Copper Corrosion phenomenon in transformers due to DBDS in mineral transformer oil

Akshatha A, Ravi Kumar, Sundara Rajan J
R & D Management Division
Central Power Research Institute
Bangalore, India 560 080

H. Ramachandra
Department of Chemistry
PES College of Engineering
Mandya, India 571 401

***Abstract*-The presence of Dibenzyl disulphide (DBDS) in transformer oil is one of the causes for copper corrosion and consequent copper sulphide formation. This Study has been carried out on paper oil insulation after thermal ageing in transformer oil containing different concentrations of DBDS. The studies have been repeated on laboratory model transformer after thermal ageing. Effect of copper corrosion is studied in terms of subtle changes in Frequency Domain Spectroscopy (FDS), Polarization Depolarization Current (PDC) and variations in real and imaginary permittivity with frequency.**

I INTRODUCTION

Power transformers are very important assets of Power transmission companies. Hence extending the life of transformers beyond their expected life in service is very important to the Power utilities. Repairing or replacing the transformer matters both in terms of cost and time. Hence great care is exercised in maintaining the health of transformer insulation. [1]. Paper-oil insulation is the heart of transformers and there are many factors which affects the life of insulation. These include oxidation, moisture, ageing due to thermal and electrical stresses etc., in addition to formation of copper sulphide due to corrosive sulphur compoundsin oil.

Sulphur compounds present in transformer oil reacts with copper conductor to form semiconducting copper sulphide on copper surface, which over a period of time migrates to inner paper layers in the windings of transformers. Copper sulphide forms a low energy path for the surface discharges to occur and these consistent discharges over a period of time leads to degradation of paper oilinsulation system.

Dibenzyl disulphide (DBDS) is the major chemical compound which is reported to cause copper corrosion [2-5]. According to published reports, DBDS undergo degradation to benzyl mercaptan over a period of time. Benzyl mercaptan is soluble in oil and very reactive towards metals like copper and silver. Because of its volatile nature, it escapes into the surroundings in case of free breathing transformers where as in sealed transformers possibility of escape is limited and hence sealed transformers are more susceptible to copper corrosion [2].

Monitoring of DBDS in oil is a tedious process as it influenced by many parameters and also there is a tendency for recombination of DBDS at certain stages of aging which makes it difficult to understand the mechanisms involved in degradation of DBDS. Hence its effect on formation of copper sulphide remains a very complex reaction which is yet to be fully understood.Hence use of electrical methods along with chemical analysis is a better approach for understanding the phenomenon of copper sulphide formation in paper-oil insulation, due to presence of DBDS. In this study, paper oil insulation has been subjected to thermal ageing at 100 ° C, with 33 and 80 ppm of DBDS in oil for 1750 hours. FDS, PDC and variation of real (ε') and imaginary (ε'') part of permittivity have been monitored. The results are compared for establishing a correlation between copper corrosion and these dielectric measurements.

II. EXPERIMENTAL METHOD

FDS and PDC measurements were carried out on conventional pigtail samples details of which are available in literature [6]. These samples are aged in transformer oil containing different concentrations of DBDS.

III. RESULTS AND DISCUSSION

Effect of concentration of DBDS on formation of copper sulphide has been studied using FDS and PDC measurements on paper oil insulation using the pigtail configuration. The specimens were aged in transformer oil containing DBDS for different durations at 100º C. Effect of degradation of DBDS and its effect on copper conductors is understood through the measurements of Tan δ, real permittivity (ε') and imaginary permittivity (ε'') as a function of frequency over the range of 0.0001 to 1000 Hz.

Fig. 1 depicts the FDS of clean paper oil insulation in pigtail configuration. Tan δ variation with frequency has regions which are characteristics of insulation ageing, oil conductivity, geometry of sample [7] etc. The FDS characteristic of clean paper oil insulation is a typical standard curve which serves as reference for this study. The corresponding variations in PDC, real and imaginary part of permittivity are shown in figure 2 and 3.

