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Diagnostic Field Testing and Condition Assessment of Power Transformers in Service

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In this era of reformation, liberalization and unbundling of electricity markets, asset management in power sector has assumed greater prominence. Power transformers are key components in any transmission & distribution network and loss of a transformer can have an enormous impact on reliability and availability of power supply and on cost. As society is more and more dependent on electricity for development, the utilities are under pressure to meet the ever-growing demands for reliable power supply. Economic factors are the main consideration and in order to minimize capital expenditure on new equipment, it is a common policy among utilities to maximize the use of existing networks by operating at their design capability. This can be achieved by according importance to the maintenance practice. A survey of the literature indicates that there are more failures of transformer due to poor maintenance, improper operation, severe weather conditions and manufacturing and design defects than due to insulation ageing. The utilities shall have a systematic O & M practice that include diagnostic tests for condition assessment and health checkup of the equipment. The objective of the condition monitoring tests is to detect the first symptoms of incipient faults, ageing development or other problems and monitor their evolution to enable the operator to take appropriate action to avoid major failure. The paper reviews the results of various diagnostic tests including dielectric response methods for condition assessment of power transformers.

Keywords: *Transformer, Diagnostic, Frequency, Moisture, Polarisation Spectrum, Dielectric spectroscopy, Partial discharge,*

1.0 INTRODUCTION

Condition monitoring of power transformers has been a continuous process and has seen many improvement over the years. Although several diagnostic tests such as dielectric loss angle, IR/PI, DGA, furan analysis are available, interpretation of data still appears to be a challenging task [1,2,3,4]. Interpretation of data requires care and experience. In recent times dielectric response methods have been introduced for detection and determination of moisture content and ageing of pressboard/paper insulation system of power transformers [5,6,7]. Moisture in the transformer affects the dielectric strength and the rate at which the insulation ages and in some cases, there is also threat of bubble evolution above a certain temperature when the load is suddenly increased [8]. Presently, the water content of the cellulose of a transformer in service is determined indirectly by measuring the moisture content in the oil sample. The moisture distributes unequally between the oil and pressboard, the greater part residing within the solid insulation. As the water concentration

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in the oil is highly temperature dependent, the measurement of moisture in oil is not a reliable indicator of dryness of the cellulose[7]. In addition to the conventional measurement of power frequency loss angle, recent attention has focussed on measuring various dielectric response parameters, which characterize some known polarization phenomena. Many testing agencies in Europe have adopted these test methods and data are being generated to study the efficacy of the test in assessing the status of the transformer insulation system.

CPRI has been carrying out variety of condition monitoring tests on power transformers in service for over 20 years. These tests include insulation resistance, dielectric loss angle, capacitance, partial discharge (PD), winding resistance, TTR. The dielectric response methods such as recovery voltage measurement and dielectric spectroscopy methods have also been adopted by CPRI for comprehensive diagnosis of health status of power transformers. These new techniques have been found to be effective in monitoring moisture dynamics in paper-oil insulation system. These diagnostic tests become significant and valid only when they are sensitive to the changes in the electrical properties of the insulation system. Since each parameter can be related to certain information on the status of the insulation, it is essential to carryout several tests to get a real feel of the insulation condition.

2.0 STRESSES ACTING ON POWER TRANSFORMERS:

The major stresses acting on the windings of a power transformer either individually or in combination are the following:

Mechanical stresses between conductors, leads and windings due to over currents or fault currents mainly caused by system short circuits. Possible variations of supporting parts of the winding or core may also cause deformation of the windings or of the cleats or leads. There can be collapse of the windings also. The deformation distortions in the windings cause changes in the geometrical distance of the windings, which in turn cause changes in the winding inductances and internal capacitance.

Thermal stresses due to local overheating overload currents and leakage flux when loading above nameplate rating or due to malfunction of the cooling system. Local hotspots, loose joints etc can give rise to high thermal stresses. Severe partial discharge resulting in arcing is another possibility.

Dielectric stresses due to system overvoltages, transient impulse conditions or internal resonance within a winding. These stresses cause deterioration of physical and chemical properties of the transformer insulation. The situation is more complicated due to the fact that dielectric failure is often and final stage consequent to the mechanical and/or thermal stresses especially if moisture and oil deterioration have already placed the transformer in a hazardous condition.

3.0 DIAGNOSTIC TESTS

For many years, the insulation system of power transformers has been and still is constituted by a combination of mineral oil and cellulosic paper and pressboard. These materials are subjected to deterioration under the operating conditions of the equipment. The deterioration of the transformer insulation is primarily a function of the temperature and time and it is also influenced by other factors such as moisture and oxygen content.

Following are the prominent diagnostic tests considered for condition assessment of transformers.

3.1 Insulation Resistance Measurement:

The IR is the elementary test practiced by all the maintenance engineers for testing of HV equipment. It reflects the moist/contaminated condition of the insulation. The IR will be usually high (several hundred Mega ohms) for a dry insulation system. The maintenance engineers use this parameter as an index of dryness of the insulation system.

IR is generally accepted as a reliable indication of the presence or absence of harmful contamination, dirt, moisture and gross degradation. Typical values of IR of transformers, sometimes, are identified by utilities, consultants and manufacturers. However, these are not reliable, as IR measurements are sensitive to changes in temperature, humidity, external leakage due to dirty insulators and bushings, duration of test etc. However Polarization index (PI) can be used as index of dryness of the insulation. It is the ratio of ten minutes IR value to the one minute IR value. It is independent of temperature as it is the ratio of two IR values. Table 1 presents the IEEE Std 62-1995 the guidelines for evaluating transformer insulation

Table 1

PI	Insulation condition
Less than 1.0	Dangerous
1.0-1.1	Poor
1.1-1.25	Questionable
1.25-2.0	Fair
More than 2.0	Good

3.2 Dielectric Loss Angle Test:

The dielectric loss angle represents the gross defects or overall dielectric losses in the insulation. In order to assess the state and quality of the entire mass of the transformer insulation, following four test schemes are used during measurement of dielectric loss angle.

