Development of Partial Discharge Signal in Ester Oil Impregnated Paper

M. Kalyanasundari, M. Ravindran, R. V. Maheswari, B. Vigneshwaran

***Abstract:** Power transformer is the most exorbitant and controversially the most essential equipment. Insulation abortion in transformer can cause stretched term interruption to supply and loss of revenue and the important maintenance procedure. The power transformer consists of organic insulation like Mineral oil, pressboard and paper. In impecunious of bio- degradability and availability, ester oil is replaced by Mineral oil. The partial discharge is a tool for evaluate the insulation atrophy of dielectric materials. In this paper the results of a laboratory based experimental investigation of partial discharge activity in oil – impregnated paper. To guesstimate the statistical parameter for different electrode configuration like different configuration under open air gap condition.*

***Keywords:** statistical parameter (skewness, kurtosis); PD; natural ester oil and Mineral oil; Needle – plane, Rod – plane, Sphere – plane curvature; Number of discharge; AC.*

I. INTRODUCTION

The popularity of the Mineral oil is due to availability and low cost as well as being an excellent dielectric and cooling medium. Transformer oil is poorly bio degradable in nature and could contaminate our soil and waterways if serious spills occur [1]. Vegetable oil is natural product available plenty. The power transformer insulation has increased by using of ester oil. It was having better environmental characteristics [2]. Partial discharge (PD) is a localized electrical discharge that partially bridges the insulation between the conductors. It causes progressive deterioration of the insulation and eventually leads to catastrophic failure of the equipment. In general PD can occur in solids, liquids, gaseous dielectric and composite dielectric. It is the powerful tool for insulation system condition monitoring [3].

To study of PD signal analysis and the PD activity were categorized. During the moisture content the PD signals were comprised up to 30% PDIV reduction for pressboard of 3% moisture as compared with dry pressboard [4].

Revised Manuscript Received on February 28, 2020.

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In Switching impulse voltage is applied to the oil – impregnated paper insulation, the number of free electrons is possible to discharge of the paper.

The switching impulse waveform in air gap constraining the large quantities of dense discharge pulses. Its waveform is having isolated from each other [5].

When compared to the thermal – electrical stress is generated during the partial discharge. Physical defects will be developed and then trap energy is inversely proportional to the density. Discharge energy is increased. When compared to the electrical and thermal stress in opposite to the electrical stress [6].

By combination of the AC – DC voltage stress, to evaluate the PRPD and ETF. The PRPD is good at developing stage and ETF was good at transition stage from pre – breakdown stage. A higher comprehends to obtain 93.75% [7]. To compare the vegetable oil and mineral oil for PD characteristics, the relative permittivity is also higher than the mineral oil. The discharge of the mineral oil having more discharge when compared to the vegetable oil. The rabbit ear patterns are developed process the PD characteristics in air gap vegetable oil are more notable than vegetable oil [8]. When saturation of the negative ions, the streaming current and leakage current at the outer electrode leads to the peak effect of the streaming current [9].

The creepage discharge of pressboard caused by surface discharge and bubbled residences; reason of more intense discharged [10]. To adding of the furfural content between oil and paper to decrease the degree of polymerization same value [11]. There are the two types of discharge state will be created surface inception voltage and surface discharge inception voltage. Due to moisture content the conductivity of oil – immersed pressboard is increased [12].

Influence of moisture, conducting particles, and gas bubbles are all on the surface of the cellulose board surface. It will be change on the PRPD, pC, PDIV. To compared the moisture in oil and moisture in pressboard samples having more surface discharge due to gas bubble moisture content [13]. Corona discharge will occurred on the cellulose pressboard due to needle – plate configuration. The test results indicate that the surface of the pressboard will fully changed into damaged.

On this basis, the aim of the present work is to carry out laboratory experiments in order to understand the partial discharge in oil – impregnated paper at corona and surface discharge at different oils at various voltage level. A due to emphasis is given to understand of statistical parameter at different AC voltage is applied. To analyzed the dielectric properties of oil (Rice bran oil, Sunflower oil, Mineral oil).

