Central Power Research Institute

Vol. 15(2)/130-135, July-December 2019
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v15i2.150408

Power Research

Evaluation of Partial Discharge Aged Transformer Oil using Optical Spectroscopy Techniques

Subrata Karmakar*, Shivani Meshram and Hussain Kalathiripi

Department of Electrical Engineering, National Institute of Technology, Rourkela – 769008, India; karmakar.subrata@gmail.com, shivani.ji286@gmail.com, hussaindd@gmail.com

Abstract

In recent times, optical spectroscopy techniques are being widely accepted for chemical analysis of transformer oil. These techniques gained popularity because of the advantages like they are quite simple to perform, give results very quickly, outcome is reliable, and they are economical. Unlike traditional methods, these can also be carried out online with cost effective equipments. In this work, breakdown voltage test is done and then, UV-Visible (UV-Vis) spectroscopy and Fourier Transform Infrared (FTIR) spectroscopy techniques have been used to investigate the condition of the transformer oil. To replicate the actual aging of oil in field, partial discharge (PD) in the laboratory environment has aged oil samples. Test results obtained from UV-Vis spectroscopy gives the qualitative analysis of transformer oil and FTIR spectroscopy evaluates the functional group present in it. The analysis is done precisely by relating the optical spectra obtained by spectroscopy techniques with the duration of aging. The results obtained justify that the optical spectroscopy techniques used, can accurately analyze the condition of aged transformer oil.

Keywords: Fourier Transform Infrared, Partial Discharge, Spectroscopy, Ultraviolet Visible Spectroscopy, Transformer Oil

1. Introduction

With increasing demand in the power, the role of the transformers has become significant in the entire electrical power system. They are the part of generation, transmission and distribution systems. Therefore, as the transformers are more, the huge amount of oil being used in them. The transformer oil plays two important roles. First, it acts as the insulating agent and second, it is used for cooling[1]. Partial discharge in the insulation of equipment occurs due to the presence of dielectric defects, which can cause further degradation of insulation and conclusively results in failure of equipment. Therefore, it is necessary to investigate the oil for the best possible transformer operations[2].

As the ageing increases the formation of byproducts increase which may chemically react with insulation, which further results in decreasing the inception voltage of PD. This accelerates the ageing and ultimately results in breakdown of oil[3]. Therefore, it is said that partial discharge plays an important role in accelerating the ageing of oil insulation.

For the analysis purpose, there are various methods to monitor the condition of oil such as breakdown test, interfacial tension, water content, and Dissolve Gas Analysis (DGA). Though DGA is quite efficient, yet it needs regular calibration and the method is also too expensive. Therefore, due to these demerits, in this work, optical techniques such as UV-Vis spectroscopy and FTIR spectroscopy have been used for analysis of aged transformer oil[4]. Both the methods are reliable, fast and economical[5–7]. For this purpose, the samples are prepared in laboratory and aged by Partial Discharge. The samples are tested with aforementioned optical spectroscopic methods. Finally, the outcomes are investigated and correlated with the transformer oil ageing.

*Author for correspondence

2. Experimental Setup for Partial Discharge test

In this test setup, shown in Figure 1, high voltage transformer (230 V/100 kV, 20 kVA) is used as a source voltage, coupling capacitor of 1000 pF used as a measurement of apparent charge appeared in the PD activity inside test object. A measuring capacitor is used for measurement of applied voltage. Measuring impedance is connected in series of test object in order to get current pulse during the PD event. After that, the current pulse has been directly fed to PD meter in order to get PD amplitude in terms of Pico coulomb and simultaneously oscilloscope is used to observe the PD signal at different applied voltages across the test object.