(a) HV winding versus LV winding grounded to the tank.

(b) LV winding versus HV winding grounded to the tank.

(c) HV winding versus LV winding ungrounded.

(d) Bushing insulation with respect to test tap.

The magnitude of Tan δ is dependent on several parameters like temperature, humidity, contamination on the bushing surface, moisture content and deterioration of the oil-paper insulation system. The tan delta foa transformer insulation should not increase with applied test voltage. If it increases with applied AC voltage a problem is suspected. Normally, the tan delta values obtained at the time commissioning are used as benchmarks to determine amount of insulation deterioration when performing field tests for condition assessment. However, it is also possible to determine extent of deterioration of insulation by comparing test results with that of similar units.

3.3 Partial Discharge Measurement

Partial discharge occur in oil filled transformers due to the presence of voids or cavities in the solid insulation, conducting particles in paper or oil, wet fibres and gas bubbles in oil, sharp conductors or electrode edges against paper. The partial discharges also occur due to poor processing, ingress of moisture, trapped air due to incorrect oil filling, long term degradation of the insulation including tracking and design defects which may produce localised over stressing. Although, initially transformers are discharge free, bubbling of oil may take place due to transient over voltages during system faults, short circuits etc., and initiate partial discharges in the gas bubbles formed as consequence of oil breakdown. These discharges cause chemical decomposition of the oil and paper. It has been well recognised that high Hydrogen content in the oil is an indication of internal partial discharges in the transformer insulation.

Measurement of partial discharges in power transformers for detection and localisation of internal defects is still a subject of intense discussion. Presently, CPRI is employing High Frequency Current Transformers (HFCTs) for sensing and measurement of partial discharges in power transformers. The HFCTs can be incorporated either in the ground leads of the test taps of the HV bushings or in neutral lead of the transformer. The measuring system is calibrated in accordance with IEC-60270 by injecting the calibrating pulses at the HV terminals of the HV bushings and sensing them at the bushing test taps and at the neutral. However external electrical interference limits the sensitivity of measurement.

3.4 Recovery Voltage Measurement

Transformer insulation is composite in structure consisting of paper/pressboard and mineral oil. These structures exhibit (interfacial) space-charge polarization effects, which are strongly influenced by the moisture content and ageing byproducts. These cause a reduction in the time constant of polarization process. In order to detect ageing or moisture content, it is necessary to analyze low time constant part of the polarization spectrum of the insulation.

The RVM method is a diagnostic tool used for evaluation of paper-oil insulation system of the transformers. The principle of the measurement may be explained as follows:

1. A DC voltage of 2 kV charges the insulation under test for a predetermined time of tc sec.
2. The test object is short circuited for pre-selected time of td.
3. Open the short circuit and allow the residual polarization to build up recovery voltage across the test object.
4. Measure the maximum recovery voltage and its rise time. Under this condition the test object discharges through its own DC resistance. These parameters are strictly related to the polarization processes and their intensities.
5. Changing tc and td in a time range of 20msec to 10,000sec while tc/td = 2, constant, a series of values Vr and tr are btained.

Plotting Vr as a function of tc a plot is obtained.

This plot is called polarization spectrum. The polarization spectrum is the characteristic of the insulation under test under specified conditions. The polarization spectrum is a smooth curve exhibiting a global peak or one maximum value. The corresponding time constant is called the dominant time constant. The dominant time constant is a function of moisture content in the insulation. In some cases, the polarization spectrum exhibits local maxima or characteristic inflexions which are related to polarization processes of fairly different time constants and considerable intensity. These local maxima indicate presence of non water ageing byproducts or non-uniform distribution of humidity in the bulk of the paper insulation. The RVM method allows monitoring of ageing process and a reference measurement taken at the time of commissioning can be helpful. Figure (1) shows polarization spectra obtained on 220kV class transformers.

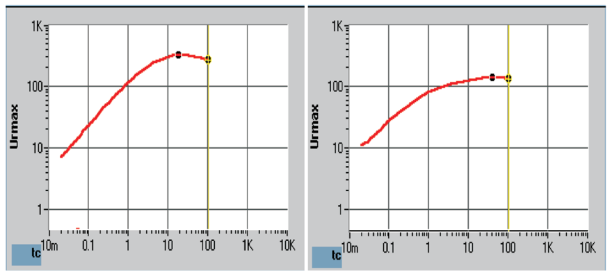


FIG.1. POLARISATION SPECTRA OBTAINED ON 220KV CLASS TRANSFORMERS

The state and condition of the transformer insulation can be ascertained directly from polarization curves. The displacement of dominant peak towards lower time constant is an indication of degradation of the transformer insulation. A small time constant indicates high moisture content or ageing status of the insulation. Non-uniform distribution of moisture and/or ageing byproducts cause local maxima in the polarization spectrum.

CIGRE task force 15.01.09 proposes an improved interpretation of the RVM data [7]. Accordingly, the moisture content in the solid insulation is no longer estimated from the position of the dominant peak in the polarization spectrum. Instead, the polarization spectrum is examined for evidence of any subsidiary maxima away from the dominant time constant. The dominant time constant corresponds to the oil peak and nay sub-dominant maximum would likely stem from polarization phenomenon in the solid insulation. The moisture content is then estimated from this corresponding time constant using the published calibration curves.