II. EXPERIMENTAL SETUP

Critical properties of vegetable oil like Rice bran oil, Sunflower oil, Mineral oil samples such as breakdown voltage, flash point, fire point,
Viscosity are studied according to the specified standards for analyzing of oil as potential replacement to mineral oil.

A.Measurement of Breakdown voltage

Breakdown voltage test is measured according to the standard IEC 60156. Breakdown voltage is defined as the important property of the oil. It depends upon the purity condition. According to the standards breakdown voltage test is carried out in the test cell within the gap of 2mm spherical electrodes. Ac voltage is varied linearly 2kV/sec by using auto transformer. Five consecutive breakdown tests for the sample. Pictorial representation of Fig 1 & Fig 2 is the front view of breakdown voltage measurement setup and test cell of the breakdown voltage setup.

$$V_{RTP} = \frac{BDV}{Gap\ Spacing} \quad (1)$$

$$V_{STP} = V_{RTP} \times \frac{HCF}{ADCF} \quad (2)$$

Fig 1. Front view of breakdown voltage measurement setup. Fig 2. Test cell of the breakdown voltage setup.

B.Measurements of viscosity

Viscosity is the important property of the liquid medium. It should measure the flow resistance of the oil. In low viscosity of oil has good heat transfer capability. Viscosity of oil has been calculated by ASTM D445 standards . Viscosity of oil is calculated by using the Redwood Viscometer. To calculated the time taken for the 50ml of oil to be flowed. Figure 3 represented by the red wood viscometer. The unit of viscosity is centiStrokes.

Kinematic Viscosity $=(A \times t) - \left(\frac{B}{t}\right)$ (3)

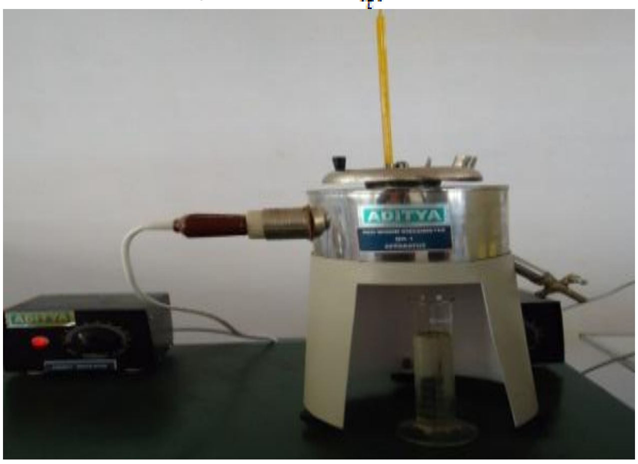

Fig 3. Redwood viscometer

C.Measurements of Flash point and Fire point

Thermal characteristics are measuring of the liquid insulating medium. According to the standards ASTM D93 measured flash point and fire point. To taken 60ml of oil is taken in Pensky martins setup by using of heating chamber the oil is heated. It is depending on the number of molecules and composition of substance. Stir the oil to have a uniform distribution of heat. A small test flame is directed into the oil. At particular temperature, the oil surface gets fire and immediately shut down. The temperature is known as Flash point. Again heat the oil, the temperature will increase. At particular temperature, the oil surface gets fire and continuously. This temperature is called Fire point. Figure 4 Represented by the Pensky – Martins closed setup.

Fig 4. Pensky – Martins Closed setup

D.Measurement of Density of oil

A density meter, also known as a densometer, is a device that measures the density. The density is varies with temperature and pressure. This variation is typically small for liquids. In most of the liquid insulation, heating the bottom of fluid results in convection of the heat from the bottom to the top, due to the decrease in the density of the heated fluid. Density is measured based on the standard ASTM D1217.

