The Journal of CPRI,
Vol. 8, No. 1, March 2012 pp. 31–40

Analysis of Transformer Insulation by Tan Delta Testing Method

Dipak Mehta* and Hitesh R Jariwala**

This paper presents analysis of power transformer insulation by one fundamental insulation power factor test, also known as Tan Delta. It is a routine test conducted at site to know the healthiness of insulation in transformers. Out of 108 transformers tested for research work, case studies were chosen for analysis purpose. Experimental data shows our experience on the measurement of Tan Delta techniques of earthing systems and dryness of insulation in transformers. Result shows that the Tan Delta testing method is very efficient method.

1.0 INTRODUCTION

Electrical properties of the insulating system change due to age and continuous electrical street. The principal contributor to the unexpected breakdown of the high-voltage equipment is the insulation failure. Compared to the magnetic, conducting and insulating materials which form the basics of any electrical equipment, the insulating material is more prone to service stresses like thermal stress, electrical stress, mechanical stress, environment stress, etc.

By measuring the electrical properties such as capacitance and Tan Delta regularly on periodical basis, it is possible to ensure the operational unexpected breakdown. Dissipation factor (Tan Delta) is one of the most powerful off-line nondestructive diagnostic tool, to monitor the condition of solid insulation of various high-voltage equipments.

Capacitance and Tan Delta values obtained on new insulation are treated as benchmark readings. Then, by measuring and comparing the periodical readings of the capacitance and Tan Delta of the insulating material with the benchmark readings, one can know the rate of deterioration of the health of the insulation [1].

In this paper, main aim of the author is to show that by knowing the rate of deterioration, we can:

(a) predict the future unexpected breakdown of the insulation of HV equipment;

(b) plan the maintenance schedule;

(c) repair the insulation before actual flashover, saving high cost of replacement of material which will reduce the inventory well as delay in procurement at the last minute.

(d) After repair, quality of insulation can be checked before returning the equipment to service.

(e) We can find out if proper earthing of transformer and core is not established.

2.0 Basic Theory

Tan Delta is the cotangent of the angle between the applied voltage and current [4], is directly obtained on capacitance–Tan Delta bridge (Figures 1 and 2). Tan Delta is a measure of insulation dielectric loss and not dielectric strength. Tan Delta of insulation depends on water content and impurities [3].

*Manager, Electrical dept, Essar Oil Ltd., Refinery Site, 39 KM, Jamngar–Okha Highway, Vadinar-361305, Gujarat, India, Email: dcmehta@essar.com
**Associate Prof., Department of Electrical Engineering, SVNIT, Surat, Gujarat, India. Email: hrj@eed.svnit.ac.in

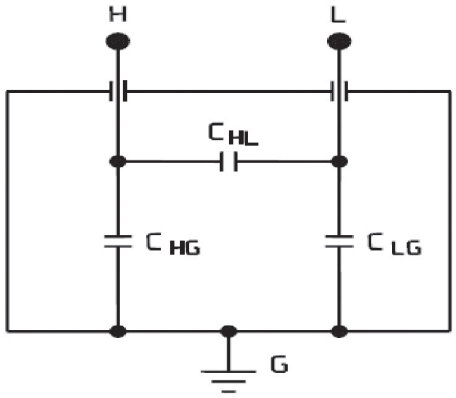

FIG. 1 BASIC CIRCUIT DIAGRAM FOR THREE CAPACITANCE IN TRANSFORMERS

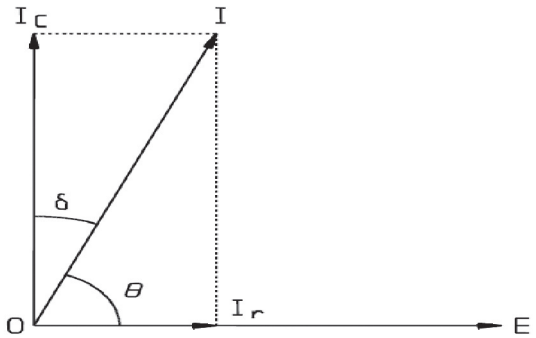

FIG. 2 VECTOR DIAGRAM

Hence, we can say that

Dissipation Factor = tan δ = Ir/Ic

3.0 TYPE OF TEST KIT USED FOR RESEARCH WORK

For research work, 108 transformers were tested through Delta-3000 Megger-sweaden make test kit [9] below Figure 3 shows control unit for Delta-3000 Test kit.