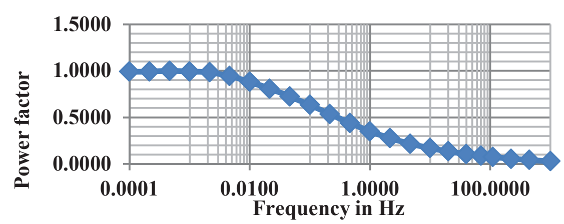

Fig. 1 FDS of clean paper oil insulation in pigtailconfiguration

978-1-4799-2597-1/13/$31.00 ©2013 IEEE

The variations in ε′ and ε″ show that there is a peak in case of real part of permittivity in the low frequency region and it decreases and remains constant till 0.0001 Hz. The variation in current in case of clean insulation shows instantaneously increase and starts decreasing in about 10 seconds and again starts increasing to reach a constant value of 12 nA after 4000 seconds and this remains constant up to 10000 seconds.

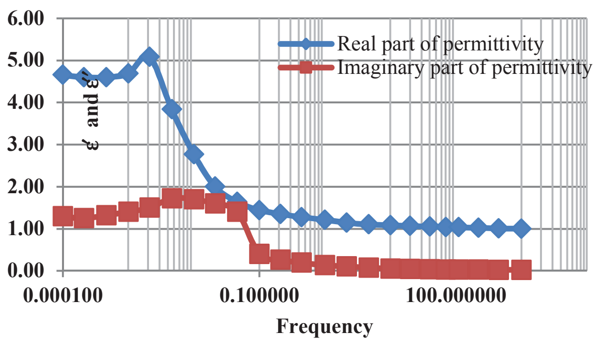

Fig. 2 Variation of Real and imaginary part of permittivity with frequency with clean paper oil insulation in pig tail configuration

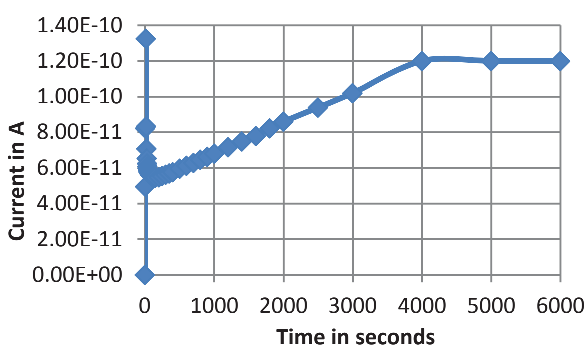

Fig 3. Polarization depolarization current variation of clean paper oil insulation in pig tail configuration

The sample was aged in oil containing 33 ppm of DBDS and thermal ageing was carried out at 100 ° C for 1053 hours. The results of FDS, PDC and variation of real and imaginary part of permittivity with frequency for this case are shown in figure 4, 5 and 6 respectively. There is a definite change in variation of tan δ with frequency. It increases in the low frequency region, unlike the constant value observed in the clean case from 0.01 to 0.0001 Hz, from 1 to 4. Similarly, real and imaginary part of permittivity values increase due to thermal ageing in oil containing 33 ppm of DBDS at 100º C for 1053 hours. PDC also shows peak and decreases within 10 seconds and settles at 20 nA as compared to 12 nA of the clean insulation case. However, the peak current increasesto 1.8 nA in comparison to 0.13 nA of the clean case.Thus increase in peak current and the saturation current are observed when thermal ageing is carried out in oil with DBDS. The effect of further ageing of paper oil sample in oil containing 33 ppm DBDS at 100 º C for 1735 hours is shown in figures 7, 8 and 9.

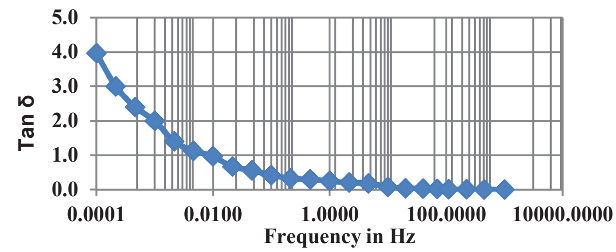

Fig 4.FDS of pig tail sample aged with 33 ppm of DBDS for 1053 hours at 100º C

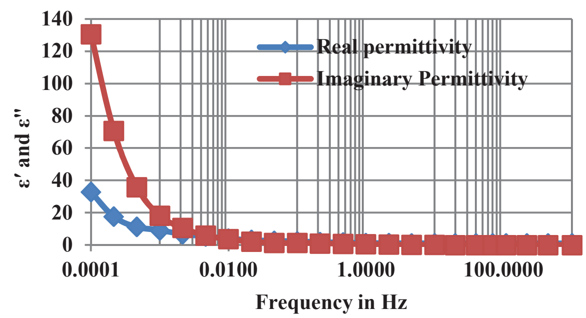

Fig. 5 Variation of real and imaginary part of permittivity with frequency after ageing of pig tail sample for 1053 hours at 100º C in oil containing 33 ppm of DBDS