The increase in moisture content in the transformer insulation can also occur due to oil leakage or small repair with temporal and partial discharge of oil or due to defects in the breathing system/filter etc. As the moisture accelerates the degradation processes in the cellulosic paper, there is a strong need for monitoring its level in the paper.

IEEE Std 62-1995 furnishes guidelines for assessment of moisture content in the solid insulation system of transformers as detailed in Table 2 below.

Table 2	
Dry	Insulation
0-2	%
Wet insulation	2-4 %
Very wet insulation	> 4 %

In the recent IEEE Std C57.106-2002, the permissible moisture level in the solid insulation system of transformers is derived from values of water content in oil, assuming thermal stability and moisture equilibrium between paper and oil [11,12] as given in Table 3.

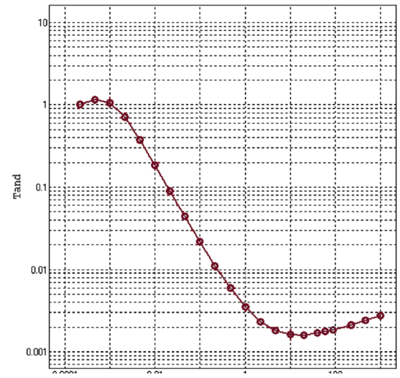
Table 3

Transformer rated voltage	**Maximum water content in oil (ppm)**			**Equiva-lent water content in paper (%)**
	50° C	60° C	70° C	
Up to 69 kV	27	35	55	3.00
69 to 230 kV	12	20	30	2.00
230 kV and above	10	12	15	1.25

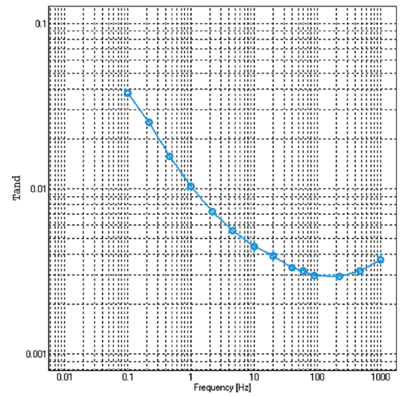
3.6 Dielectric spectroscopy

Dielectric spectroscopy is another method used for insulation diagnosis of power transformers and medium voltage power cables. The dielectric spectroscopy is nothing but the measurement of dielectric loss, capacitance and permittivity of the insulation as a function of frequency. This frequency domain analysis of dielectric losses and capacitance is used to detect moisture content and ageing byproducts in the insulation. Figure 2 shows typical dielectric spectroscopy patterns obtained on 220kV & 11 kV class transformers. The main features of the frequency response of the paper-oil insulation system are

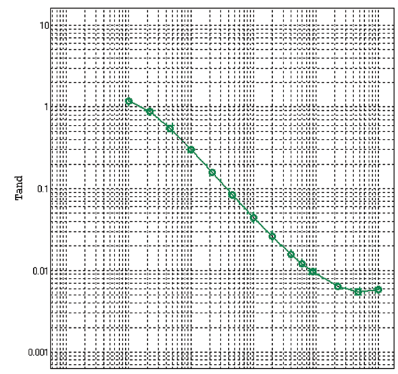
a) The curve exhibits a minimum loss (tan delta minimum) usually in the frequency range 1-100Hz at room temperature. As ageing progresses or moisture content increases the tan delta minimum tends to shift towards right.



A. MOISTURE CONTENT: 0.7% 11KV/433V, 400 kVA



B. MOISTURE CONTENT: 2.4 % 11kV/220 kV, 120MVA



C. MOISTURE CONTENT: 3.9 % 11kV/220 kV, 115MVA

FIG. 2 VARIATION OF TAN DELTA WITH FREQUENCY

b) The tan delta-frequency characteristic also exhibits a peak at low frequencies and low moisture contents

c) Appearance of low frequency dispersion at low frequencies. The low frequency dispersion refers to an increase in both permittivity and loss factor with decreasing frequency and the phenomenon is typical for paper-oil insulation system. Most difficulties arise in distinguishing the low frequency dispersion and the increase of loss due to DC conductivity. As ageing progresses and moisture content increases, steepness of the curve increases towards lower frequencies.

3.7 Frequency Response Analysis (FRA):

During its life a transformer can be subjected to several short circuits with high fault currents. The dynamic forces of these external short circuit currents may cause deformations or displacements of the winding assemblies. In particular, the winding insulation of old transformers can become rather vulnerable to short circuit forces because of the reduced mechanical strength and the shrinkage of the aged paper which may result in a loss of the winding clamping pressure.

In most cases, however, a displacement of a winding after an external short circuit does not immediately lead to a transformer failure, but there is a high risk that a mechanical damage in the turn or coil insulation due to abrasion or crushing of the aged, brittle paper may eventually cause an insulation breakdown at the next over-voltage stress. Therefore, simple non-intrusive offline methods for detection of winding movement and failures are of high importance, because opening a transformer and visual inspection is time consuming and expensive.

Traditional electrical measurements of turns ratio, impedance and inductance at 50 or 60 Hz are not sensitive enough for the detection of small winding displacements. As deformation results in minor changes of the internal inductance and capacitance of the winding structure, a change in the characteristics frequency response (e.g. impedance, admittance) can be detected at the terminals of the transformer by frequency response analysis (FRA) or in the time domain by the low voltage impulse (LVI) method.

4.0 CASE STUDIES

4.1 220 kV Class, Transmission Transformers:

CPRI carried out Tan δ and RVM tests on 26 nos. of 220 kV class transformers at various substations of a State Electricity Board. The oil samples were also subjected to DGA & furan analysis. Out of 26 transformers, 16 transformers were found to be undergoing normal level of ageing. Insulation conditions of 10 transformers were found to be unhealthy and recommended for dehydration. The ranges of values of various test parameters obtained on these transformers are presented in Table 4.