FIG. 3 DELTA 3000 TEST KIT MEGGER

Following test mode used for testing [2]:

(a) UST: Ungrounded Specimen Testing

(b) GST: Grounded Specimen Testing

(c) Guard mode

4.0 EQUIVALENT CIRCUIT FOR POWER TRANSFORMER

The Tan Delta Dissipation factor test conducted according to the clause No. 10.10.3 in ANSI C 57 12.90. DF is very sensitive to temperature. DF (Tan Delta) values do not change with applied voltage. The reference temperature commonly used is 20° average oil temperature and ambient temperature are recorded while testing. In case of oil-filled transformers according IEEE-62 1995 [6] power factor between 0.5 % and 1.0 % may be acceptable; however, power factor >1.0 % should be investigated. Values of Correction Factor K are listed below in Table 1 [7].

TABLE 1

CORRECTION FACTOR AS PER IEEE C57 12.90

Test Temperature (°C)	Correction Factor K
10	0.80
15	0.90
20	1.00
25	1.12
30	1.25
35	1.40
40	1.55
45	1.75
50	1.95
55	2.18
60	2.42
65	2.70
70	3.00

Factors affecting measurements of Tan Delta are:

1. Oxidation, free water, wet particles, contaminations and material incompatible are all possible sources of high Tan Delta
2. Design characteristics of transformer main factors of high Tan Delta
3. Wrong connection and measurements

Tan Delta measurement should be regarded as a diagnostic tool to evaluate the condition of insulation. However, there are many factors contributing high Tan Delta. In most of cases, excessive moisture in insulation and dry out processes affecting Tan Delta. But attached case studies are mainly focusing on very important factor, i.e. earthing condition and insulation. It also includes loose earthing connection, open grounding and wrong grounding method [1]. Figure 4 shows equivalent circuit diagram for two phase winding transformers

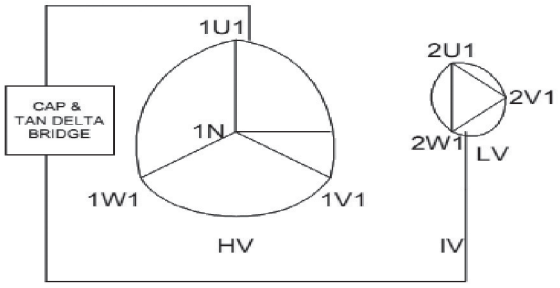

FIG. 4 EQUIVALENT CIRCUIT

5.0 CASE STUDIES

Out of 108 transformers Tan Delta tested, completed five transformer case studies were chosen for analysis purpose.

5.1 Case Study 1

Transformer Rating: 20 MVA, 33/6.9 kV

Above transformer is tested on 21/12/2010 for Tan Delta test and Tan Delta value was found to be much higher of CHG mode for both 2 kV and 5 kV as given in Table 2, all other values, found satisfactory and within limit according to IEEE-62 1995.

After that, it is required to test transformer drying out process to check whether transformer oil is contaminated or not. After necessary testing like oil test [8,5], insulation resistance test with polarization index was conducted and found satisfactory according to IS: 1866-2005 [5]. Test results are shown in Table 3.

TABLE 2

TAN DELTA TEST RESULTS FOR CASE STUDY 1

Sl. No.	Insulation mode	Test voltage (kV)	% PF
1	CHL	2	0.32
2	CHL	5	0.33
3	CHG	2	0.91
4	CHG	5	0.94
5	CLG	2	0.42
6	CLG	3	0.41

TABLE 3

OIL TEST AND IR-PI TEST FOR CASE STUDY 1

BDV (kV)	70.2
Water content (PPM)	18
IFT (mN/m)	38
NN (mg KOH/g)	0.021
Resistivity (ohm-cm)	13.15
PF at 90°C	0.02
Flash point (°C)	156

Table 4 shows IR and PI test results, which also show healthiness of transformer.

TABLE 4

IR AND PI TEST RESULTS FOR CASE STUDY 1

Top Oil temp		39 °C	
Combination	60 Sec	600 Sec	PI
HV to LV	12.5 G-ohms	18.0 G-ohms	1.44
HV to earth	9.2 G-ohms	12.0 G-ohms	1.30
LV to earth	5.0 G-ohms	7.0 G-ohms	1.40

After that, it was decided to run this transformer normally and above transformer is retested on 15/11/2011, almost after one year and test value is found almost equal as compared with earlier results. Tan Delta test values are shown in below Table 5.