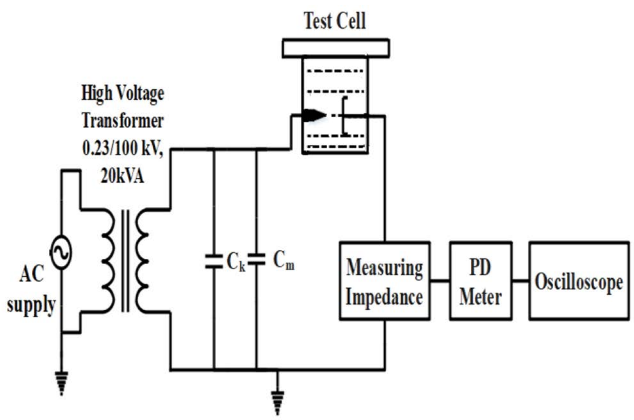

Figure 1. Partial discharge setup for ageing of transformer oil.

3. Preparation of Transformer Oil Sample

An acrylic container of dimension 20 cm x 20 cm x 20 cm is taken. In this, five liters of oil is poured at the beginning. The electrode fitted in the container has the 2 cm gap. Pin- plate type of electrode configuration is used. The reason to use this configuration is, electric field produced is highly divergent. This field is responsible for the accelerated ageing of partial discharge. The applied voltage is 25 kV as mentioned in the Table 1. The oil samples have been collected after 50 hrs and 100 hrs duration. Sample prepared are of three categories. Sample S-1 is the pure un-aged oil. Sample S-2 and S-4 are pure oil aged for 50 hrs and 100 hrs respectively whereas, S-3 and S-5 are with fine copper pieces aged for 50 hrs. and 100 hrs. respectively as shown in Table 1.

Table 1. Description of transformer oil samples

SI. No.	Sample Code	Sample Description	PD Ageing Duration (hrs.)	Applied voltage (kV)
1	S-1	Fresh Transformer Oil	0	0
2	S-2	Transformer Oil for PD ageing	50	25
3	S-3	Transformer Oil for PD ageing with Cu	50	25
4	S-4	Transformer Oil for PD ageing	100	25
5	S-5	Transformer Oil for PD ageing with Cu	100	25

4. Breakdown Voltage and Optical Spectroscopy Test Method

4.1 Breakdown Voltage (BDV) test (ASTM D 877)

To analyze the insulating property of transformer oil, its breakdown voltage is estimated. Lower the breakdown voltage, the poorer the condition of transformer oil. To measure the breakdown voltage, 500 ml of transformer oil is filled in the testing vessel. Testing vessel is fitted with two hemispherical electrodes. The electrodes are submerged in the transformer oil and the sphere are kept at 2.5 mm apart. Test voltage is applied at the rate of 2 kV/s. At a certain voltage level breakdown occurs between the two electrodes and observed as an electric arc. For accurate results, each sample is tested for five times and average breakdown voltage is noted down.

4.2 UV-Visible Spectroscopy

The range of wavelength for which UV-Vis spectroscopy works is 200 nm to 800 nm. The UV-Vis spectrometer used for the test is Shimadzu / model 3600, which can work for wavelength of 185 nm – 3300 nm, has Wavelength accuracy of UV-VIS region - ± 0.2 nm and Wavelength repeatability of UV-VIS region, which is less than±0.08 nm.

It comprises of UV and Visible light sources, monochromator, two identical cuvettes, cuvette holder and detector. Isooctane solvent is used in both the reference and sample cuvette, and one drop of sample is mixed with solvent in sample cuvette. When light is projected on the cuvette, energy is absorbed by the sample. The absorbed energy is equal to band gap energy and results in electronic transition from ground to excited state. Detector measures the transmitted light through the sample[8]. Detector is connected to a computer, which has the software that shows the absorption spectra of the samples. Figure 2 is the photograph of UV-Vis spectrometer used for transformer oil analysis.

Figure 2. UV-Vis spectrometer used for transformer oil analysis.

4.3 FTIR Spectroscopy

The range for which FTIR spectroscopy works is 2.4 μm to 25 μm and has the range of wavenumber in 400-4000 cm^{-1}. The bond shared by two atoms demonstrates two types of vibrations, namely Bending and Stretching, which occur at a particular frequency. When the energy of vibration matches with the external excitation energy, the bonds between the atoms break due to absorption of energy resulting in absorbance spectra.

