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(Research Article)

Partial discharge characteristics of thermally aged mineral oil and eco-friendly vegetable oil under uniform electric field

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Abstract

Partial discharge (PD) detection plays an important role in the life assessment of liquid insulation in transformers. This paper investigates on the PD activity and characteristics in thermally aged mineral oil and eco-friendly rice bran and Sesame oils. To simulate surface discharges, plane-plane electrode configuration with pressboard of 1mm and 3mm thickness was used. The phase resolved PD patterns of thermally aged rice bran oil, sesame oil and mineral oil with pressboard were recorded and analyzed. From the results it is observed that the inception voltage of eco-friendly vegetable oils is higher than mineral oil. Also vegetable oil shows better PD characteristics hence they can be used for high voltage insulation applications.

Keywords: Phase Resolved PD; PD Inception Voltage; Peak charge; Average charge; Number of pulses

1. Introduction

Reliability of electric power systems mainly depends on the high voltage transformers. With increase in demand of electrical power, it is crucial that electricity supplies should be protected and always available. Any breakdown of transformer results in heavy repair expenses. A large amount of distribution transformer failure is due to long term thermal aging and degradation of insulation system [1]. Partial Discharges (PD) are one of the major reasons for degradation of high voltage insulation systems. PD measurement is used as diagnostic tool for monitoring the condition of insulation system [2-4]. PD inception voltage, charge magnitude, number of discharge pulses and its distribution are the important parameters to be analyzed. Mineral oil are the commonly used insulating fluid in power apparatus. Mineral oil are poorly biodegradable and cause serious contamination of soil and water ways if spill occurs. Since petroleum products are eventually going to run out leading to shortage. Hence it is necessary to carry out in the development of new biodegradable insulating fluids. Vegetable seed oils are biodegradable, non-toxic and most environmental friendly [5-11]. Hence extensive studies were carried out to find suitable insulating oil for electrical applications.

Ageing is influenced by four parameters namely electrical, thermal, chemical and mechanical stresses. In the present work, mechanical stresses are not considered. Also effects of chemical stresses are not independently studied as they are influenced by temperature and electrical stresses. Hence, ageing has been carried out under a typically high temperature of 120^{0}C [76] that may exist commonly in real life transformers.

Partial discharge (PD) due to electric field enhancement in a localized area of insulation accelerates the degradation and thermal aging of insulating oil. Hence PD plays a major role in determining the insulation strength and life time of oil [12]. Therefore it is very important to understand the PD characteristics of thermally aged vegetable oil. Considering these facts the major aim of present work is to obtain the typical PD patterns of thermally aged two vegetable seed oil

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to find its suitability for power apparatus applications. In this paper Phase Resolved PD characteristics of thermally aged rice bran oil, sesame oil under uniform fields are investigated. For the comparison the PD characteristics of mineral oil are also discussed.

2. PD characteristics of Aged oil-Pressboard Insulation System

2.1. Experimental Set up

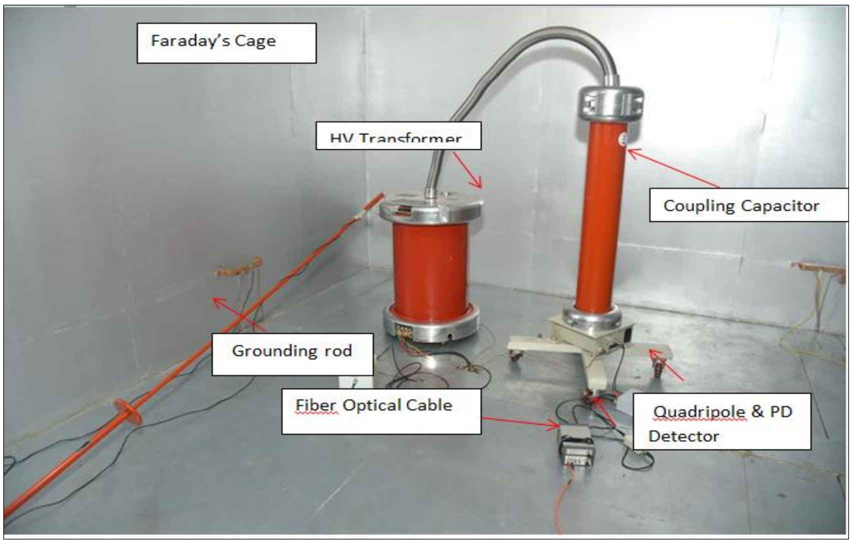

Figure 1 PD measurement system with PD free transformer and coupling capacitor

The variable High voltage source is obtained by using a 10kVA, 100kV transformer (PD free). A 1000pF capacitor is used as coupling device. The whole test setup is enclosed inside the Faraday's chamber (cage) in order to avoid the noise pickup by the PD system. The PD measurement is carried out according to the Standard test procedures (IS-60270) Figure-1 shows the laboratory setup of the PD measurement system enclosed in Faraday's cage. Before measuring PD, the test setup is calibrated. The calibration is done without high voltage or under high voltage conditions and has two main individual settings: i) Voltage calibration and ii) Charge calibration. Calibrator CAL 542 is connected to the test object. The charge calibration is performed by injecting known value of charge to the test object using the calibrator. For the Voltage calibration, the voltage is set to a known value and then calibrated.