TABLE 5

RETESTED TAN DELTA TEST RESULTS FOR CASE STUDY 1

Sl No.	Insulation mode	Test voltage	% PF
1	CHL	2	0.32
2	CHL	5	0.33
3	CHG	2	0.94
4	CHG	5	0.97
5	CLG	2	0.42
6	CLG	3	0.41

Hence, basically Tan Delta is a comparison method, so here during one year of span, the rate of increase of Tan Delta is much lower as given in Figure 5. So this transformer may be run as normal and yearly Tan Delta value shall be investigated.

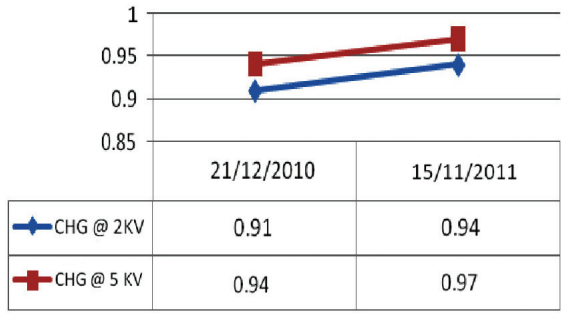

FIG. 5 TAN DELTA VALUE FOR CHG AT 2 kV AND 5 kV

5.2 Case Study 2

Transformer Rating: 31.5 MVA, 110/11 kV.

Above transformer was tested as a part of routine test. Capacitance and Tan Delta test were performed along with other low-voltage electrical tests and SFRA. SFRA and other electrical tests were indicative of normal condition of the transformer. While C and TD test data were not looking normal, decrement in capacitance and abnormal Tan Delta values (negative) were observed. Below Table 6 shows test results for case study 2.

TABLE 6

TAN DELTA TEST RESULTS FOR CASE STUDY 2

Sl. No.	Insulation mode	Test Voltage kV	% PF
1	CHL	5	–0.1
2	CHL	10	–0.12
3	CHG	5	1.09
4	CHG	10	1.09
5	CLG	2	8.51
6	CLG	6	8.52

This being a new transformer, it was expected that Tan Delta test values will be found below 0.5 %. However, Tan Delta values of high-voltage winding were at 1 % while that of a low-voltage winding was much higher at over 8 %. Inter-winding insulation exhibited negative Tan delta values.

Above transformer is opened at workshop and core earthing was found poor. The same was rectified and Tan Delta test was repeated and a comparison of the test data was made. Change in Tan Delta values of all the three winding configuration became normal and less than 0.5 %.

Table 7 Shows Tan Delta values before rectification and after rectification.

TABLE 7

TAN DELTA TEST RESULTS FOR CASE STUDY-2 AFTER RECTIFICATION OF PROBLEM

Insulation mode	Test voltage kV	% PF before rectification	% PF after rectification
CHL	5	–0.1	0.18
CHL	10	–0.12	0.18
CHG	5	1.09	0.88
CHG	10	1.09	0.88
CLG	2	8.51	0.84
CLG	6	8.52	0.83

Figure 6 shows graphical representation of results for before fault rectification.

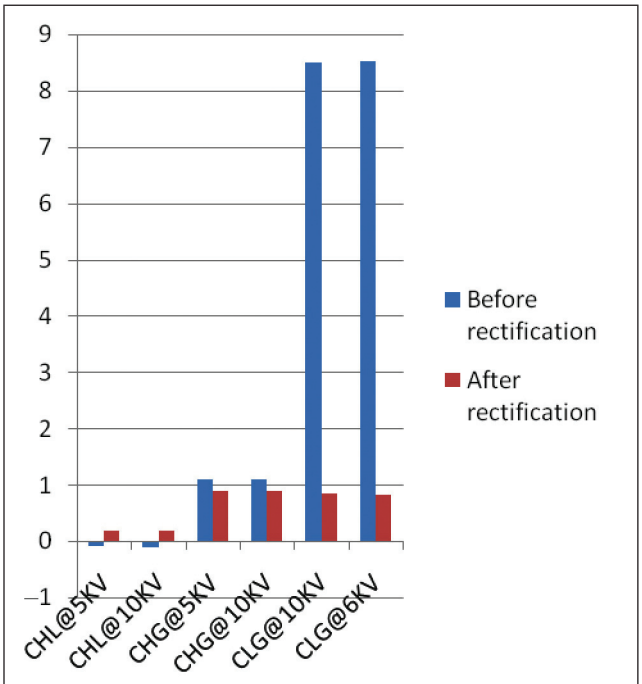

FIG. 6 TAN DELTA VALUES FOR BEFORE RECTIFICATION AND AFTER RECTIFICATION FOR CASE STUDY 2

Figure 7 shows core earthing assembly.