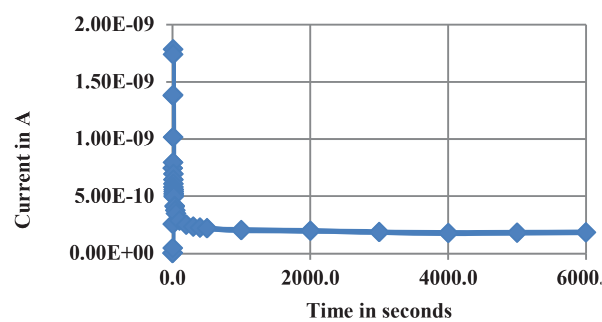

Fig. 6 PDC variation insulation inpig tail configuration aged in oil with 33 ppm of DBDS for 1053 hours at 100º C

The FDS of paper oil sample in pigtail configuration, when aged in transformer oil containing 33 ppm DBDS at 100 º C for 1735 hours shows a prominent tan δ peak at 0.0022 Hz and the magnitude is significantly very high. This is shown in figure 7. Thus copper sulphide formation results in a very high value of dissipation factor in the low frequency region. There is considerable increase in imaginary part of permittivity and this point towards possible increase in Cu_2S formation and migration into paper surface.

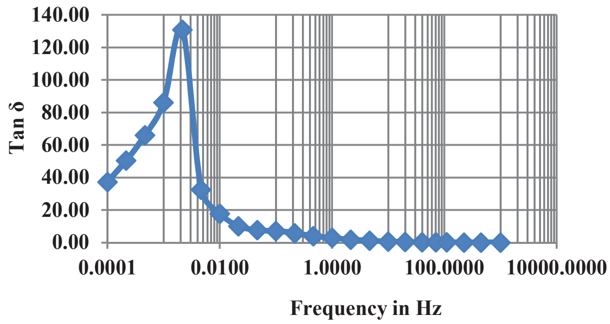

Fig.7 FDS of paper oil insulation in pig tail configuration aged in oil containing 33 ppm of DBDS and aged at 100 ° C for 1735 hours

The variation of ε′ and ε″ with frequency in case of prolonged ageing of oil containing 33 ppm of DBDS and aged for 1735 hours is shown in figure 8. While the real part of permittivity decreases very significantly, the imaginary part shows a very large increase in value. Thus increase in corrosion activity and formation and migration of copper sulphide has its influence in decreasing the real part of permittivity and a large increase in imaginary part of permittivity is observed. The corresponding variations in PDC are shown in figure 8. The current peaks in less than 10 seconds and then increases and stabilized at 70 nA and remains around this value till 1000 seconds. The magnitude of current is much larger than the ageing at 1053 hours. Thus current shows increasing trend with duration of ageing in presence of DBDS.

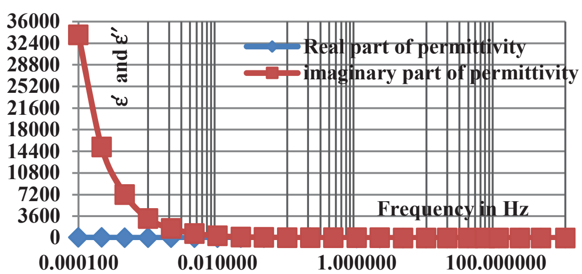

Fig. 8 Real and imaginary part of permittivity of paper oil insulation in pig tail configuration aged in oil containing 33 ppm of DBDS and aged at 100 ° C for 1735 hours

The FDS, PDC and values of real and imaginary part of permittivity in case of ageing with 80 ppm of DBDS at 100º C for 1053 hours is shown in figure 9, 10 and 11 respectively. The values of tan δ are below the corresponding values obtained for 33 ppm of DBDS in oil after ageing for 1053 hours. It is interesting to note that PDC peaks to 0.8 nA and reduces to very low value in less than 10 seconds, similar to the case with ageing with 33 ppm for 1053 hours.