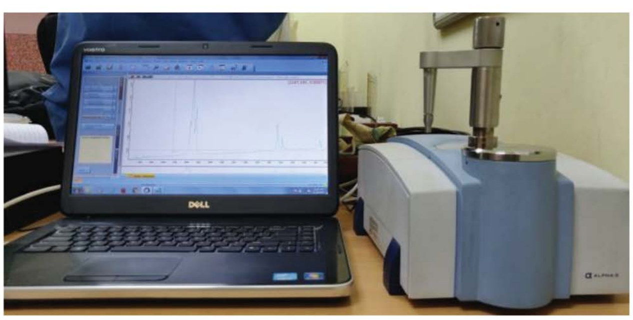

Figure 3. FTIR spectrometer used for transformer oil analysis.

For testing the samples, Perkin Elmer, USA/ RX-I FTIR spectrometer is used. It has Wavelength range of 400-4000 cm^{-1}. In this a single drop of sample is used and as the spectrometer is connected to the computer which has the software that gives the absorption spectra with respect to wave numbers.

5. Results and Discussion

Using the experimental setup, the partial discharge of the transformer oil is performed. Voltage is increased at the rate of 2 kV and the inception voltage of partial discharge is seen at 5 kV. For accelerated ageing, 25 kV is applied to the transformer oil for a different time duration. The oscilloscopic results for Partial discharge setup of transformer oil are shown in Figure 4. It is also found that partial discharge signal is appeared in both positive and negative half cycle of sinusoidal applied voltage of 25 kV. Further, it is also found that the magnitude of PD is varying randomly. The PD magnitude is much higher compared to PD occur during its inception voltage.

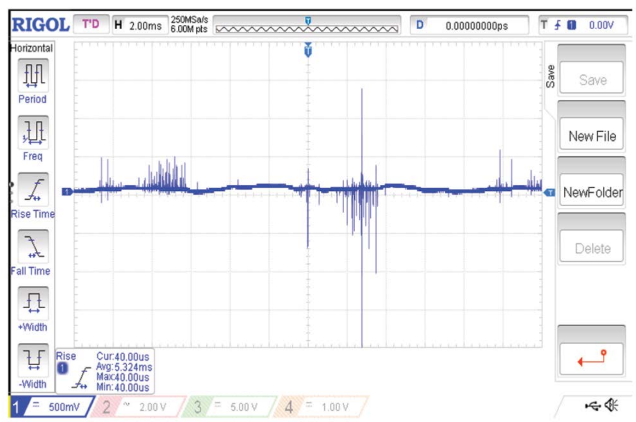

Figure 4. Oscilloscopic result of partial discharge at 25kV of transformer oil.

Breakdown voltage test shows the gradual decrement of voltage in the samples of transformer oil as shown in Table 2 as well as Figure 5. This decrement is due to the presence of moisture continent and impurity.

Table 2. Breakdown voltage of different sample

Sample	RMS Breakdown Voltage (kV)
S1	25.2
S2	24.4
S3	22.6
S4	19.8
S4	19.2

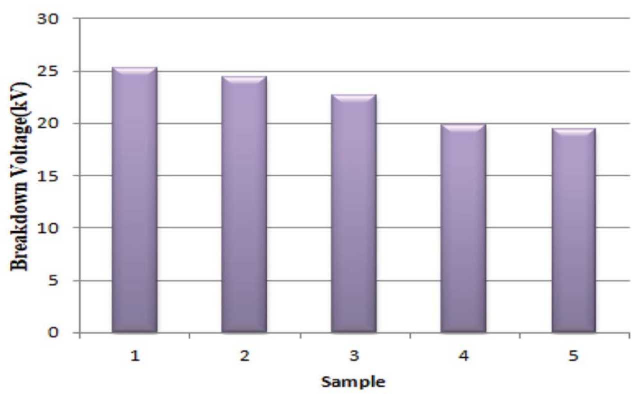

Figure 5. Breakdown voltage of different samples.