5.3 Case Study 3

Transformer Rating: 10 MVA, 66/11.5 kV

The transformer was scheduled for maintenance work, e.g. replacement of gaskets, arrest of oil leak and replacement of insulating oil, etc. Capacitance and Tan Delta test as well as other electrical tests were performed prior to the maintenance work. Tan Delta was to be followed up after the repair work on the transformer. Tan Delta values found much higher than limit. Tan Delta test results were indicative of deteriorated condition of the dielectric given in Table 8.

TABLE 8

TAN DELTA TEST RESULTS FOR CASE STUDY 3

Sl. No.	Insulation mode	Test voltage kV	% PF
1	CHL	5	2.22
2	CHL	10	2.22
3	CHG	5	3.94
4	CHG	10	3.94
5	CLG	2	3.69
6	CLG	6	3.69

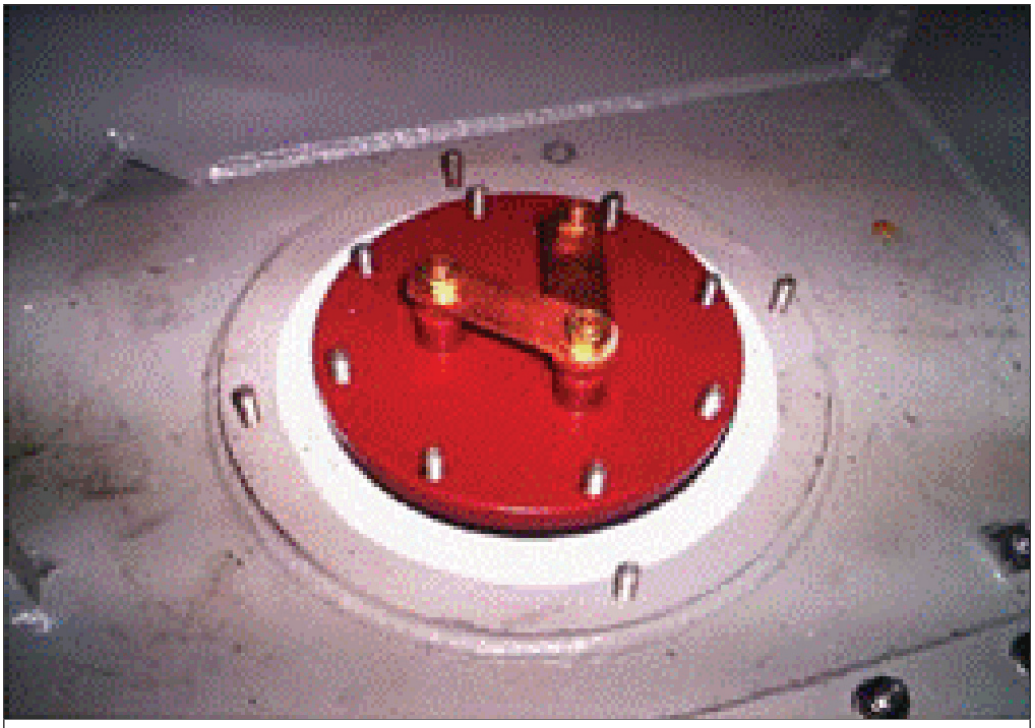

FIG. 7 POOR CORE EARTHING FOR CASE STUDY 2

Tan Delta value of high-voltage winding was at 2.22 %, while that of a low-voltage winding was at over 3.69 %, and value of inter winding was also 3.94 %. The above Tan Delta values were measured before oil filtration.

Tan Delta test was repeated after repairing and oil filtration on the transformer. Visible improvement in Tan Delta values were seen in test results, as there was an improvement in the condition of dielectric.

Table 9 shows Tan Delta test values after necessary filtration and overhauling.