2.2. Thermal ageing of Mineral & Eco-friendly oils

Ageing is influenced by four parameters namely electrical, thermal, chemical and mechanical stresses. In the present work, mechanical stresses are not considered. Also effects of chemical stresses are not independently studied as they are influenced by temperature and electrical stresses. Hence, ageing has been carried out under a typically high temperature of 120^0C that may exist commonly in real life transformers The thermal ageing has been carried out with oil and other materials like pressboard, copper conductor and CRGO steel thermally aged at 120^0C upto 200hours. At 100 hours & 200 hours of ageing, the PD characteristics of rice bran oil, sesame oil and mineral oil under uniform field configuration are recorded and analysed.

Copper, pressboard and CRGO are the major contributors for oil contamination. Therefore, in the present work only these three materials are added to the oils during thermal ageing. In addition to temperature, the extent of ageing also depends on the weight ratio of material to oil, The materials - copper in conductor form, pieces of CRGO laminations, pieces of pressboard are obtained from a standard transformer vendor. Quantity of pressboards was added approximately based on materials in a distribution transformer. All the above mentioned materials are calculated & added to 1kg of oil and were provided thermal ageing at 120^0C

3. Results and discussion

The Phase Resolved PD (PRPD) patterns of 100 and 200 hours thermally aged Mineral oil, Rice bran oil and Sesame oil under uniform field stress with 1mm and 3mm pressboards are recorded and analyzed. The PRPD patterns of above samples are obtained by varying the test voltage and corresponding PD parameters like peak charge magnitude (Q_{peak}), Average charge magnitude (Q_{avg}), number of PD events/sec (n) are recorded.

3.1. PRPD pattern of Thermally aged Mineral Oil/Pressboard Insulation

The phase-charge (Φ-q) and phase-charge-number (Φ-q-n) plots of 100 hours thermally aged mineral oil with 1mm and 3mm pressboards under uniform field electric stress were captured by varying the voltage. The test voltage is varied until the observable PD pulses are detected by the detector. Figure 2 shows the Phase-charge and phase-charge-number plots of thermally aged Mineral oil/1mm Pressboard during the inception of PD. when the test voltage is 0.90 kV(PDIV), Q_{peak}=547pC, Q_{avg}=13.88pC, n=31.54PD/sec values are captured by the detector. The PD charge distribution is more distributed in negative half cycle (140^0-360^0) of applied voltage which indicates the surface discharge on the pressboard layer. When the test voltage is 5kV, Q_{peak}=499pC, Q_{avg}=18.2pC, n=746.6PD/sec values are captured by the detector. The PD charge distribution is distributed in both half cycles, but more significant in negative half cycle (180^0-360^0) of applied voltage which indicates the both surface and corona discharges takesplace as shown in figure 3.

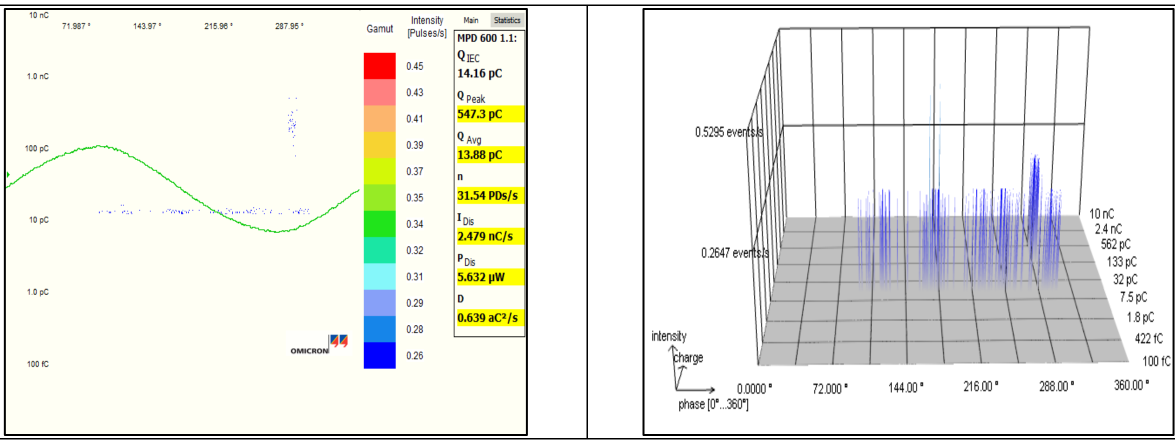

Figure 2 Phase-charge and phase-charge-number plots of 100hours thermally aged Mineral oil/1mm Pressboard under uniform fields at PDIV (0.90 kV)