Figure 6 depicts the absorption spectrum with respect to wavelength for all the samples. It is observed that the highest absorption is coming nearly at wavelength 328 nm. At this wavelength, minimum absorption is noticed for S-1 which contains fresh transformer oil and maximum absorption spectra is observed for S-5 which contains Copper (Cu) as impurity and is aged for 100 hrs.

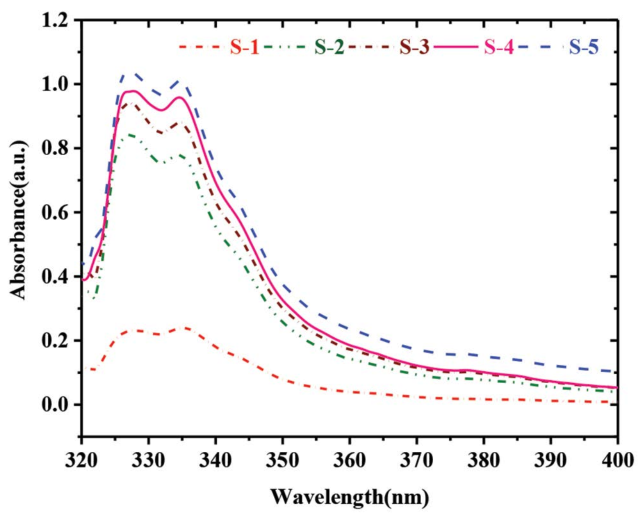

Figure 6. Absorption spectra of fresh and aged oil samples.

When radiation passes through samples, some energy is absorbed which results in transition of electron from ground energy level to excited energy level. From Figure 6, it is observed that, as the ageing increases, the absorption spectrum goes high. This is observed by comparing spectrum of S-2, which was aged by PD for 50 hours and S-4, which was aged for 100 hours by Partial Discharge. In addition, as the impurity increases, the ageing gets accelerated. This is realized by matching the spectrum of S-2 and S-3 in Figure 6. Lastly, it is also clear that there is no absorption happening in visible region. Table 3 describes the absorbance of fresh and aged samples at 328 nm.

Table 3. Peak absorbance of different sample

Sample	Wavelength(nm)	Absorbance(a.u.)
S-1	328	0.2110
S-2	328	0.8254
S-3	328	0.9524
S-4	328	0.9895
S-5	328	0.9989

Using the FTIR spectroscopy test, the functional groups of organic compounds present in the transformer oil are determined. Figure 7 shows the absorption spectra of fresh and aged oil samples.

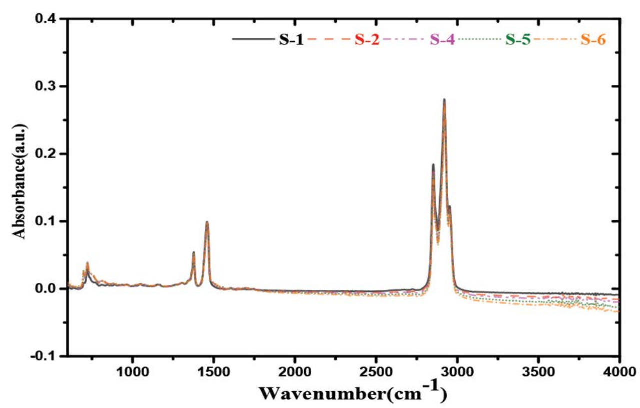

Figure 7. Absorption spectra of fresh and aged oil samples.

On evaluation of the absorption spectrum, it can be characterized into three major zones. These zones are enlarged for clear understanding.

The first zone is present in the range 650 cm^{-1} to 800 cm^{-1} as shown in Figure 8. The absorbance spectra have the maximum peak around 724 cm^{-1} which gives the indication regarding presence of alkenes i.e. = C-H. These types of functional groups have a strong intensity and exhibit bending.