It is interesting to note that ε′ and ε″are much lower than the corresponding values for 30 ppm of DBDS which is aged for same duration. This is an indication that recombination process is set in to reduce the rate of copper corrosion when 80 ppm of DBDS is used.

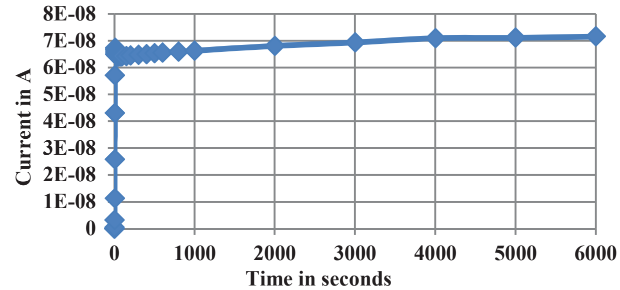

Fig. 9 PDC of paper oil insulation in pigtail configuration after aging in oil containing 33 ppm of DBDS at 100 ° C for 1735hours

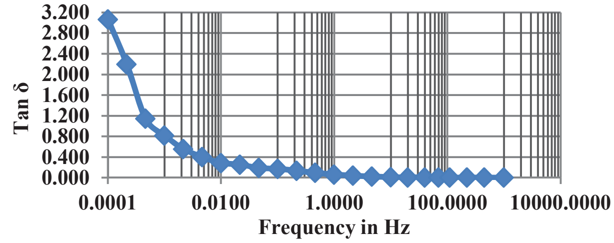

Fig. 10 FDS of paper oil insulation in pig tail configuration after ageing in oil containing 80 ppm of DBDS at 100 ° C for 1053 hours

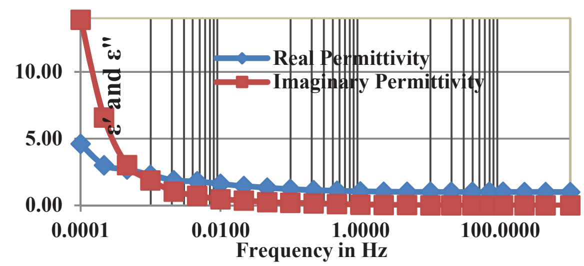

Fig.11 Real and imaginary part of permittivity of paper oil insulation in pig tail configuration after ageing in oil containing 80 ppm of DBDS at 100 ° C for 1063 hours

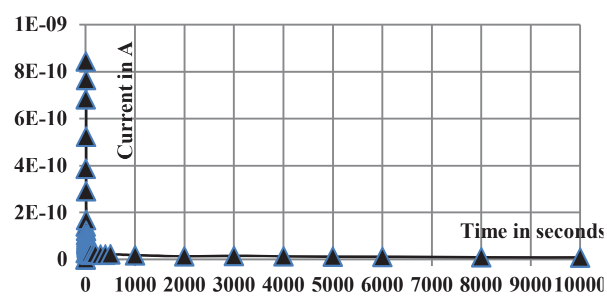

Fig.12 PDC of paper oil insulation in pig tail configuration afterageing in oil containing 80 ppm of DBDS at 100 ° C for 1063

Results for thermal ageing in oil containing 80 ppm of DBDS for 1753 hours at 100° C are shown in figure 13, 14 and 15 respectively. A significant increase in tan δ is observed due to thermal ageing but the values are below the corresponding values of 30 ppm of DBDS aged for same duration.

The real permittivity is much higher than the values with 33 ppm of DBDS. The imaginary permittivity also shows higher magnitudes as compared to 1053 and 1735 hours of ageing with 33 ppm of DBDS. However, the PDC shows a different trend and the current settles at half the magnitude of the peak current in comparison to 1053 hours of ageing with same concentration of DBDS. The peak current in this case is 6 nA and the saturating current is slightly lower at 4 nA.