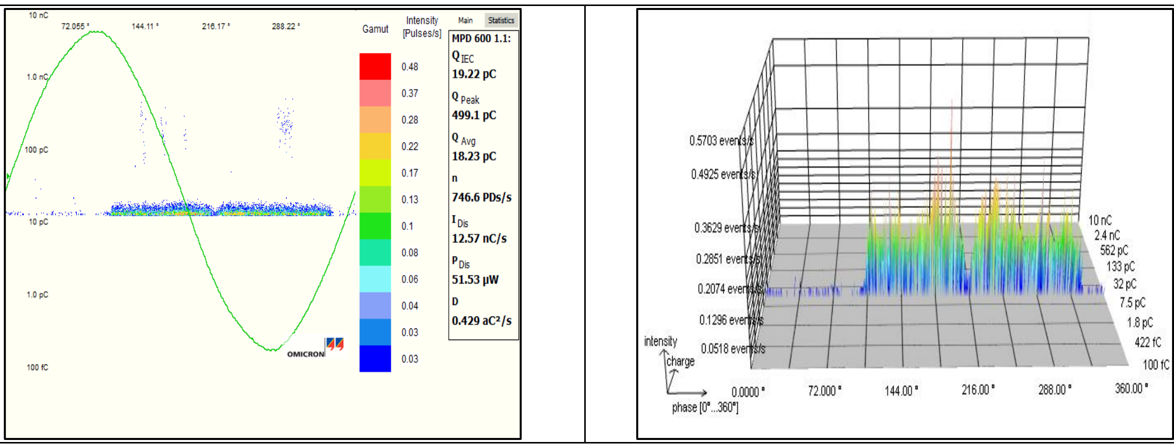

Figure 3 Phase-charge and phase-charge-number plots of 100 hours thermally aged Mineral oil/1mm Pressboard under uniform fields at 5kV

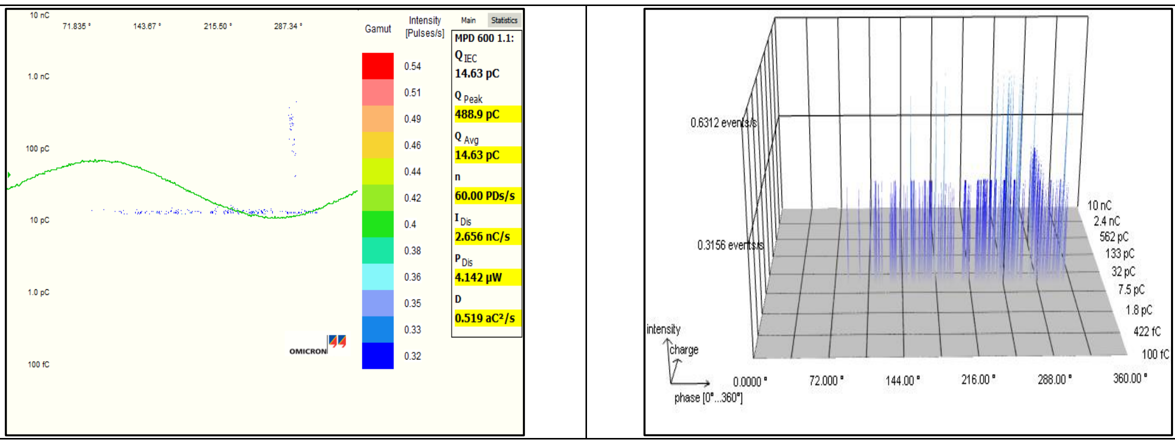

Figure 4 Phase-charge and phase-charge-number plots of 100 hours thermally aged Mineral oil/3mm Pressboard under uniform fields at PDIV (0.816kV)

