11: Time vs Number of counts at the start of Experimentation (a) and end of experiment (b) for pigtail specimen impregnated in Synthetic ester oil (NE)



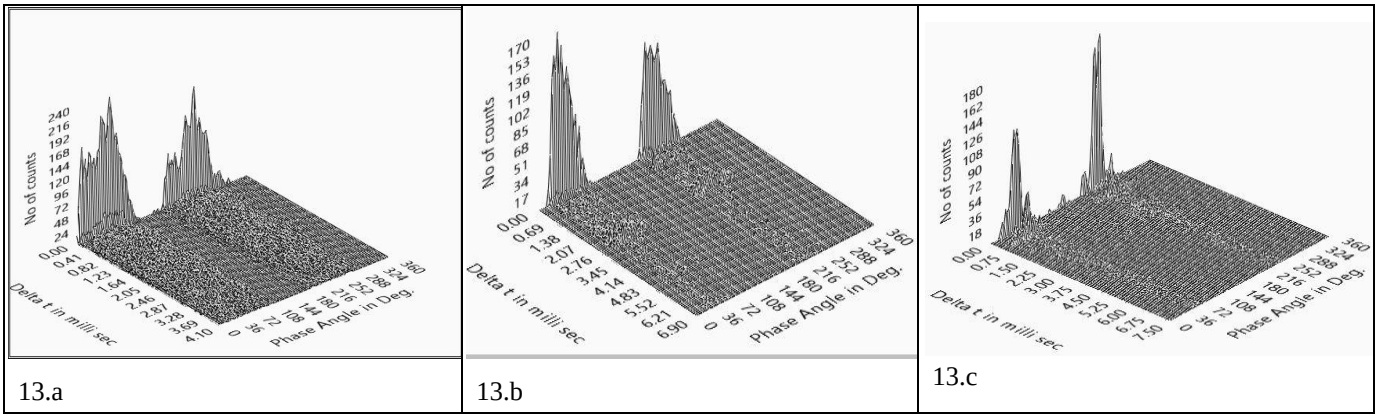
4.3.3 PHASE-TIME-NUMBER (PTN):

Figures 12 and 13 show an equivalent 3D plot depicting the Phase-Time-Number of counts distribution for mineral oil, natural ester oil, and synthetic ester oil at the start and end of the experiment, respectively. Discharge count per second in mineral oil is 200, natural ester oil is 160 and for synthetic ester oil 190 at start of experiment. Discharge count at the end of experiment for mineral oil , natural ester oil and synthetic ester oil are 240, 170,180 respectively indicating sharp increase in the discharge counts per second under the influence of voltage stress.



12.a 12.b 12.c

Figure 12: Phase - Time- Number of counts variations at the start of Experimentation for pigtail specimen impregnated in Mineral oil (12.a), Natural ester oil (12.b), and Synthetic ester oil (12.c).



13.a 13.b 13.c

Figure 13: Phase -Time - Number of counts variations at the end of Experimentation for pigtail specimen impregnated in Mineral oil (13.a), Natural ester oil (13.b), and Synthetic ester oil (13.c).

CONCLUSION:

Quality of Insulation plays vital parameter in high voltage power transformer. Partial discharge inception voltage, breakdown voltage and PD pattern behavior of Mineral oil, Natural ester oil and synthetic ester oil experimental data were obtained and presented. The break down voltages is higher in ester oil compare to mineral oil because of higher viscosity and inherent chemical properties of ester oil. Partial discharge Inception voltage is higher in ester oil because of superior oil paper interface in ester oil compare to mineral oil. A new method of PD data representation similar to PQN (Phase-Charge-Number) called PD pulse sequence in terms of PTN (Phase-Time-Number) Patterns are acquired and illustrated in Phase vs Time, Number of counts vs Time and Phase- Time- Count. From the result it is found that pigtail specimen impregnated in ester oil showed larger Intra-cluster time compare to mineral Insulting liquid. Higher time indicates less chance of PD repetition rate in oil. If the Time is less than next pulse start immediately with the end of previous pulse as shown for mineral oil case but for ester oil pulse repetition was less. More research in progress to obtain figure of merit for complex PD phenomena.

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