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Performance evaluation of transformer oil using uv-visible spectrophotometer

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ABSTRACT. To ensure reliable operation of Power transformer, condition monitoring of transformer becomes obligatory. In this paper, condition assessment of transformer oil under various working conditions is performed using UV-visible spectrophotometer. Test samples include both laboratorial prepared ones and those obtained from in service transformers. An index table of spectral responses for various faults which predominantly occur in the transformer is developed. The index table will acts as a reference for spectral response of faulted transformer oil. In this paper, an attempt has been made to determine the quality of transformer oil using their spectral response characteristics.

Keywords: transformer, dielectrics, oil transformer, spectral response, UV spectra.

Avaliação de desempenho de óleo do transformador utilizando espectrofotômetro UV-visível

RESUMO. Para assegurar uma operação confiável do Poder transformador, monitoramento de condição de transformador se torna obrigatória. Neste trabalho, avaliação do estado do óleo do transformador sob várias condições de trabalho é realizado usando espectrofotômetro UV-visível. As amostras de teste incluem tanto laboratoriais entes preparados e aqueles obtidos a partir de transformadores em serviço. Uma tabela de índice de respostas espectrais para várias falhas que ocorrem predominantemente no transformador é desenvolvido. A tabela índice funciona como uma referência para a resposta espectral do óleo do transformador com defeito. Neste trabalho uma tentativa foi feita para determinar a qualidade de óleo de transformador com as suas características de resposta espectral.

Palavras-chave: transformador, dielectrics, transformador de óleo, a resposta espectral, espectros UV.

Introduction

Transformer oil acts as an effective coolant in transformer and provides insulation between internal live parts. Under operating conditions, the transformer oil undergoes severe mechanical, electrical and thermal stresses. When the transformer is subjected to overloaded operating conditions and elevated temperature, the possibility of chemical interactions between solid and liquid part of the insulation increases. These interactions deteriorate the quality of the insulating fluid and over certain period of time, the insulating fluid losses its ultimate reason of existence in the transformer. Therefore it is important to monitor the quality of the transformer oil and to make sure that the insulating fluid still holds on to its electrical properties. If the specified electrical properties are not met, then necessary action has to be taken regarding maintenance such as filtration of transformer oil or its replacement. Since transformer oil contains 70% of diagnostic information, by continuous monitoring we can prevent any potential fault inside the transformers. Variation in different oil characteristics may be therefore be used to identify the type of problem in transformer.

UV spectrophotometer diagnostic system is based on the absorbance of the light by the transformer oil, which can be used for the detection of abnormalities in transformer. Karmakar et al. (2011) has examined the change in optical quality of the transformer oil due to three parameters namely arcing, thermal breakdown and partial discharge in transformer oil. Fofana et al. (2010) analysed the deterioration of liquid insulation due to ageing in mineral and ester oil by laboratory grade spectrophotometer and ratio-turbidimeter. Arshad and Islam (2007) investigated power transformer's dielectric response and aging assessment using oil contamination level identification with UV-Spectrometry measurements. Palmer et al. (2000)

examined the change in absorbance property of transformer oil for transformer oil degraded in the laboratory and for transformer oil drawn from in service transformers. Ota et al. (2003) has analyzed the effect of acetic acid in transformer oil. Lundgaard et al. (2005, 2008) analyzed ageing of mineral oil impregnated cellulose by acid catalysis. Bengstsson et al. (2006) evaluated the transformer oil with respect to corrosion and deposition of CU_2S. Oommen (1993) studied the impact of corrosive and non corrosive sulphur in transformer oil. Karthik and Raja (2012) investigated the characteristics of aging of transformer oil using DGA, Furan analyzer etc.