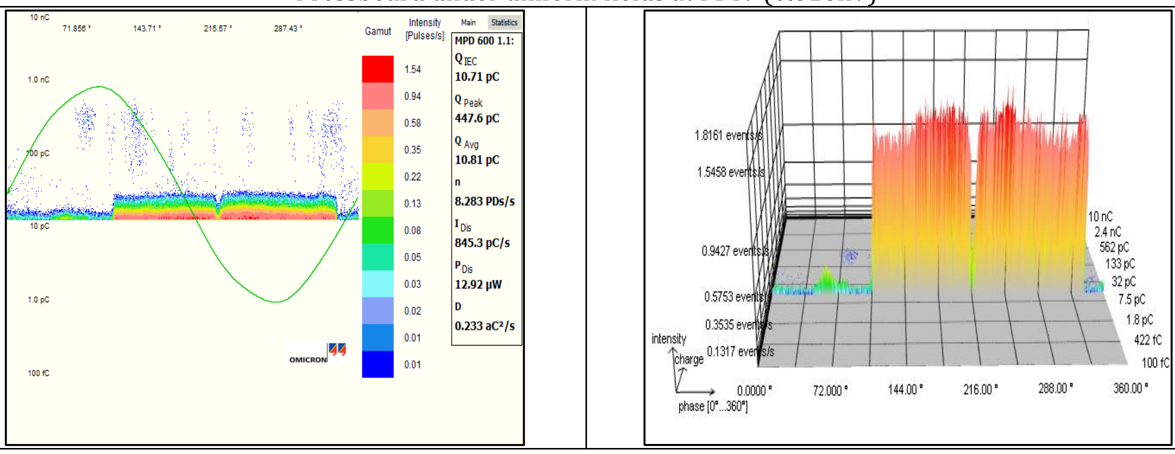

Figure 5 Phase-charge and phase-charge-number plots of 100 hours thermally aged Mineral oil/3mm Pressboard under uniform fields at 17kV

Figure 4 shows the Phase-charge and phase-charge-number plots of thermally aged Mineral oil/3mm pressboard during the inception of PD. when the test voltage is 0.816kV(PDIV), Qpeak=489pC, Qavg=14.6pC, n=60PD/sec values were captured by the detector. The PD charge distribution is more distributed in negative half cycle of applied voltage which indicates the surface discharge on the pressboard layer. When the test voltage is at 17kV, Qpeak=468pC, Qavg=10.8pC, n=8.28PD/sec values were captured by the detector. The PD charge distribution is distributed in both half cycles, but more significant from 1000-3600 and less charge distribution in positive half cycle (00-900) of applied voltage which indicates the both surface and corona discharges takesplace as shown in figure 5.

3.2. PRPD pattern of Thermally aged Rice bran Oil/Pressboard Insulation

Figure 6 shows the Phase-charge and phase-charge-number plots of thermally aged Rice bran oil/1mm pressboard during the inception of PD. when the test voltage is 1.41kV(PDIV), Q_{peak}=611pC and n=21PD/sec values were captured by the detector. The PD charge is distributed in both half cycles and very few peak charge in –ve half cycle of applied voltage. When the test voltage is at 5kV, Q_{peak}=378pC, Q_{avg}=19.8pC, n=496PD/sec values were captured by the detector. The PD charge distribution is distributed in both half cycles, but predominant in the phase angle 108^0-360^0 and less charge distribution in positive half cycle (0^0-72^0) of applied voltage which indicates the both surface discharge and corona discharge occurs as shown in figure 7.

Figure 8 shows the Phase-charge and phase-charge-number plots of thermally aged Rice bran oil/3mm pressboard during the inception of PD. when the test voltage is 1.44kV(PDIV), Q_{peak}=287pC, Q_{avg}=15pC and n=111PD/sec values were captured by the detector. In positive half cycle (0^0-45^0) PD charges are very less and the charges are distributed in the phase angle 80^0 – 360^0 of the applied voltage which indicates the corona discharge. When the test voltage is at 17kV, Q_{peak}=843pC, Q_{avg}=10.75pC, n=23.3PD/sec values were captured by the detector. The PD charge distribution is distributed in both half cycles, but predominant in the phase angle 108^0-360^0 and less charge distribution in positive half cycle (0^0-108^0) of applied voltage which indicates the both surface and corona discharges takesplace as shown in figure 9.

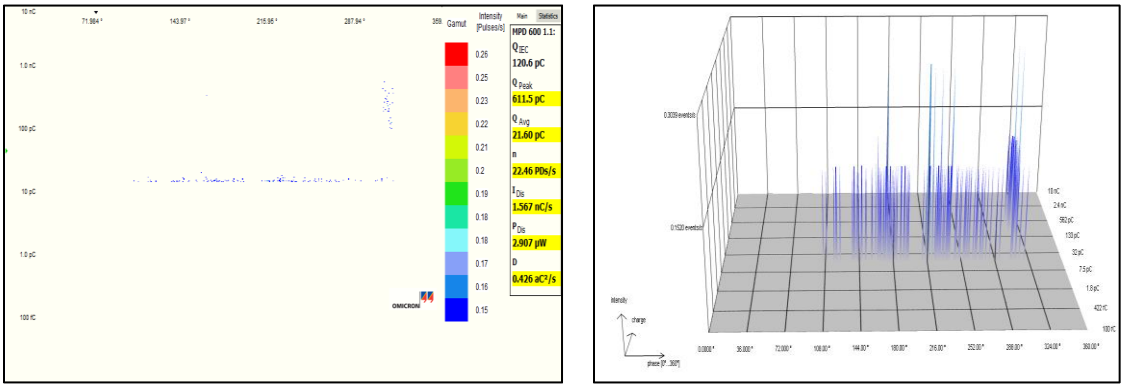

Figure 6 Phase-charge and phase-charge-number plots of 100 hours thermally aged Rice bran oil/1mm Pressboard under uniform fields at PDIV