TABLE 4

Sl. No.	Test Parameter	
1.	Tan δ	0.31 – 5.54
2.	Moisture in paper / pressboard (%)	< 2.0 – 5.65
3.	Water level in oil (ppm)	14 – 53
4.	BDV of Oil (kV)	29 – 73
5.	Tan δ of Oil at 90°C	0.0039 – 0.4
6.	Oil resistivity (Ω cm) x 10^{12}	0.31 – 5.54
7.	H2 (ppm)	0 – 994
8.	C_2H_2 (ppm)	ND
9.	Furan content (ppb)	0 – 2162

TABLE 5

Group	Tan δ (%)	No. of transformers
A	≤ 1.0	7
B	1.0 < Tan δ ≤ 2.0	9
C	2.0 < Tan δ < 4.0	7
D	≥ 4.0	3

Analysis of the data showed that Tan δ values form four distinct groups as shown in Table 5.

The Tan δ values obtained on group A & B transformers indicated low/normal dielectric losses. The oil test results also indicated normal condition of the transformers. The group C transformers exhibited high dielectric losses. The respective polarisation spectra also revealed higher moisture level in the paper/pressboard insulation used therein (3.7% – 4.6%). Insulation condition of these transformers was not healthy. It was recommended to dehydrate the transformers to extend their life.

The group D transformers were found to be in highly deteriorated condition. The Tan δ values indicated extremely high dielectric losses. The polarisation spectra revealed higher level of moisture (4.19% – 5.65%) in the solid insulation system of the transformers. The oil test results also confirmed the nhealthy status of the transformers. The BDV (29 kV) & resistivity were low and moisture level (53 ppm) and dissipation factor (0.4) were high. However, the furan contents in the oil samples were low. On the basis of this data, it was recommended to withdraw the transformers from service immediately and subject them to overhauling and dehydration.

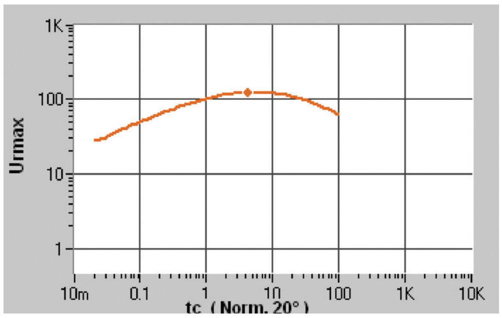
4.2 132kV, 63 MVA, 3 - Phase Transformer

Diagnostic test results obtained on this 25-year-old transformer installed at a steel plant are presented in Table 6.

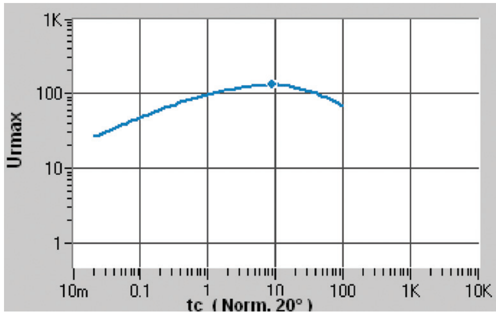
TABLE 6

Test scheme	Tan δ (%)	PI	Moisture content (%) RVM	Moisture content (%) Spectro-scopy
HV v/s LV grounded	0.808	1.26	3.59	3.5
HV v/s LV (un-grounded)	0.788	1.21	3.27	3.4
LV v/s HV grounded	0.812	1.56	3.18	3.5

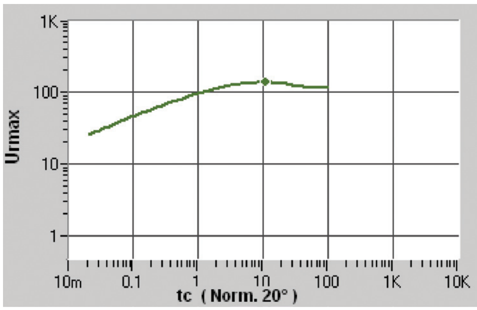
As it can be seen, the tan δ values lie in the normal acceptable range for a 25 years old transformer. The dielectric losses are low. Figure 3 shows the polarization spectra obtained on the three insulation sections of the transformer.



A. HV V/S LV GROUNDED



B. HV V/S LV(UN-GROUNDED)

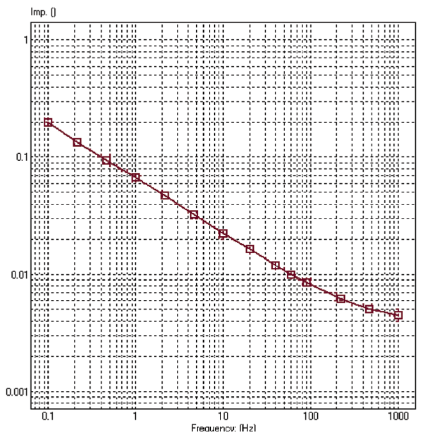


C. LV V/S HV GROUNDED

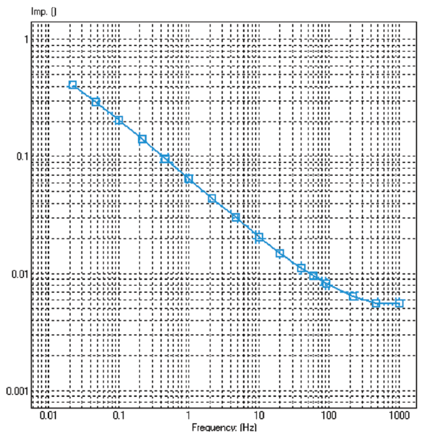
FIG. 3 POLARIZATION SPECTRA OBTAINED ON 132KV/11KV, 63MVA TRANSFORMER

The polarization spectra are smooth curves exhibiting global dominant peaks. From the curves it can be inferred that the moisture is uniformly distributed in the insulation. The estimated moisture levels corresponding to the global peaks are furnished in Table-6. These values are high for an in-service transformer.