On considering the above literature review, UV-visible spectrophotometer has been considered as an effective tool for online monitoring of transformer. But to make the purpose more effective, the faults can't be limited within arcing, thermal and partial discharge. Increased acidic content in transformer oil over period of service, presence of free sulphur and its compounds in transformer oil, degradation of Kraft paper with elapsed heating and the real time defects occurring in the transformers such as Line-Line fault, Lightning, Overload, Short circuited faults should also be considered. Therefore the ultimate aim of this research work is to make the UV spectrophotometer technique as an effective monitoring tool to monitor the performance of transformer oil and transformer.

Material and methods

In this paper, 12 samples of naphthenic transformer oil with various levels of fault and composition were prepared. The samples include both laboratory prepared sample and those obtained from power transformer and field transformers. The list of sample analysed is shown in the Table 1. Sample S-1 stands for new transformer oil which acts as a reference for both wavelength and absorbance for the rest of the samples. Photographs of test samples are given in Figure 1. Test is carried out by Shimadzu make UV visible spectrophotometer.

Most of the transformers are designed to operate for a maximum of 20-30 years if properly designed, installed and maintained. The main reason for the transformer failure is degradation of their insulation system. So anything that adversely affects the insulating properties inside the transformer reduces the transformer life. S-2 is 20 years worked out transformer oil obtained from power transformer rated 11/66kV.

As per ASTM D 2864, elemental sulphur and thermally unstable sulphur compounds in electrical insulating oil can cause corrosion of certain transformer metals such as copper. Deposition of sulphur and its compounds are more pronounced in sealed transformer and often lead to the deposition of the copper-sulphur compounds in the insulation paper. This in turn increases the conductivity of the insulation paper and results in the total deterioration of the property of the insulation. In addition presence of these compounds in the transformer oil results in the corrosion of the windings in transformer.

Table 1. Description of Transformer oil sample.

Name of the Sample	Samples Description
S-1	Pure Transformer Oil
S-2	20 Years Oil
S-3	Oil + CU_2S (60 ppm)
S-4	Oil +Sulphur (50 ppm)
S-5	Oil +Acetic acid (100 ppm)
S-6	Oil + Kraft paper (heated at 100°C, 10h)
S-7	Oil (heated at 100°C, 10h)
S-8	Oil (arcing 50 times)
S-9	Transformer oil from Line-Line faulted transformer
S-10	Highly burned oil
S-11	Transformer oil from Overloaded transformer
S-12	Transformer oil from Lightning affected transformer

Sulphur content in transformer oil is up to 0.5%, in order to prevent the copper corrosion in transformer the level should be maintained below 0.1%. Sulphur level in the depleted transformer oil ranges from 48 to 1900 ppm. It becomes important to detect the presence of sulphur and its compounds in transformer oil to prevent the corrosion of windings. Therefore to monitor the presence of sulphur, sample S-3 is prepared by adding 60 ppm of cuprous sulphide (CU_2S) to 100 mL of transformer oil and sample S-4 is prepared by adding 50 ppm of sulphur to 100 mL of transformer oil. For the complete miscibility of CU_2S and sulphur with the transformer oil, the samples S-3 and S-4 were stirred by magnetic stirrer for 2 hours separately in the laboratory.

Mechanical property of insulation paper reduces as it ages, although electrical properties may not show significant change. In transformers it is mainly the oil impregnated cellulose system of windings that governs larger risks. Acetic acid is formed along with formic and levulinic acids due to ageing of cellulose in transformer. Since lower molecular weight acids are most easily absorbed by insulation paper sample S-5 is prepared by adding 100 ppm of acetic acid to 100 mL of transformer oil. For the complete miscibility of acetic acid with the transformer oil, the sample S-5 was stirred by magnetic stirrer for 2 hours separately in the laboratory.

Figure 1. Snap shot of Test samples.