E.Measurement of Pour point

ASTM D5949, Standard Test Method for Pour Point of Petroleum Products (Automatic Pressure Pulsing Method) is an alternative to the manual test procedure. It uses automatic apparatus and yields pour point results in a format similar to the manual method (ASTM D97) when reporting at a 3°C. Less operator time is required to run the test using this automatic method. Additionally, no external chiller bath or refrigeration unit is needed this test method has better repeatability and reproducibility than manual method ASTM D97. The lowest temperature at which movement is detected on the sample surface is determined to be the pour point. Figure 5 represented by the pour point kit.

Fig 5. Pour point kit

F. Partial Discharge Test

Fig 6. Experimental setup for partial discharge

Test Procedure on Measurement of Partial Discharge test

A partial discharge (PD) in a HV transformer occurs when the electric field enhances in a localized area of insulation. The major types of PD in a transformer may be classified into two categories such as corona discharges and surface/interface discharges. Corona discharge may occur due to the presence of any floating conducting particle in the liquid insulating medium. Surface/interface discharges in transformers mainly occur at the interface of oil and paper layers. In order to simulate surface discharges, a rod - plane electrode and Sphere – plane electrode with paper configuration was used, while a needle-plane electrode set up was employed to simulate corona discharges. The tip of the needle has a curvature radius of 1.5µm. The high voltage supply was connected to the top portion of needle electrode and the bottom portion of plane electrode was solidly grounded. Since it is difficult to get a stable PD source from needle – plane electrode configuration, a 3mm thick paper was used upon the ground electrode. The gap distance between the needle and ground electrode was maintained at 5mm.In the case of rod – plane electrode configuration, thickness of the paper material used was 4 mm. PD signals were picked by connecting a high frequency current transformer (HFCT) around the ground connection of the test cell. HFCT is a clip – on device clamped around the ground lead and it has a 50 MHz frequency bandwidth which

is sufficient to cover the entire range of PD. Output of the HFCT is connected to the PD detector. The power supply is given as shown in Figure 6 Figure 5 shows the experimental setup that having coupling capacitance, high voltage test transformer, and PD kit to hold the specimen. The transformer rated voltage is 2*0.22/100/0.22kV, rated current 2*22.8/0.1A, rated output is 10kVA. Testing transformer is used to produce AC, DC and impulse voltage. AC supply is given to specimen by means of transformer. Test setup is controlled by means of control desk. Figure 5.9 shows that the different electrodes configurations like needle-plane, rod-plane. PDs were detected through a large bandwidth system, able to sample the complete PD waveforms at a sampling rate of up to 100 MSa/s and bandwidth of 0-50 MHz. The sensitivity ranges from 2 mV/div to 5 V/div. No coupling capacitor was inserted in parallel to the test specimen. The PD pulses were sent to a remote PC for further processing.

III. RESULTS AND DISCUSSION

According to specified standards the critical properties are calculated. Breakdown voltage, Flash and fire point, Pour point, Density of ester oil and Mineral oil values are tabulated in Table 1. Time taken for 50 ml of oil flow and viscosity is calculated in Table 2. Pour point various value from 0ºC to -80ºC of dielectric fluids is shown in Table 1. The ranges of values in 0.88(kg/cm^3). Density several of dielectric fluids is shown in Table 1. Evaluation of statistical parameter is showed in Table 3 at various voltage levels. Table 1- 3 is obtained the values of Breakdown voltage of the oil sample, viscosity of the oil, Flash and fire point of the oil sample, Pour point values of oil samples, Density of the oil samples, Evaluation of the statistical parameters for different configuration under open air gap test condition in various AC voltage.