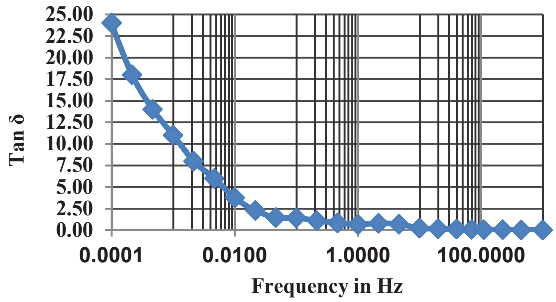

Fig 13 FDS of paper oil insulation in pig tail configuration after ageing in oil containing 80 ppm of DBDS at 100 ° C for 1735 hours

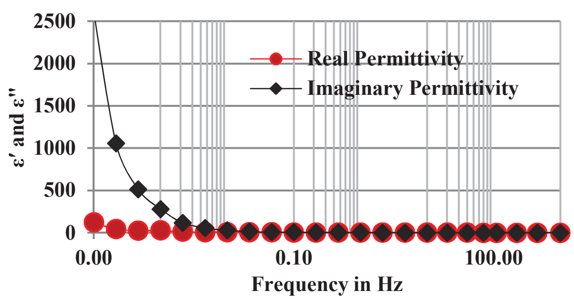

Fig. 14 Real and imaginary part of permittivity of paper oil insulation in pig tail configuration afterageing in oil containing 80 ppm of DBDS at 100 ° C for 1735 hours

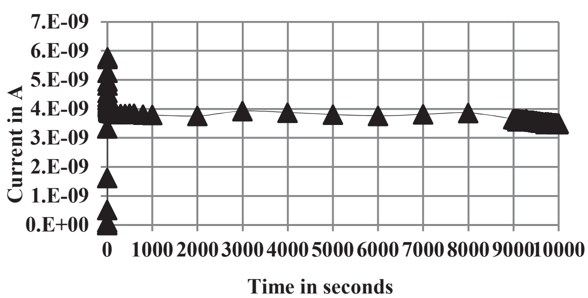

Fig. 15 PDC of paper oil insulation after ageing in oil with 80 ppm of DBDS at 100° C for 1735 hours

III. CONCLUSIONS

The following are some of the conclusions of this study:

(1) Results of FDS, PDC, ε′ and ε″ show correlation to copper corrosion and Cu_2S formation.
(2) Increase in Cu_2S formation is seen as increase in tan δ value at lower frequency below 0.0001 Hz.
(3) Imaginary part of permittivity shows increase due to Cu_2S formation on paper surface.
(4) PDC can also be correlated to Cu_2S formation on paper through current magnitudes, and the level of saturation current to peak current.
(5) Recombination of DBDS is observed at 80 ppm of DBDS and not at 33 ppm of DBDS through FDS, PDC and ε′ and ε″ variations.
(6) The trends in FDS, PDC, and ε′ and ε″ variations are specific to the type of cellulose insulation used (like paper, pressboard etc.) and the specimen geometry used.

More studies are necessary to achieve consistency and repeatable results which can be adopted for insulation diagnostics of transformers.

ACKNOWLEDGMENT

The authors wish to thank the authorities of Central Power Research Institute and the Standing committee on R&D for sponsoring this work under National Perspective Plan of Ministry of Power, Government of India.

REFERENCES

[1] J. S. N'cho, I. Fofana, A. Beroual, T. Aka- Ngnui, J. Sabau, "Aged oil reclamation: Facts and Arguments based on laboratory studies", IEEE transaction on dielectrics and Electrical Insulation, Vol.19, No 5, October 2012

[2] Lance Lewand, Scott Reed, "Destruction of dibenzyl disulfide in transformer oil", 2008 Doble Engineering Company -75th Annual International Doble Client Conference

[3] F. Kato, T. Amimoto, E. Nagao, N. Hosokaw, S. Toyama, J. Tanimura, "Effect of DBDS concentration and heating duration on copper sulphide formation in oilimmersed transformer insulation", Vol.18, No.6, Dec-2012

[5] Jelena M Lukic, Draginja Nikolic, Valentina Mandic, Sandra B. Glisic, Dusan Antonovic, Aleksandar M. Orlovic, "Removal of sulphur compounds from mineral insulating oils by extractive refining with N-methyl -2-pyrrolidone", ACS publications, I&EC Research, March7, 2012

[6] N. Rudranna, J. Sundara Rajan " Modelling of Copper sulphide migration in paper oil insulation of transformers" IEEE Transaction on Dielectrics and Electrical Insulation, Vol.19, No. 5, October- 2012

[7] Gobi k. Supramanian, P.Eng.C.Eng, Mohd A Talib, "TNB experiences using dielectric response technique to assess insulation condition of high voltage current transformers", International journal of energy engineering (IJEE) April.2013, Vol3,ISS2, P.P 1-12