When transformer is subjected to overload operating conditions, the increase in temperature within the windings causes the mechanical strength of the insulation paper to get reduced. This in turn may adversely impact the insulation's performance, which may lead to transformer failure. Further the cause of most transformer failures is the breakdown of the insulation system. Therefore in order to analyse such changes in quality of transformer oil due to elapsed heating, samples S-6 and S-7 were prepared. The sample S-6 is prepared by heating transformer oil along with Kraft paper for the time period of 10 hours at the temperature of 100°C and the sample S-7 is prepared by heating transformer oil for the time period of 10 hours at the temperature of 100°C. The dimension and the thickness of the Kraft paper are 120 x 80 and 0.5 mm.

Electrical discharge is often possible in high voltage Power apparatus. Discharge is caused in the insulating fluid due to failure of withstand capability of dielectric liquids. Discharges may seriously damage other parts of the insulating materials and if these discharges persists continuously it will leads to total failure of transformer. Sample S8 is prepared (50 times of arcing) by means of test set up which comprises of HV AC test transformer. The dimension and capacity of test cell are 12 x 11.5 cm and 500 mL. HVAC is fed to Test cell which consist of two sphere electrodes separated by 2.5 mm, the test cell is filled with transformer oil, by means of varying the test voltage using HV transformers the arcing is produced. Test set up is shown in Figure 2.

As the insulating oil deteriorate, the probability of occurrence of transformer failure increases. It is therefore important to regularly monitor the transformer's insulation. If the data's obtained through continuous monitoring allows one to determine the condition of transformer oil, then the fault can be predicted and rectified. In this aspect sample S-9 (Transformer oil from Line-Line faulted transformer), S-10 (Highly burned oil), S-11 (Transformer oil from Overloaded transformer) and S-12 (Transformer oil from Lightning affected transformer) where obtained from transformers rated 11kV/433V, 11kV/230V, 11kV/433V and 11kV/433V respectively.

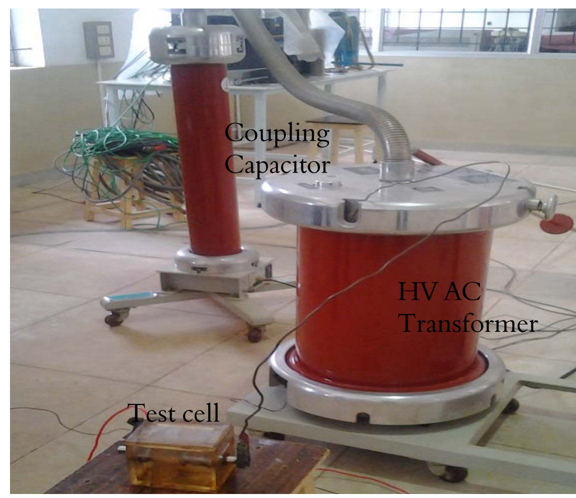

Figure 2. Experimental setup under which the transformer oil is arced 50 times.

Results and discussion

Transformer oil is of highly absorbing material, the value of absorbance generally exceeds the spectrophotometer saturation range (max. peak absorbance range is 4). In order to overcome this complexity, 2 drops of test sample is diluted by 10 mL of isooctane solution.

During measurement of spectral response using spectrophotometer, iso-octane is used as reference solvent in one quartz curvette and another curvette consists of 2 drops of samples diluted by 10 mL of iso-octane. Spectral responses for various test samples obtained are listed in Table 2.

Sample S-1 of pure transformer oil serves as the reference for remaining samples. Its wave length is found to be in the region of 265.60 nm, absorbance of 0.397. Spectral response of S1 is given Figure 3.

Table 2. Spectral response of the sample.