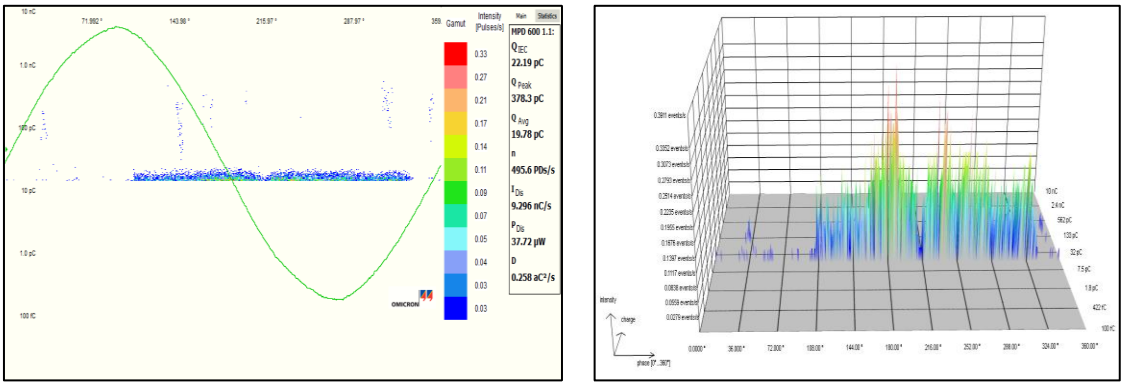

Figure 7 Phase-charge and phase-charge-number plots of 100 hours thermally aged Rice bran oil/1mm Pressboard under uniform fields at 5kV

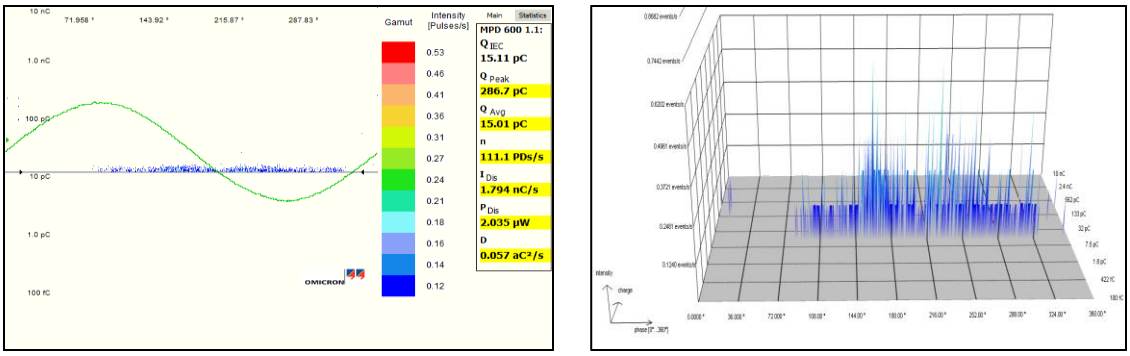

Figure 8 Phase-charge and phase-charge-number plots of 100 hours thermally aged Rice bran oil/3mm Pressboard under uniform fields at PDIV

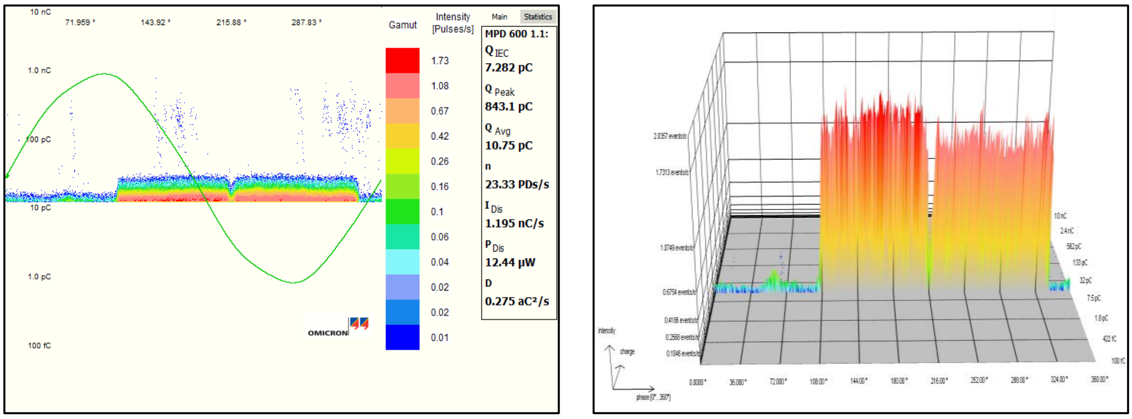

Figure 9 Phase-charge and phase-charge-number plots of 100 hours thermally aged Rice bran oil/3mm Pressboard under uniform fields at 17kV

3.3. PRPD pattern of Thermally aged Sesame Oil/Pressboard Insulation

Figure 10 shows the Phase-charge and phase-charge-number plots of thermally aged Sesame oil/1mm pressboard during the inception of PD. when the test voltage is 1.15kV(PDIV), Q_{peak}=415pC and n=2.36PD/sec values were captured by the detector. In both half cycles PD charges are very less and having same peak values of charge. When the test voltage is at 5kV, Q_{peak}=293pC, Q_{avg}=19.8pC, n=57.6PD/sec values were captured by the detector. The PD charge distribution is distributed in both half cycles, but predominant in the phase angle 108^0-360^0 and less charge distribution in positive half cycle (0^0-72^0) of applied voltage which is as shown in figure 11.