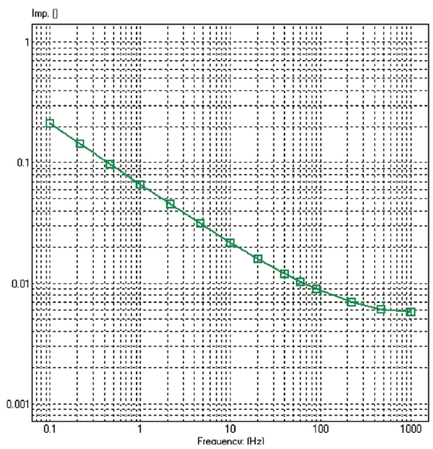
The dielectric spectroscopy patterns obtained on the transformer are depicted in Figure 4.



A. HV V/S LV GROUNDED (3.5%)



B. HV V/S LV (3.4%)



C. LV V/S HV GROUNDED (3.5%)

FIG. 4 TAN DELTA – FREQUENCY CHARACTERISTICS

The slope of the characteristics increases towards lower frequencies and the tan delta minimum appears at the higher frequency end. These characteristics indicate high moisture level in the insulation. The estimated moisture levels from these characteristics were comparable to the values obtained from the RVM test. The oil test results also indicated high moisture content (41ppm) and low BDV (32kV). The DGA results were normal indicating normal internal condition of the transformer. The results of furan analysis indicated healthy condition of the Paper/ Pressboard insulation of the transformer. Based on this analysis, it was recommended for filtration and hot circulation of the oil.

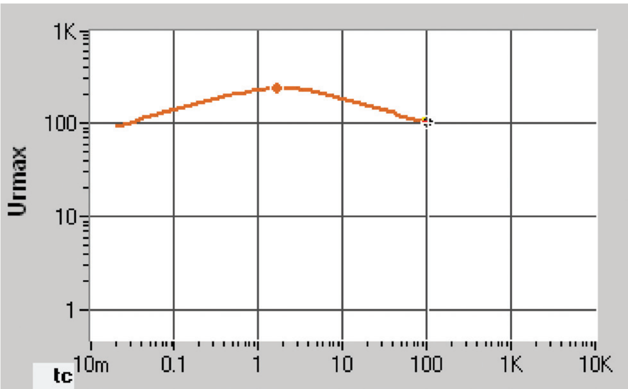
4.3 400kV/220kV/33kV, 105MVA Auto transformers:

These 20 years old auto transformers were not commissioned and stored in the yard. In order to commission these auto transformers, the utility wanted to assess the effect of long storage time on their insulation system. CPRI conducted the IR/PI, tan delta, RVM, dielectric spectroscopy, oil analysis, DGA, furan analysis and DP test to assess health status of their insulation system. For conducting DP test two paper samples were extracted from the transformers. The diagnostic test data presented two categories of transformers. The first category of transformers exhibited moisture absorption throughout the insulation structure, whereas the second category exhibited non-uniform distribution of moisture in the insulation. Results of the PI, Tan δ and RVM tests obtained on the representative unit of the first category are presented in Table 7.

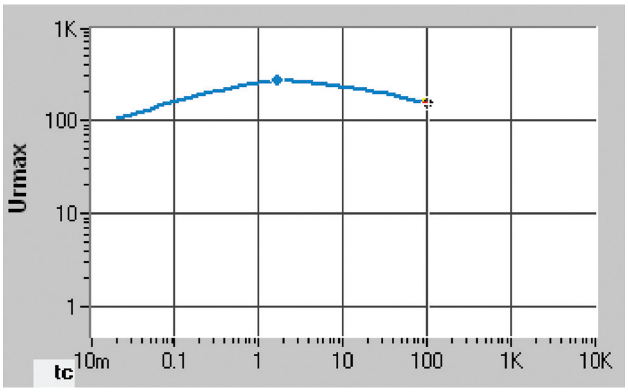
TABLE 7

Insulation section	**IR 60sec (GΩ)**	**PI**	**Tan δ (%)**	**Moisture level-RVM (%)**
HV vs Tertiary grounded	0.508	1.05	6.677	4.05
Tertiary vs HV grounded	0.234	1.11	6.349	4.05
HV vs Tertiary ungrounded	0.487	1.18	5.336	4.05

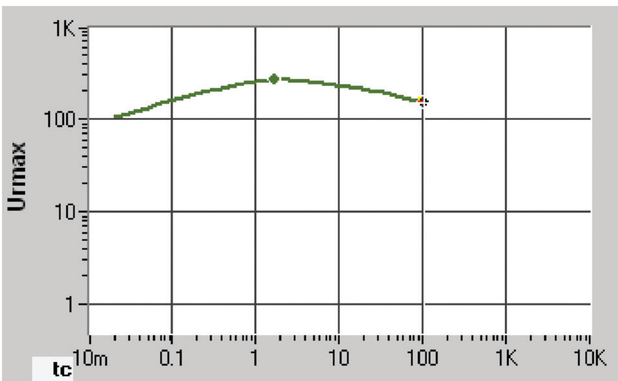
As it is evident in the Table 7, the IR and PI values were low and the tan delta values were high indicating high dielectric losses in the transformer insulation. The polarisation spectra shown in Figures 5, indicated high moisture level (4.05%) uniformly distributed throughout the structure of transformer insulation.