Test samples	Absorption Maximum (nm)	Absorbance
S-1	265.60	0.397
S-2	254.80	0.365
S-3	265.80	0.386
S-4	265.80	0.402
S-5	266.00	0.453
S-6	268.60	0.803
S-7	218.00	2.864
S-8	268.40	0.544
S-9	280.60	3.493
S-10	278.80	3.643
S-11	268.00	3.643
S-12	320.20	3.816

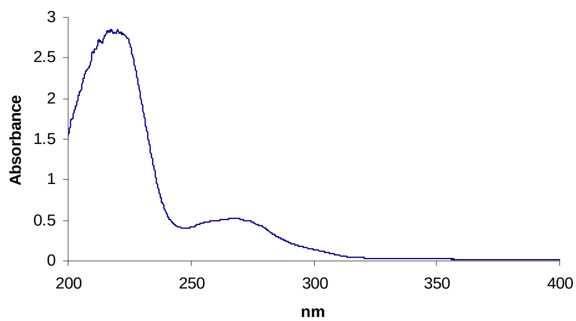

Figure 3. Spectral response of the pure transformer oil (S-1).

Twenty years worked out sample S-2 immediately shows the drastic reduction in both wavelength and absorption peak which is shown in Figure 4. Samples S-3 (presence of cupric sulphide) and S-4 (presence of sulphur) shows similar wavelength, but their absorbance peak slightly varies which is shown in Figures 5 and 6. Sample S5 (presence of acetic acid) shows a unique type of wavelength (266 nm) and absorbance which is shown in Figure 7.

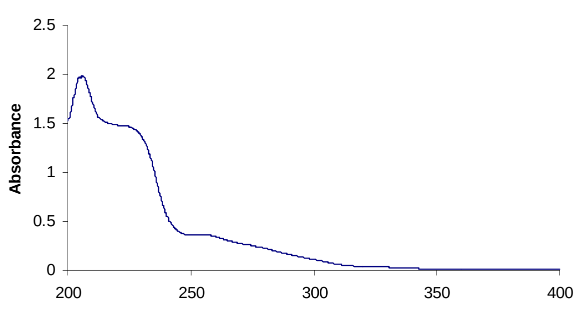

Figure 4. Spectral response of 20 years worked out transformer oil (S-2).

Elapsed heating of transformer oil deteriorates the quality of the transformer oil. The transformer oil heated along with Kraft paper Sample S-6 doesn't show any increased bandwidth than that of S-1 but shows increased absorbance peak (0.803) which is shown in Figure 8. Sample S-7 (transformer oil heated at 100°C) shows abrupt change in the values of both bandwidth and absorption peak. The sample S-7 has a unique type of wavelength (218 nm) which is much lower than that of S-1 and absorbance peak (2.864) is much higher than S-1, which is shown in Figure 9.

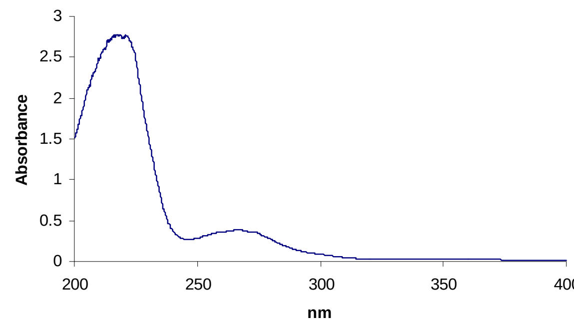

Figure 5. Spectral response of transformer oil with CU_2S (S-3).

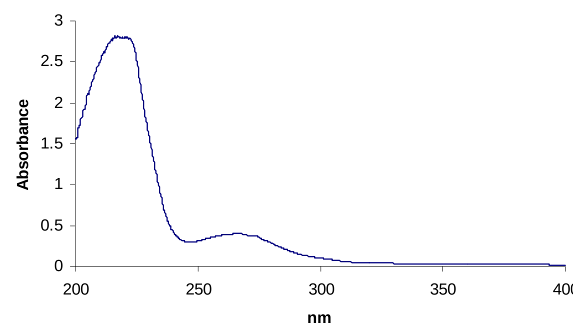

Figure 6. Spectral response of transformer oil with sulphur (S-4).