TABLE 9

TAN DELTA TEST RESULTS FOR CASE STUDY 3 AFTER NECESSARY FILTRATION AND REPAIRING

Insulation mode	Test voltage kV	% PF before rectification	% PF after rectification
CHL	5	2.22	0.95
CHL	10	2.22	0.95
CHG	5	3.94	1.27
CHG	10	3.94	1.27
CLG	2	3.69	0.81
CLG	6	3.69	0.81

Figure 8 shows the graphical comparison for Tan Delta values before and after repairing and rectification.

5. 4 Case Study 4

Transformer Rating: 42 MVA, 132/11 kV.

During testing above transformer, influence of external connection is observed.

Above transformer was tested as a part of routine test. Tan Delta test was performed along with other low-voltage electrical tests. This being a new transformer, it was expected that Tan Delta test values will be found below 0.5 %. Other electrical tests were indicative of comparable condition of the transformer. While Tan Delta values were marginally higher than factory value. Table 10 shows test results for case study-4.

Tan Delta test was performed by disconnecting all the lead at bushings of primary and secondary windings. But disconnection at neutral lead was done near to the ground level, instead of at the terminal of neutral bushing. This way the additional capacitance of support insulators featured in overall measurement of the winding's capacitance. Figure 9 shows neutral connection at the end of transformer tank.

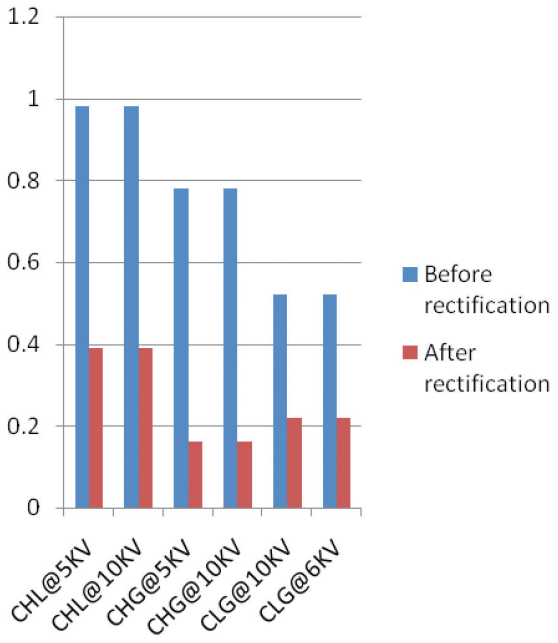

FIG. 8 GRAPHICAL REPRESENTATION FOR CASE STUDY 3

TABLE 10

TAN DELTA TEST RESULTS FOR CASE STUDY 4

Sl. No.	Insulation mode	Test voltage kV	% PF
1	CHL	5	0.98
2	CHL	10	0.98
3	CHG	5	0.78
4	CHG	10	0.78
5	CLG	2	0.52
6	CLG	6	0.52

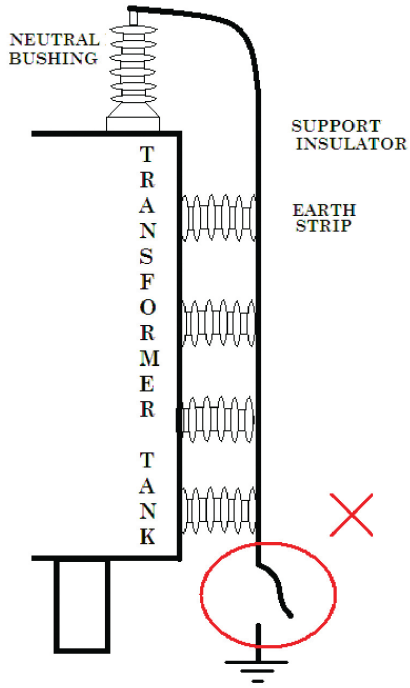

FIG. 9 NEUTRAL CONNECTION REMOVED AT BOTTOM OF TRANSFORMER TANK

Lead at neutral was removed as shown in Figure 10 from the bushings terminal and the test was repeated. Test data exhibited decrement in the measured capacitance, as the support insulates were excluded from the measurement.