Figure 12 shows the Phase-charge and phase-charge-number plots of thermally aged Sesame oil/3mm pressboard during the inception of PD. when the test voltage is 1.14kV(PDIV), Q_{peak}=435pC, Q_{avg}=15pC and n=101PD/sec values were captured by the detector. In positive half cycle (0^0-72^0), no PD charges were observed and the peak PD charge were in negative half cycle. When the test voltage is at 17kV, Q_{peak}=274pC, Q_{avg}=19pC, n=1165PD/sec values were captured by the detector. The PD charge distribution is distributed in both half cycles, but predominant peak charges is in the phase angle 280^0-360^0 and less charge distribution in positive half cycle (0^0-72^0) of applied voltage which is as shown in figure 13.

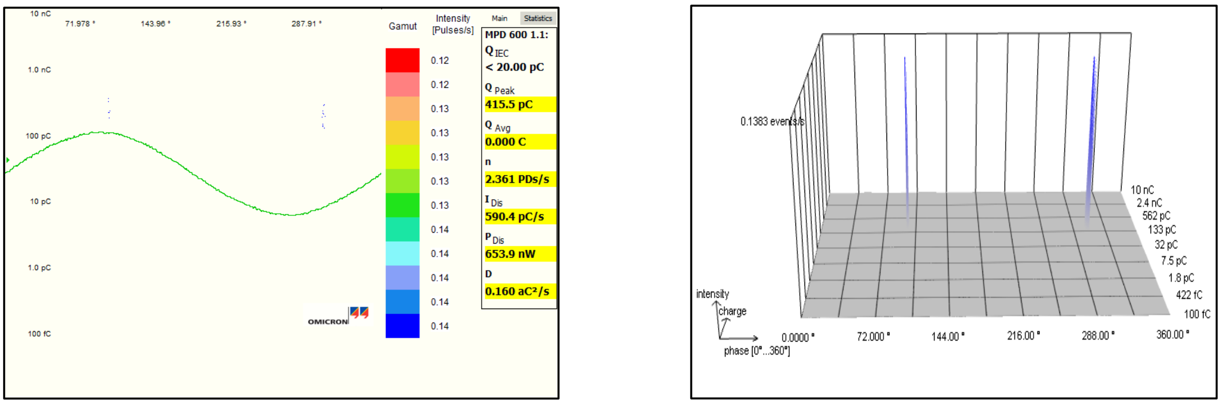

Figure 10 Phase-charge and phase-charge-number plots of 100 hours thermally aged Sesame oil/1mm Pressboard under uniform fields at PDIV

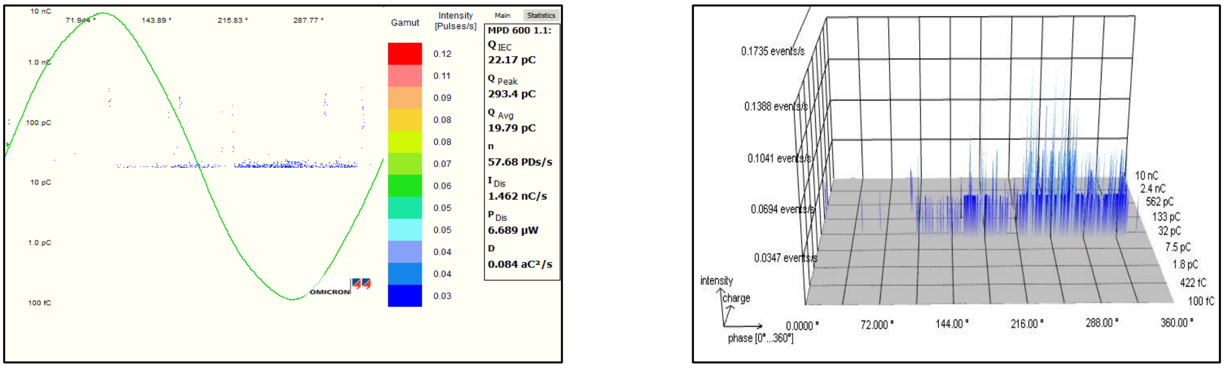

Figure 11 Phase-charge and phase-charge-number plots of 100 hours thermally aged Sesame oil/1mm Pressboard under uniform fields at 5kV