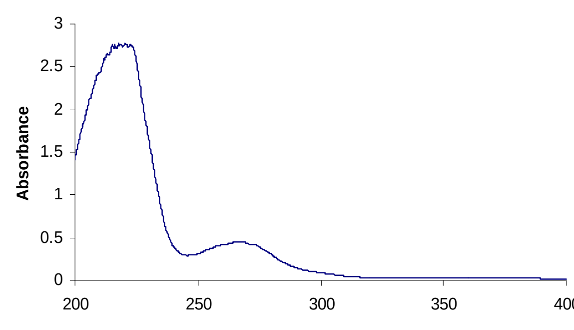

Figure 7. Spectral response of transformer oil with acetic acid (S-5).

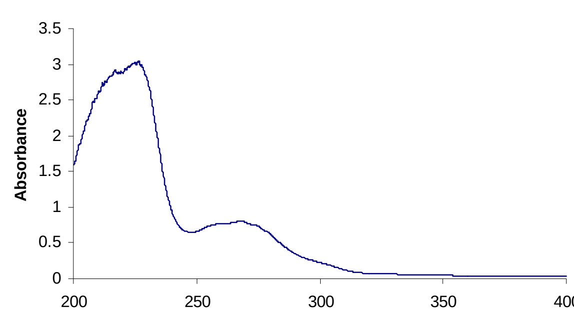

Figure 8. Spectral response of overheated transformer oil heated with Kraft paper (S-6).

Spectral response of sample S-8 (50 times arcing) shows a wave length of 268.40 nm with absorbance peak 0.5. Maximum absorbance wavelength of S-8 is more or less same as that of S-6 and S-11, but S-8 absorbance peak value entirely differs. Spectral response is shown in Figure 10.

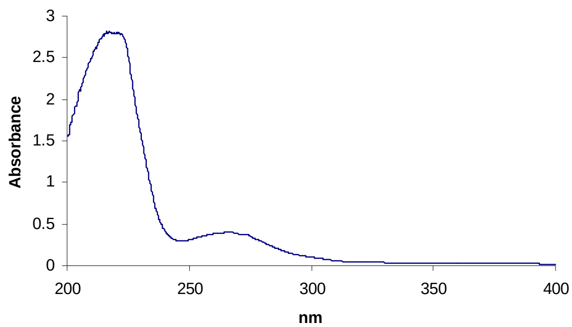

Figure 9. Spectral response of overheated transformer oil (S-7).

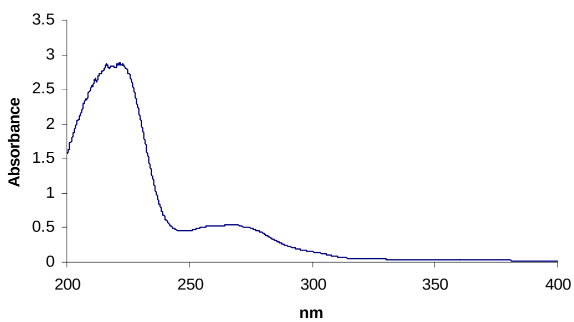

Figure 10. Spectral response of transformer oil arced 50 times (S-8).

Spectral response of sample S-9 (Oil from L-L faulted transformer) shows a very high wave length (280.60 nm) with increased absorbance peak (3.493). The absorbance peak has reached more or less the saturation level. Spectral response is shown in Figure 11.

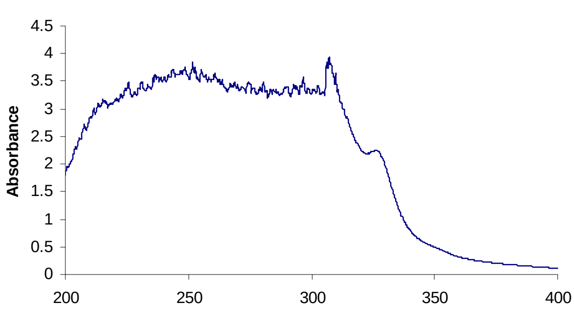

Figure 11. Spectral response of transformer oil obtained from L-L faulted transformer (S-9).