A. HV V/S TV GROUNDED



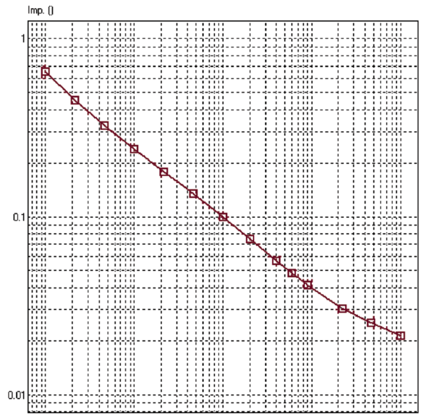
B. HV V/S TV



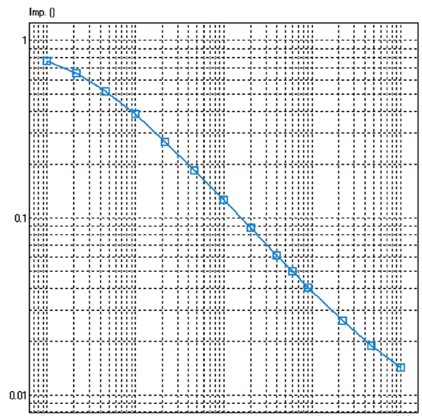
C. TV V/S HV GROUNDED

FIG. 5 POLARIZATION SPECTRA OBTAINED ON 400KV/220KV, 105 MVA AUTO TRANSFORMER

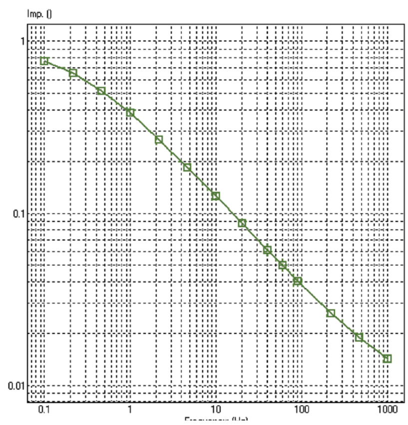
The Dielectric spectroscopy patterns shown in Figures 6 indicated very high dielectric losses in the entire transformer insulation. The steep slopes towards lower frequencies indicate high DC conductivity of the oil. The appearance of tan delta minimum point at the high frequency end indicates high moisture content in the solid insulation system of the transformer. The estimated moisture levels in the three insulation sections of the transformer (4.7%, 5.0% and 4.9%) were also quite high for an EHV class transformer.



A. HV V/S TV GROUNDED



B. HV V/S TV



C. TV V/S HV GROUNDED

FIG. 6 TAN DELTA – FREQUENCY CHARACTERISTICS

The oil test results indicated very low BDV (25kV) and high moisture content (56ppm). DGA indicated normal internal condition of the transformer. No furan content was detected. The DP values obtained on the two paper samples of the transformer were 913 and 893. These results indicated healthy condition of the paper insulation. On the basis of these results it was recommended for dehydration of the transformer.

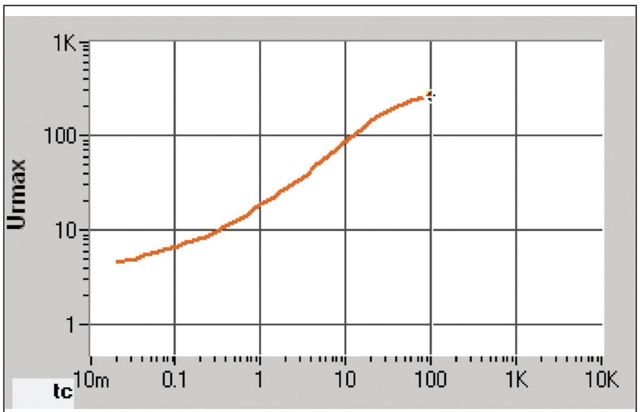
Table 8 presents the data obtained on the representative unit of second category of transformers.

As it can be seen the Table 8, the HV winding insulation with respect to tertiary grounded exhibits high tan delta values indicating high dielectric losses in this insulation section. The Tan delta values obtained on the other two sections were in the normal range.

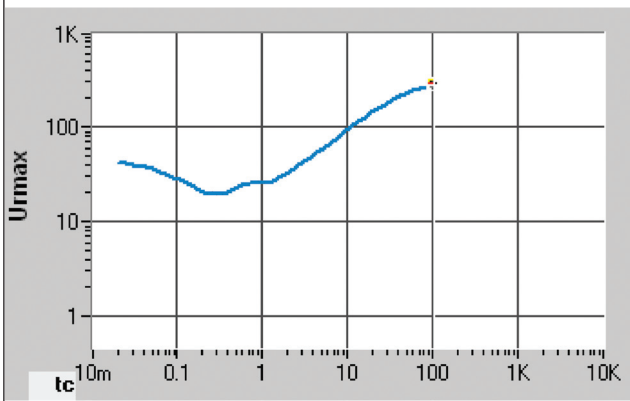
TABLE 8

Insulation section	IR 60 sec (GΩ)	PI	Tan δ (%)	Moisture level-RVM (%)
HV vs Tertiary grounded	7.46	2.10	2.368	< 2.0
HV vs Tertiary ungrounded	20.3	2.47	0.224	< 2.0
Tertiary vs HV grounded	11.5	2.90	0.314	2.63