The second zone comprises of the absorption spectra of fresh and aged samples oils between 1340 cm^{-1} and 1600 cm^{-1} as shown in Figure 9. This signifies the presence of Alkanes i.e. -C-H and Aromatic (C=C) functional groups. In this zone, there are absorption peaks at around 1376 cm^{-1} and 1460 cm^{-1}. Alkanes demonstrate bending and have variable intensities. Aromatic group shows medium-weak intensity and stretching.

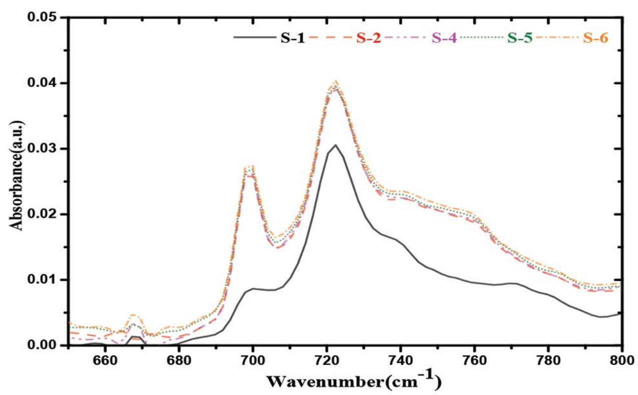

Figure 8. Absorption spectra of fresh and aged oil samples between 650 cm^{-1} to 800 cm^{-1}.

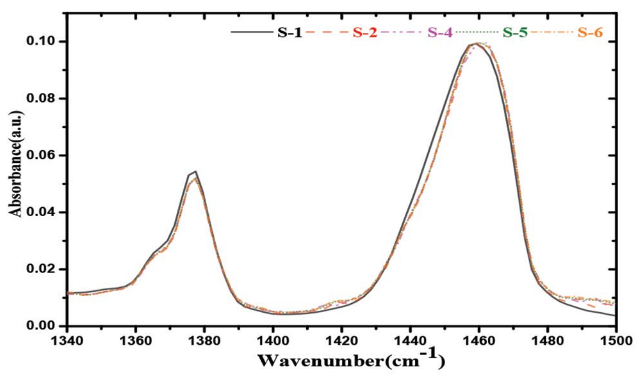

Figure 9. Absorption spectra of fresh and oil aged samples between 1340 cm^{-1} to 1600 cm^{-1}.

Lastly, zone 3 comprises of Absorption spectra between 2820 cm^{-1} and 2980 cm^{-1} as shown in Figure 10. These peaks confirm the presence of Alcoholic groups (O-H), and Alkanes (C-H). The peaks 2852 cm^{-1} and 2923 cm^{-1} are with strong intensity. Table 4 shows the functional group present in different samples.

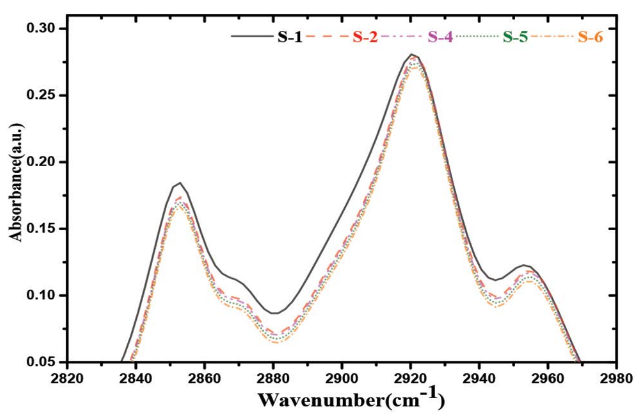

Figure 10. Absorption spectra of fresh and aged samples of oil between 2820cm^{-1} and 2980 cm^{-1}.