Table 1 Breakdown Voltage, Flash and Fire point, Pour point, Density of oil samples

S.No	Name of the Oil	Break Down Voltage in kV (Gap distance in 2mm)	V_{RTP} (kV/cm)	V_{STP} (kV/cm)	Flash point(ºC)	Fire point(ºC)	Pour point value in(ºC)	Density (kg/cm^3)
1	Rice bran oil	40	200	271.24	310	330	-8	0.901
2	Sunflower oil	30	150	203.44	280	295	-14	0.902
3	Mineral oil	20	100	136.51	250	270	-12	0.827

Table 2 Viscosity of oil samples

S. No	Name of the Oil	Viscosity at Room Temperature(34ºC)		Viscosity at 40ºC		Viscosity at 60ºC		Viscosity at 70ºC	
		Time (sec)	cSt	Time (sec)	cSt	Time (sec)	cSt	Time (sec)	cSt
1.	Rice bran Oil	668	173.42	445	115.31	320	82.66	220	56.41
2.	Sunflower oil	572	148.419	217	55.62	136	34.095	113	27.85
3.	Mineral oil	144	43.188	93	22.33	74	18.36	65	15.742

Table 3 Evaluation of statistical parameter for different configuration under open air gap test condition in various AC voltage

Configuration	Applied Voltage in kV	Skewness	Kurtosis	No of discharge
Rod to plane in Rice bran oil	4	0.661752	91.03015	83
	5	0.226731	54.52304	96
	6	0.384679	28.57732	122
Rod to plane in Sunflower oil	4	0.747776	68.44396	87
	5	0.173004	11.05398	156
	6	0.074136	5.77064	174
Rod to plane in Mineral oil	4	0.590843	41.46314	194
	5	0.115016	15.68451	239
	6	0.114897	8.080065	257
Needle to Plane in Rice bran oil	2	5.461746	78.88472	115
	3	3.905953	61.22941	167
	4	4.364902	56.53914	198
Needle to Plane in Sunflower oil	2	2.312918	27.22445	201
	3	4.018668	52.9032	203
	4	0.345487	41.71873	250
Needle to Plane in Mineral oil	1.5	2.94033	37.41238	213
	2	4.082195	62.8834	235
	3	2.00335	95.16901	259
Sphere to plane in Rice bran oil	4	2.767755	35.69152	78
	5	4.144957	61.2772	90
	6	3.726214	56.84167	110
	7	3.444322	49.07923	130
Sphere to plane in Sunflower oil	4	3.755298	40.01073	82
	5	2.585905	18.37541	98
	6	3.759509	42.77038	123
Sphere to plane in Mineral oil	5	0.021148	25.81419	179
	6	0.06109	6.983985	221
	4	3.819945	55.42639	107

IV. SCRUTINY OF PROPERTIES BASED ON VALUES

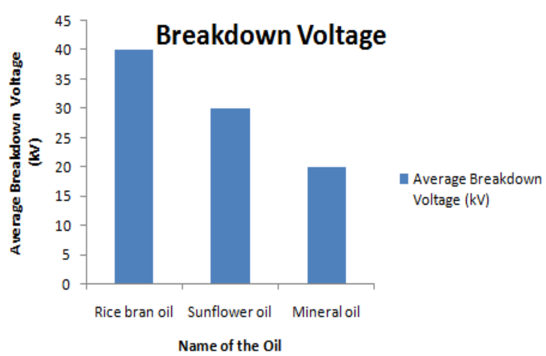

Fig 1.Breakdown Voltage of the Oil sample

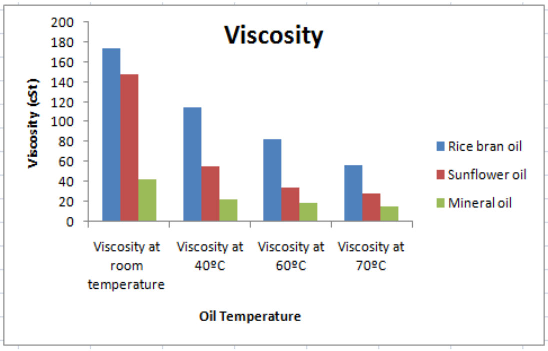

Fig 2. Viscosity of dielectric fluids under various Temperature Condition.