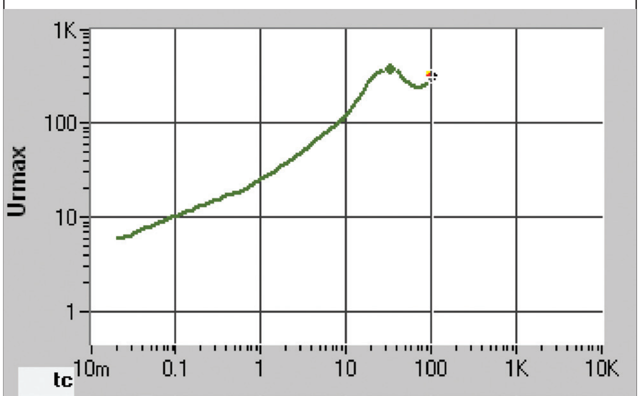
The RVM patterns obtained on the transformer are shown in Figures 7. The spectrum in Figure 7(a) indicates the homogeneous condition of HV winding insulation with respect to ground. The initial section of the spectrum in Figure 7(b) indicates increase in DC conductivity of the oil in the barrier insulation system. The tertiary winding insulation with HV winding grounded exhibits non-uniform distribution of moisture as depicted in Figure 7(c). The estimated average moisture level in this part of the transformer insulation was 2.63%.



A. HV V/S TV GROUNDED

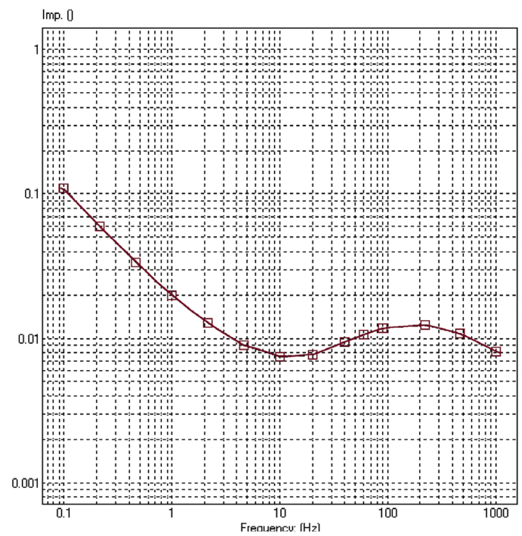


B. HV V/S TV

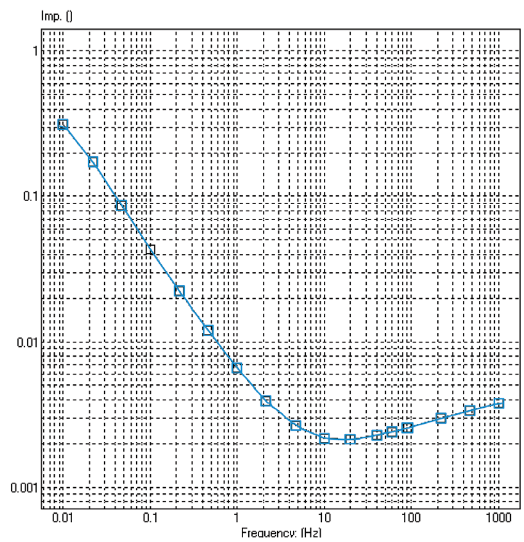


C. TV V/S HV GROUNDED

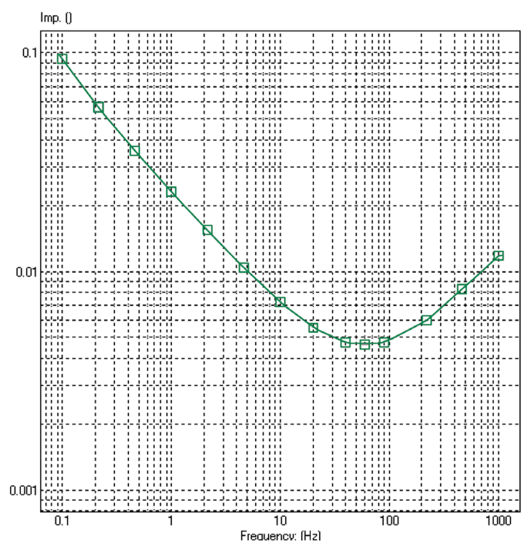
FIG. 7 POLARIZATION SPECTRA OBTAINED ON 400KV/220KV, 105 MVA AUTO TRANSFORMER



A. HV V/S TV GROUNDED



B. HV V/S TV



C. TV V/S HV GROUNDED

FIG. 8 TAN DELTA – FREQUENCY CHARACTERISTICS

The Dielectric spectroscopy pattern shown in Figure 8(a) indicates higher dielectric losses in the Paper / Pressboard insulation of the HV winding insulation section with respect to ground (Tertiary grounded). The estimated average moisture level in this insulation section was 2.7%. The insulation section between HV winding and Tertiary winding shows {Figure 8(b)} low dielectric losses. The tan delta varies from 0.377% at 1000Hz to 4.35% at 0.1Hz and the estimated average moisture level was 1.0%. The tan delta-frequency characteristic of the tertiary winding insulation with respect to ground (HV grounded) shown in Figure 8(c) shows tan delta variation from 1.176% at 1000Hz to 9.33% at 0.1Hz. The estimated average moisture level was 2.6%.

The oil test results showed low BDV (30kV) and high moisture content (45ppm). The DGA results indicated normal internal condition of the transformer. No furan content was detected in the oil. No symptoms of paper ageing in the oil. The DP values obtained for the two paper samples extracted from the two locations in the HV winding of the transformer were 888 and 909. These values indicated healthy condition of the paper insulation. The mechanical strength of the paper insulation was good.