Table 4. Intensity of different functional group

Wavenumber (cm^{1})	Functional Group	Intensity
724	=C-H (Alkene)	Strong
1376	-C-H (Alkane)	Variable
1460	C=C (Aromatic)	Medium-Weak
2852	C-H (Alkane)	Strong
2923	O-H (Acid)	Strong

6. Conclusion

Transformer oil is aged by partial discharge and then, different tests such as UV-visible, FTIR spectroscopy, and breakdown voltage are performed. Because of the partial discharge effect on the samples, the breakdown voltage of them is reduced. From UV-Vis spectroscopic test, it is observed that as the aging increased, the peaks of absorption spectra also increased. The presence of impurity accelerated the ageing process, which is observed by the comparison of different aged samples i.e., aged without impurity, and samples aged with Copper pieces. From the results, it is observed that the maximum absorption peak is at nearly 328 cm^{-1} and no absorption has been found in the visible region. In addition, the results with FTIR spectroscopy have given different functional groups and corresponding bond intensities present in the aged oil samples. Test results show the presence of functional groups such as alkanes, aromatics, and alcohols. It is also observed that the functional group intensity also increases with the ageing. Overall, quite satisfactory results have been obtained regarding ageing condition of Transformer oil. Hence, these methods have proved that they have strong potential to assess the condition of the transformer condition.

7. References

1. Hadjadj Y, Fofana I, Sabau J, Briosso E. Assessing insulating oil degradation by means of turbidity and UV-Vis spectrophotometry measurements. IEEE Transactions on Dielectrics and Electrical Insulation. 2015 Oct, 22(5):2653–60. https://doi.org/10.1109/TDEI.2015.005111
2. Tsuboi T, Takami J, Okabe S, Inami K, Aono K. Partial discharge aging effect on insulation reliability evaluation with Weibull distribution for oil-immersed transformers.

IEEE Transactions on Dielectrics and Electrical Insulation. 2010 Dec; 17(6):1869–76. https://doi.org/10.1109/TDEI.2010.5658240
3. Kiiza RC, Niasar MG, Nikjoo R, Wang X, Edin H. The effect of partial discharge by-products on the dielectric frequency response of oil-paper insulation comprising of a small cavity. IEEE Transactions on Dielectrics and Electrical Insulation. 2015 Oct; 22(5):2923–30. https://doi.org/10.1109/TDEI.2015.004424
4. Gómez NA, Wilhelm HM, Santos CC, Stocco GB. Dissolved Gas Analysis (DGA) of natural ester insulating fluids with different chemical compositions. IEEE Transactions on Dielectrics and Electrical Insulation. 2014 Jun; 21(3):1071–8. https://doi.org/10.1109/TDEI.2014.6832250
5. Bakar NA, Abu-Siada A, Islam S, El-Naggar MF. A new technique to measure interfacial tension of transformer oil using UV-Vis spectroscopy. IEEE Transactions on Dielectrics and Electrical Insulation. 2015 Apr; 22(2):1275–82. https://doi.org/10.1109/TDEI.2015.7076831
6. Ueta G, Tsuboi T, Okabe S, Amimoto T. Study on degradation causing components of various characteristics of transformer insulating oil. IEEE Transactions on Dielectrics and Electrical. 2012; 19(6):2216–24. https://doi.org/10.1109/TDEI.2012.6396983
7. Kalathiripi H, Karmakar S. Fault analysis of oil-filled power transformers using spectroscopy techniques. 9th IEEE International Conference on Dielectric Liquids (ICDL), Manchester, United Kingdom; 2017 Jun. https://doi.org/10.1109/ICDL.2017.8124633
8. Cui Y, Zhu L, Ji S, Cao P, Zhang F. Partial discharge development in needle-plane configuration of oil-paper insulation under ac voltage. IEEE Transactions on Dielectrics and Electrical Insulation. 2017 Aug; 24(4):2469–76. https://doi.org/10.1109/TDEI.2017.006270
9. Liao R-J, Yang L-J, Li J, Grzybowski S. Aging condition assessment of transformer oil-paper insulation model based on partial discharge analysis. IEEE Transactions on Dielectrics and Electrical Insulation. 2011 Feb; 18(1):303–11. https://doi.org/10.1109/TDEI.2011.5704522