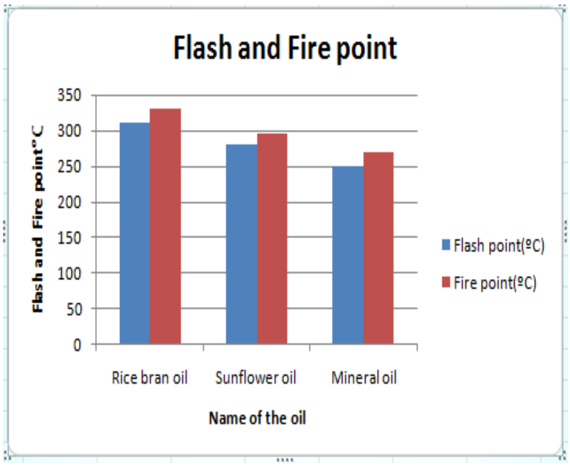

Fig 3. Flash point and Fire point for Various Insulating Fluids

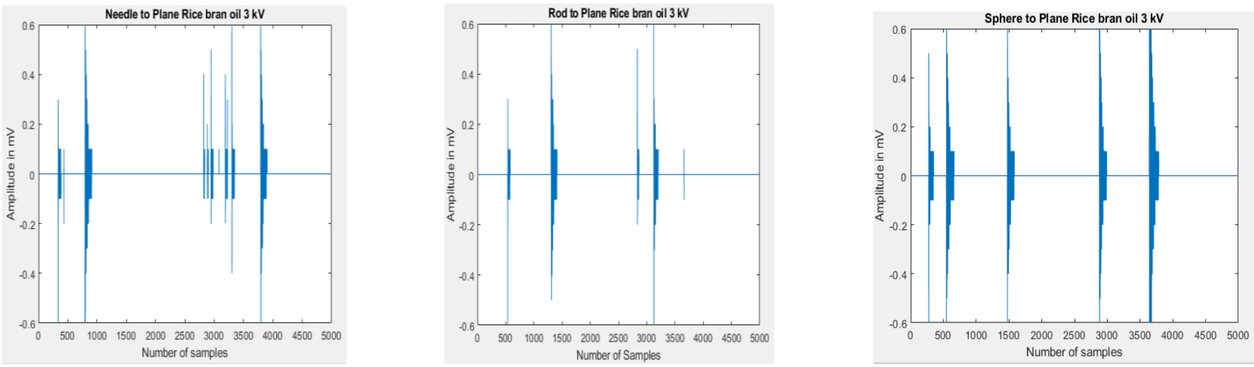

Fig 4. Partial Discharge Waveform for Needle – plane, Rod – Plane, Sphere – Plane Configurations under open air gap condition in Un aged Rice bran oil.

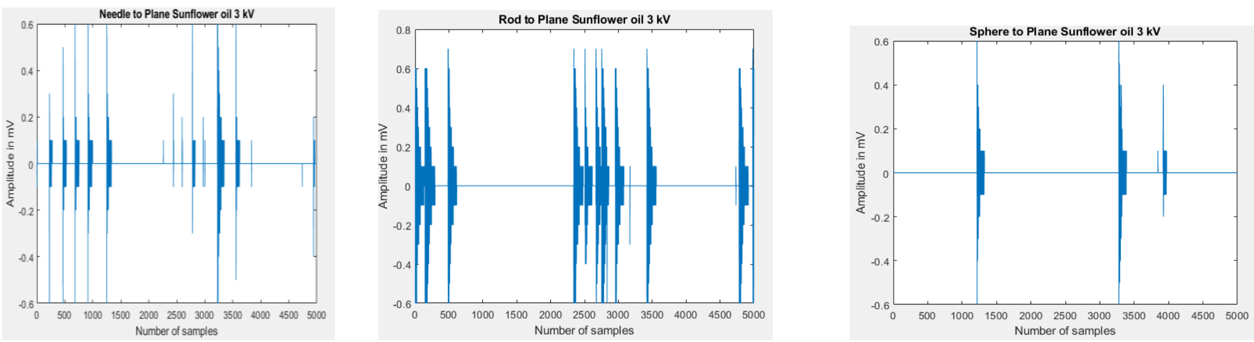

Fig 5. Partial Discharge Waveform for Needle – plane, Rod – Plane, Sphere – Plane Configurations under open air gap condition in Un aged Sunflower oil.