4.4 11kV/220kV, 165 MVA Generator transformer:

This 18 years old transformer was operating at a partial load of 110 MVA instead of 165 MVA. It was reported by the site engineers that any increase in the load would immediately trigger the Buckholtz relay. A variety of diagnostic tests including the physicochemical analysis of the oil were carried out to detect and identify the defective component in the transformer. The IR, Tan δ, RVM and PD test results are summarised in Table 9.

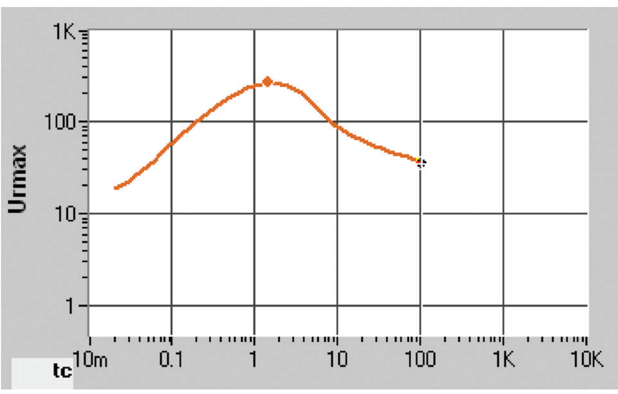
As it is evident in Table 9, the Tan δ of the two sections of the HV winding insulation i.e., with respect to ground and with respect to LV winding, were extremely high. The dielectric losses in the

HV winding insulation were abnormally high. In contrast to this, the dielectric losses in the LV winding were relatively lower. The partial discharge magnitude at the operating voltage of 220kV (line to line) was also extremely high. As the Tan δ values of the HV winding insulation indicated abnormal deterioration, it was suspected that intense partial discharge activity may be taking place in the HV winding part of the transformer.

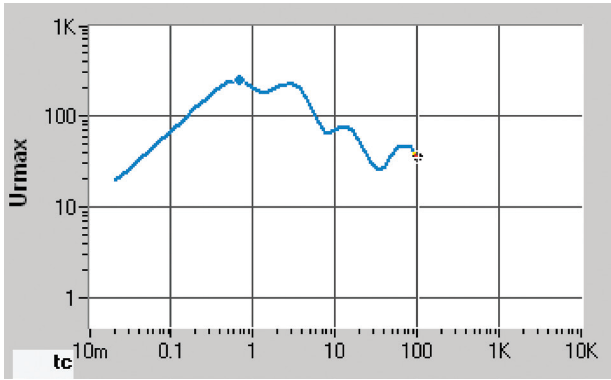
TABLE 9

Test scheme	IR (M Ω)	Tan δ (%)	Relative moisture content in paper (%)	PD magnitude (nC) at 220kV
HV versus LV grounded	223	5.939	4.14	106
LV versus HV grounded	175	1.501	4.09	
HV versus LV	320	6.158	4.55	

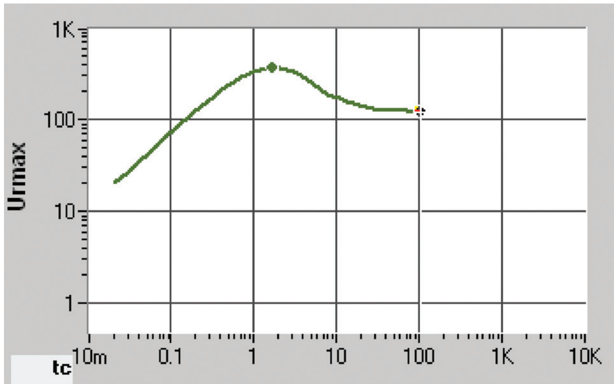
Figure 9 presents the polarization spectra obtained on the transformer. The average moisture level in the HV winding insulation Figure 9(a) with respect to ground was 4.14%. The polarization spectrum obtained for the barrier insulation exhibited local maxima as shown in Figure 9(b). These characteristic inflexions indicate presence of substantial levels of contamination or degradation byproducts of insulation ageing.



A. HV V/S LV GROUNDED



B. HV V/S LV(UN-GROUNDED)



C. LV V/S HV GROUNDED

FIG. 9 POLARIZATION SPECTRA OF 11KV/220KV, 165MVA GENERATOR TRANSFORMER

The estimated moisture content in the paper was also high (4.55%). Although, the moisture level in LV winding insulation was high, it did not exhibit heterogeneity. The DGA test results indicated high levels of methane, ethane and ethylene gas concentrations. The high concentration of ethylene may be attributed to severe hot spots (300°C - 700°C) in the transformer. These results indicated high risk of thermal breakdown in the transformer. Therefore it was recommended to withdraw the transformer from service immediately for thorough inspection and overhauling.

However, two months later the site engineers reported that the transformer failed before any decision could be taken. On physical inspection of the failed transformer, the R – phase HV winding was found to be damaged extensively. The transformer was repaired at site by replacing the R – phase limb with a new one. Vacuum drying was carried out before filling the transformer with the oil. Results of the RVM & PI tests carried out after the repair and subsequent dehydration are presented in Table 10.

TABLE 10

Test scheme	IR (M Ω)	Tan δ (%)	Relative moisture content in paper (%)
HV versus LV grounded	721	1.44	1.94
LV versus HV grounded	778	1.49	1.60
HV versus LV	968	1.70	2.09

These data lie in the normal range expected for a healthy transformer in service. Subsequently, the transformer was reinstated into service.

5.0 CONCLUSIONS

1. It is essential to perform several condition monitoring tests, since each test can give only limited information on the insulation condition of the power transformers.
2. The field experience gained so far, shows that Dielectric response methods can be used as effective diagnostic tools for reliable assessment of insulation system of power transformers.
3. It is desirable to perform partial discharge test on power transformers in service to detect incipient and highly localised deterioration processes in their insulation systems.

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