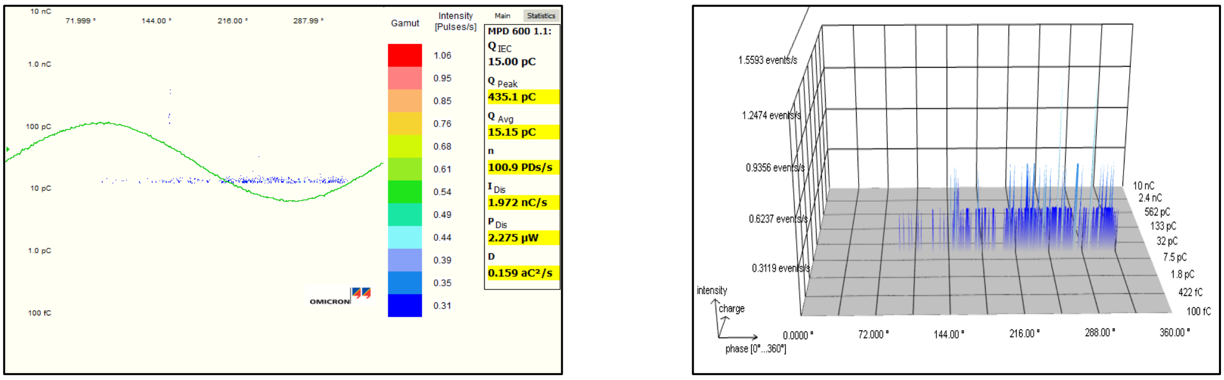

Figure 12 Phase-charge and phase-charge-number plots of 100 hours thermally aged Sesame oil/3mm Pressboard under uniform fields at PDIV

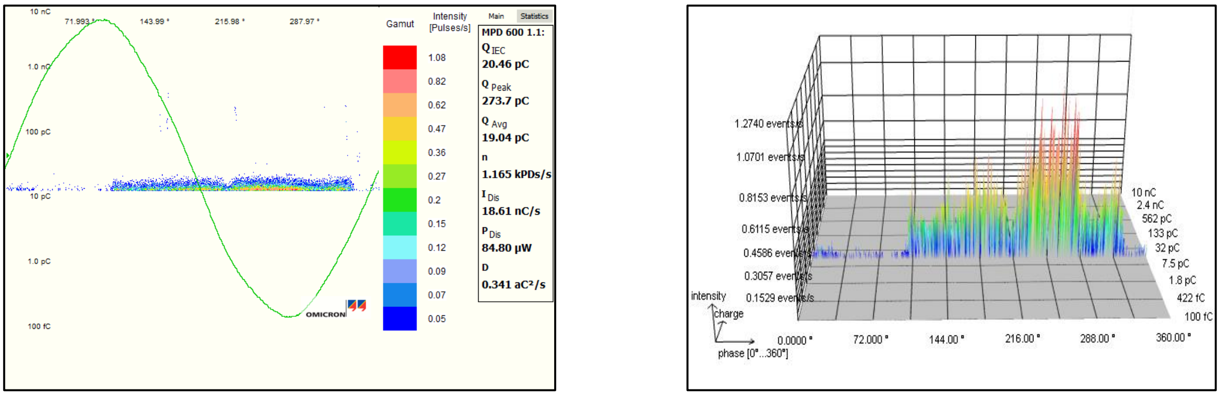

Figure 13 Phase-charge and phase-charge-number plots of 100 hours thermally aged Sesame oil/3mm Pressboard under uniform fields at 17kV

3.4. Comparison of Thermal ageing studies of different oil/Pressboard Insulation System

Table 1shows the comparison of PD results of treated fresh oil/pressboard insulation and thermally aged oil/pressboard insulation system for 100 hours and 200 hours under uniform electric field at 120^{o}C. The thermal ageing results are compared with fresh oil results. After 100 hours of aging, slight increase/improvement of 15% to 25% in PD inception voltage of rice bran and sesame oil and the magnitude of peak discharge is increased in all the three oils. Also the number of PD events/sec increased in all the oils. The improvement in PD inception voltage of natural esters is due to the removal of water content in oil during thermal ageing.

After completion of 100 hours of aging, slight improvement of 15% to 25% in PD inception voltage of rice bran and sesame oil and marginal reduction in the magnitude of peak discharge in mineral and Sesame oils (for 3mm pressboard). The number of PD events/sec has increased to 300% in all the oils which may be due to absorption of water by the pressboards from the oil. The improvement in PD inception voltage of natural esters is due to the removal of water content in oil during thermal ageing.