Spectral response of sample S-10 (highly burned oil) shows a wavelength (278.80 nm) which is a unique type. Here also the absorbance peak has reached saturation level (3.643) of the instrument. Spectral response is shown in Figure 12.

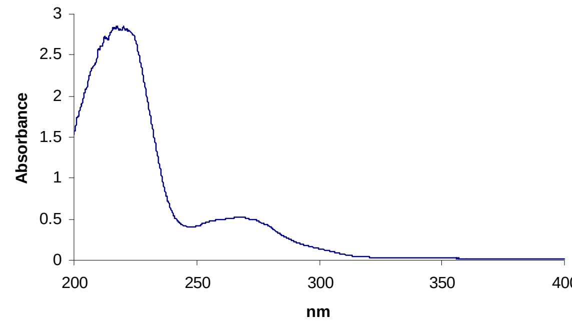

Figure 12. Spectral response of highly burned transformer oil (S-10).

Spectral response of S-11 (Oil from over loaded transformer) shows a similar pattern of wavelength regarding S-6 and S-8 but the absorbance peak is much higher (3.64) when compared with S-6 and S-8. Spectral response is shown in Figure 13.

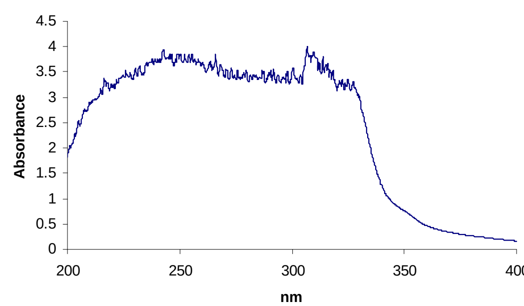

Figure 13. Spectral response of transformer oil obtained from overloaded transformer (S-11).

Spectral response of S-12 (Oil obtained from Lightning affected transformer) shows a unique type of wavelength (320.20 nm) and absorbance peak is very high, more or less reached instrument saturation level. Spectral response is shown in Figure 14.

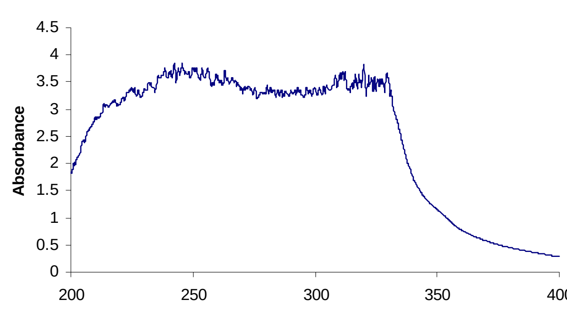

Figure 14. Spectral response of transformer oil obtained from lightning affected transformer (S-12).

Total of 12 samples were tested, each samples obtained are of with various fault conditions and compositions. Every samples show their own spectral response. The spectral response wavelength ranges between 200-350nm. When more number of samples for variety of faults, materials is prepared, then it leads to form an index value for wave length and absorption peak. On comparing UV spectral responses obtained from unknown test samples and the index table we have already formed, we shall establish the performance level of transformer oil and the fault acquired in it. Moreover the analysis of transformer oil is done with in short time and at reduced cost.

Conclusion

In this paper, an effort has been made to monitor the state of transformer oil using UV visible spectrophotometer. It is observed that UV spectrophotometer acts as an effective tool for transformer's insulation assessment. An index value of wavelength and absorption peak with the aid of twelve samples has been formed. Performance evaluation of transformer oil can be optimized, when more number of test samples is prepared for variety of faults. Based on results we shall establish a general index for variety of faults, thermal degradation and composition of materials. The index value of samples helps to determine condition of insulation system. Correlation between the spectral for unknown test samples and the index statistics previously formed steer to determine type of fault and performance level of transformer oil.

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