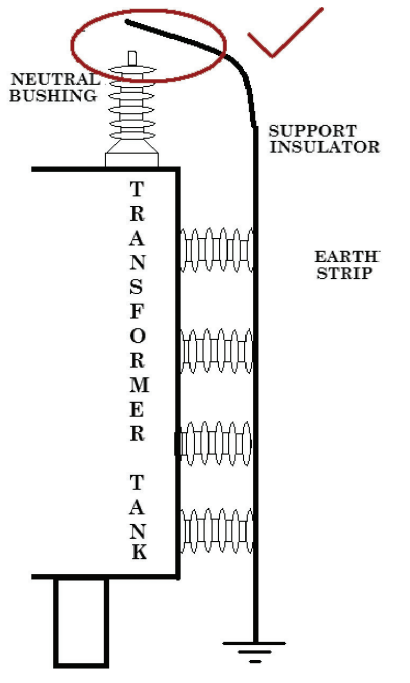

FIG. 10 NEUTRAL CONNECTION REMOVED AT TOP OF TRANSFORMER TANK

A major reduction in Tan Delta values was also seen in CH reading, as the support insulators with dirty surfaces were excluded from the measurements.

Table 11 shows comparison of Tan Delta value before and after rectification of problem.

Figure 11 shows graphical comparison for Tan Delta values before and after repairing and rectification.

TABLE 11

TAN DELTA TEST RESULTS FOR CASE STUDY 4 AFTER NECESSARY CORRECTION IN NEUTRAL CONNECTION

Insulation mode	Test voltage kV	% PF before rectification	% PF after rectification
CHL	5	0.98	0.39
CHL	10	0.98	0.39
CHG	5	0.78	0.16
CHG	10	0.78	0.16
CLG	2	0.52	0.22
CLG	6	0.52	0.22

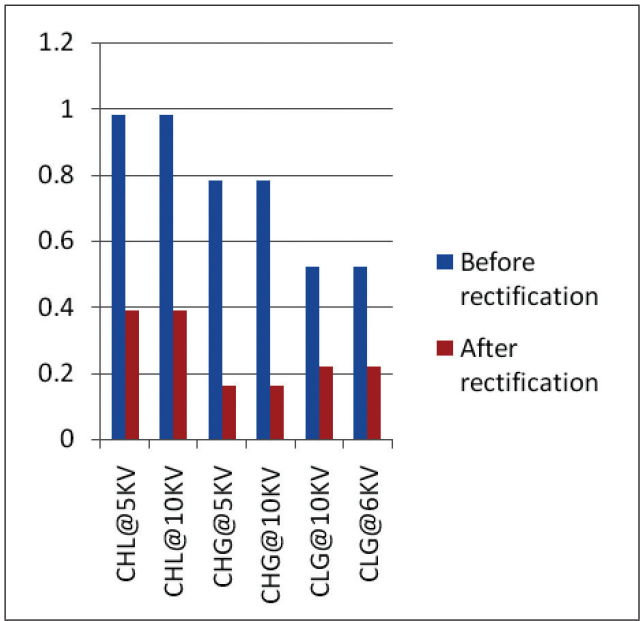

FIG. 11 GRAPHICAL REPRESENTATION FOR CASE STUDY 4

5. 5 Case Study 5

Transformer Rating: 4 MVA, 33/6.9 kV.

Above transformer is tested on 21/03/2011 for Tan Delta test and Tan Delta values were found much higher than CHL, CHG and CLG mode for both 2 kV and 5 kV as shown in Table 12.

TABLE 12
TAN DELTA TEST RESULTS FOR CASE STUDY 5

Sl. No.	Insulation mode	Test voltage kV	% PF
1	CHL	2	3.2
2	CHL	5	4.02
3	CHG	2	31.1
4	CHG	5	51.1
5	CLG	2	68.7
6	CLG	3	78.9

Now, according IEEE-62 1995 power factor between 0.5 % and 1.0 % (20°C) may be acceptable; however, power factor >1.0 % should be investigated.

After that, it is required to test transformer drying out process to check whether transformer oil is contaminated or not. After necessary testing like oil test, insulation resistance test with polarization index was conducted and found unsatisfactory according to IS: 1866-2005. Test results are shown in Table 13.

TABLE 13
OIL TEST AND IR-PI TEST FOR CASE STUDY 5

BDV (kV)	15
Water content (PPM)	200
IFT (mN/m)	32
NN (mg KOH/g)	0.023
Resistivity (ohm-cm)	15.8
PF at 90°C	0.5
Flash point (°C)	164

Table 14 shows IR and PI test results, which also shows healthiness of transformer.