Table 1 PD results of oil/Pressboard insulation under uniform field

Thermally aged Oil with 1mm Pressboard under uniform field				
PD Parameters	Insulating oil	0hr	100hr	200hr
PDIV in kV	Mineral oil	0.88	0.9	0.87
	Rice bran oil	1.13	1.41	1.18
	Sesame oil	1.0	1.15	1.01
Peak discharge Q_{Peak} in pC	Mineral oil	293	547	372
	Rice bran oil	347	611	374
	Sesame oil	164	415	429
Number of PD events/sec	Mineral oil	12.2	31.5	3.11
	Rice bran oil	7.33	21	2.35
	Sesame oil	1.87	2.3	4.35
Thermally aged Oil with 3mm Pressboard under uniform field				
PD Parameters	Insulating oil	0hr	100hr	200hr
PDIV in kV	Mineral oil	0.922	0.816	0.81
	Rice bran oil	1.31	1.44	1.03
	Sesame oil	1.11	1.14	1.06
Peak discharge Q_{Peak} in pC	Mineral oil	618	489	283
	Rice bran oil	266	287	356
	Sesame oil	466	435	345
Number of PD events/sec	Mineral oil	19.2	60	5.9
	Rice bran oil	11.1	37	4.28
	Sesame oil	9.66	30	1.66

4. Conclusion

Due to environmental concerns, biodegradable oil is increasing being used as replacement for mineral oil in transformers. Therefore it is necessary to compare their PD activity. The PD inception voltage of thermally aged Rice bran oil and Sesame are higher than of mineral oil. For the Plane- plane testing, peak PD magnitude, number of PD events/sec, discharge power of Rice bran oil and Sesame oil are lesser than of mineral oil. The experimental results shows that both eco-friendly vegetable oil insulation has the required potential to be used as liquid insulation in transformers and also obtained results motivates the researchers to carry out further research on these vegetable oils.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] D. Prasad, S.Chandrasekar, "Effect Of Nano-Sio2 Particles On Partial Discharge Signal Characteristics Of Fr3 Transformer Oil", 2017.

[2] G.C. Stone, "Partial Discharge Diagnostics and Electrical Equipment Insulation Condition Assessment", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 12, No. 5, pp. 891-904, 2005

[3] R. Bartnikas, "Partial Discharges. Their Mechanism, Detection, and Measurement", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. 9, pp. 763-808, 2002

[4] F.H. Kreuger, Discharge Detection in High Voltage Equipment, Butterworth-Heinemann, 1989

[5] J. Li, Z. Zhang, P. Zou, S. Grzybowski, and M. Zahn, "Preparation of a Vegetable Oil-based Nanofluid and Investigation of Its Breakdown and Dielectric Properties", IEEE Electr. Insul. Mag., vol.28, no.5, pp. 43-50, 2012.

[6] Suwarno M. Ilyas, "Study on the Characteristics of Jatropha and Ricinnus Seed Oils as Liquid Insulating Materials", in Proceedings of the Annual Report Conference on IEEE Electrical Insulation and Dielectric Phenomena, pp.162-166, 2006.

[7] U.U.Abdullahi, S.M.Bashi, Robia Yunus, Mohibullah and Hj.An1ir Nurdin, "The Potentials of Palm Oil as a Dielectric Fluid", in Proc. of National Power & Energy Conference (PECon), pp. 224-228, Kuala Lumpur, Malaysia, 2004.

[8] Suwarno Aditama, "Dielectric properties of Palm oils as liquid insulating materials: effects of fat content", in Proc. of International symposium on electrical insulating materials, pp.91- 94, Japan, June 2005.

[9] Martin, N. Lelekakis, W. Guo, and Y. Odarenko, "Further Studies of a Vegetable-Oil-Filled Power Transformer", IEEE Electr. Insul. Mag., vol. 27, no. 5, pp. 6-13, 2011.

[10] L. Hosier, A. Guushaa, E.W. Westenbrink, C. Rogers, A. S.Vaughan, and S.G.Swingler, "Aging of Biodegradable Oils and Assessment of Their Suitability for High Voltage Applications", IEEE Trans. Dielectr. Electr. Insul., vol. 18, no. 3, pp. 728-738, 2011.

[11] S.Senthilkumar, B.Karthik and S.Chandrasekar, "Investigations on PD Characteristics of Thermal aged Palm and Corn Oil for Power Transformer Insulation Applications", J Electr Eng Technol Vol. 9, No. 742, 2014

[12] Abdul Rajab, Umar K, D.Hamdani, Aminuddin.S, Suwarno, Y.Abe, M.Tsuchie, M.Kozako, S.Ohtsuka and M.Hikita, "Partial Discharge Phase Distribution of Palm Oil as Insulating Liquid", TELKOMNIKA, Vol.9, No.1, April 2011, pp 1-8.

[13] V Champa, A N Nagashree, S vasudevamurthy, B V Sumangala, G R Nagabhushana, "Effect of antioxidants on the performance of vegetable oils as liquid dielectrics". International journal of electrical engineering and technology (IJEET), vol.4, issue 2, 2013, pp. 393-404.

[14] Girish S K and Dr B V Sumangala "Investigations on Partial Discharge Characteristics of Vegetable oil and Mineral oil", International Journal of Engineering Research and Technology, Volume 10, Issue 02, Febraury 2021, pp. 95-97.

[15] Girish S K and Dr B V Sumangala "Investigations on Partial Discharge Activity in Mineral and Eco friendly Vegetable oils", in proceedings of international conference on Advanced Research in Engineering and Technology, December 2022.