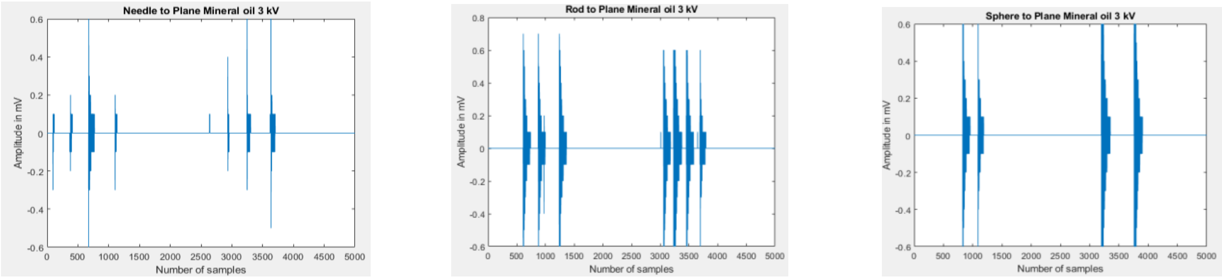

Fig 6. Partial Discharge Waveform for Needle – plane, Rod – Plane, Sphere – Plane Configurations under open air gap condition in Un aged Mineral oil.

From obtained results, it is found that Rice bran oil has higher breakdown voltage among all oil samples and mineral oil possesses lower value of breakdown voltage. Among analyzed vegetable oil, rice bran oil show higher values of flash point and fire point temperature. For these properties, mineral oil has lowest values. Viscosity is always higher for vegetable oils. This nature is also evidence in this work. Viscosity of rice bran oil is very much higher than that of other oil samples. Lowest value for viscosity is achieved in mineral oil. From this analysis, it is evident that the vegetable oil samples have potential as substitute to mineral oil. Only drawback is their viscosity values. But viscosity may be reduced by some other method without affecting other properties. The statistical parameter (ie) skewness lies on the positive side. The kurtosis of needle to plane in mineral oil have the large value when compared to the others. So the number of discharges gets increased. Here, the Rice bran oil has the less number of discharges compared to Sunflower and Mineral oil. When the voltage gets increase the number of discharges also gets increased. Hence it is proved on table 6. They have very high values than mineral oil which is not in acceptable range. The statistical parameters evaluated were useful in describing the behavior of a distribution, to calculate the number of discharge and to judge the severity of insulation degradation and the position of PD. The investigated vegetable oil had better electrical and thermal properties.

V. CONCLUSION

Petroleum based mineral oils are generally used for electric power apparatus insulation and cooling applications. Since the conventionally used mineral oils are not biodegradable and difficult to decompose, there is a need for the development of alternate vegetable based insulation oils for such applications. Mineral oil and Natural ester (Rice bran oil and Sunflower oil) are analyzed and from the analysis, it is concluded that vegetable oil have better breakdown voltage, flash point, fire point, Density of oil, than the mineral oil.

As different dielectric fluids are increasing by addition of antioxidants, nano particles their PD characteristics has to be analyzed in order to find its suitability for electric power apparatus. Formation of PD plays a major role in determining the life time of liquid insulation. Statistical analysis of PD pattern and to calculate the number of discharge is carried out. It is concluded that the statistical parameters evaluated from PD wave forms provides information about the insulating materials.