TABLE 14
IR AND PI TEST RESULTS FOR CASE STUDY 1

Top oil temp		39°C	
Combination	60 Sec	600 Sec	PI
HV to LV	140 M-ohms	125 M-ohms	0.89
HV to earth	85 M-ohms	69 M-ohms	0.81
LV to earth	22 M-ohms	15 M-ohms	0.68

From above Table 14 oil contamination test result and IR and PI test result it is observed that PI values and also other oil test results were found to be very poor.

Hence, this transformer was opened at our workshop and after physical verification of core assembly, heavy water and other contaminations were observed between HV and LV windings. After necessary cleaning and heating cycle in oven, moisture content and other particles were removed and again Ten Delta test and other test were performed and results were found to be satisfactory as per Table 15.

TABLE 15
RETESTED TAN DELTA TEST RESULTS FOR CASE STUDY 5

Sl. No.	Insulation mode	Test voltage kV	t PF
1	CHL	2	0.42
2	CHL	5	0.43
3	CHG	2	0.72
4	CHG	5	0.76
5	CLG	2	0.56
6	CLG	3	0.57

Figure 12 shows visual inspection of core assembly.

Figure 13 shows graphical comparison for Tan Delta value of case study 5.

FIG. 12 VISUAL INSPECTION OF CORE ASSEMBLY

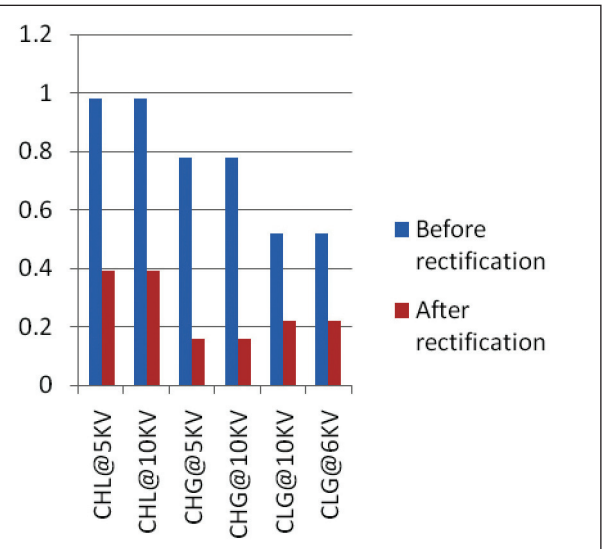

FIG. 13 GRAPHICAL REPRESENTATION FOR CASE STUDY 4

6.0 CONCLUSIONS

Tan Delta testing of transformer is an integral part of condition assessment at factory and at site for routine testing. Tan delta testing is actually comparison method. From above all case studies, conclusion is derived that from Tan Delta testing we can analyze transformer insulation condition and condition of grounding connection of transformer.

By measuring the electrical properties such as capacitance and Tan Delta regularly on periodical basis, it is possible to ensure the operational unexpected breakdown. Dissipation factor (Tan Delta) is one of the most powerful off-line nondestructive diagnostic tools to monitor the condition of solid insulation of various high-voltage equipment.

ACKNOWLEDGMENT

It is a matter of extreme honor and privilege for me to offer my grateful acknowledgment to my guide Prof. H.R. Jariwala for providing me a chance to work under their guidance and supervision, assisting with all kinds of support and inspiration and valuable suggestions. I am also thankful Essar Corporate University for financial support for this research work.

REFERENCES

[1] "Failure analysis and diagnostics of power transformer using dielectric dissipation factor", by Malpure B D and Baburao K Crompton Greaves Limited, Mumbai. 2008 *International Conference*, Beijing, China.

[2] Manual on Transformers, CBIP 2006.

[3] Power Factor testing in Transformers by Alex Rojas-2006, IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela-1-424-0288-3/06.

[4] Power Factor Testing of transformer insulation by Hodtum J B, AIEEE 27-30, 1940 AIEE pacific cost convention.

[5] IS-1866:2005.

[6] IEEE-62 1955.

[7] IEEE Standard C57.12.90-1999.

[8] Dipak Mehta. "Condition monitoring of power transformer by analyzing dissolved gas analysis and oil contamination test", Essar Oil Limited, *Journal of Information Knowledge and Research in Electrical Engineering*, Vol. 2, No. 1.

[9] Delta-3000 Technical Manual by Megger.