ACKNOWLEDGMENT

This work is financially supported by the Department of Science and Technology – fund for the improvement of S&T infrastructure in universities & higher educational institutions (DST-FIST) Grant ID (SR/FST/College-061/2017) and also the authors are grateful to the management of the National Engineering College, Kovilpatti, Tamilnadu, India.

REFERENCES

1. Bo Gao, Rui Yu, Guangcai Hu, Cheng Liu, Xin Zhuang and Peng Zhou "Development Processes of Surface Trucking and Partial Discharge of Pressboards Immersed in Mineral Oil: Effect of Tip Curvatures" 12, 554; doi:10.3390/en12030554 Energies, 2019.
2. Andrea Cavallini, Chandrasekar. S and Gian Carlo Montanari, (2007), "Inferring ceramic insulator pollution by an Innovative Approach Resorting to PD Detection", IEEE Transaction on Dielectrics and Electrical Insulation, Vol. 14, No. 1, pp. 23-29.
3. George K. Frimpong, Oommen. T.V and Roberto Asano, (2011), "A survey of Aging Characteristics of cellulose Insulation in Natural Ester and Mineral oil", IEEE Electrical Insulation Magazine, Vol.27, No.5, pp. 36 – 48.
4. J. Dai, Z. D. Wang and P. Jarman, "Creepage Discharge on Insulation Barriers in Aged Power Transformers", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 17, No. 4; 2010.
5. Jiangang Deng, Mingyuan wang, Yuanxiang Zhou, Zhongliu Zhou, Yunxiao Zhang, Ling Zhang and Xinqu Liu "Partial discharge characteristics of uniform gap in oil-impregnated paper insulation under switching impulse voltage", Vol:23, No:6; 2016.
6. Yan-Hui Wei, Hai-Bao Mu, Guan-jun Zhang and George Chen, "A Study of Oil-impregnated Paper Insulation Aged with Thermal-Electrical Stress : PD Characteristics and Trap Parameters" IEEE Transactions on Dielectrics and Electrical Insulation Vol. 23, No. 6; 2016.
7. Simeng Li, Wen Si and Qingquan Li, "Partition and Recognition of Partial Discharge Development Stages in Oil-Pressboard Insulation with Needle-Plate Electrodes Under Combined AC-DC Voltage Stress", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 24, No. 3; 2017.
8. Lu Cui,Weigen Chen, A. S. Vaughan, Bo Xie1, Jian Li and Zhenze Long, "Comparative Analysis of Air-gap PD Characteristics: Vegetable Oil/pressboard and Mineral Oil/pressboard", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 24, No. 1; 2017.
9. Qingguo Chen, Lin Lin, Yuan Gao, Jiahui Li, "Flow Electrification Characteristics of Oil-pressboard Insulation under AC Superimposed on DC Electric Field", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 22, No. 5; 2015.
10. C.Thirumurugan, G.B. Kumbhar and Ramesh Oruganti, "Effects of Impurities on Surface Discharges at Synthetic Ester/Cellulose Board", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 26, No. 1; February 2019.
11. Sheng Lan, Mingliang Huang, Yuhang Zhang and Yongbin Yuan, "Experimental Study of Oil-Paper Insulation under Combined Thermal Stress and Corona Discharge", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 26, No. 3; June 2019.
12. L. Syed Mohammed Mazood, M. Bakrutheen, M. Willjuice Iruthayarajan, And M. Karthik," STUDIES ON CRITICAL PROPERTIES OF VEGETABLE OIL BASED INSULATING FLUIDS", IEEE INDICON 2015 1570185471.
13. Yanjie Cui, Lingyu Zhu, Shengchang Ji, Pei Cao and Fan Zhang," Partial Discharge Development in Needle–plane Configuration of Oil-paper Insulation under AC Voltage", IEEE Transactions on Dielectrics and Electrical Insulation Vol. 24, No. 4; August 2017.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

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