Life Assessment of Transformer: A Case Study

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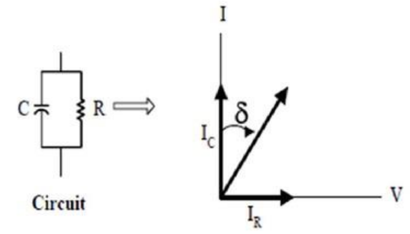
***Abstract-*.Power Transformers are the most vital equipment in a sub-station / Receiving station. Failure of a Transformer leads to loss of revenue besides affecting reliability of power supply to consumers. In order to ensure that Power Transformers provide long and trouble-free service, several diagnostic tests are carried out and remedial actions initiated throughout their operational lifetime. For the oil-filled Transformers, more particularly which are in service for more than 15 years, it is advisable that we should also estimate the residual life of the Transformers. Many methods are there which access the life of transformer like Tan & and capacitance measurements for windings, Degree of Polymerisation, Effect of moisture, Furan testing, Dissolved gas Analysis, Partial Discharge measurement, Magnetising current measurement etc. These methods can help the utilities in making optimum use of the Transformers and also taking timely decisions regarding refurbishment / replacement of Transformers, The paper presents the real life case study of assessing life of 315 MVA Power Transformer.**

I. INTRODUCTION

Power transformer are most vital and costliest equipment of Electrical Power System .In order to ensure reliable and economic power supply it is essential that we should utilize the installed transformer optimally . In order to access the life of transformer various methods like Tan & and Capacitance measurement for windings, Tan & and Capacitance measurement for Bushing, Partial Discharge Measurement , Insulation resistance measurement, Magnetizing current measurement , Ratio test, Dissolved Gas Analysis , Furan testing etc.

II. TAN DELTA TEST

Tan Delta test is a diagnostic test conducted on insulation of cables and winding. It is used to measure the deterioration in winding .It also give an idea of ageing process in the cable and ensure us to predict the remaining life of the cable .It is alternatively known as loss angle test or dissipation factor test Dissipation factor (Tan δ)



Modes of measurement

There are three modes of measurement

1) Ungrounded Specimen test(UST)
2) Grounded Specimen Test(GST)

A. Ungrounded Specimen test(UST)

The Ungrounded Specimen Test (UST) is referred to as the test of an insulation sample that is not grounded. This test configuration automatically provides a 'guard' connection that can be used effectively to measure only one component out of a multi component insulation system. The UST is of great advantage as its 'guard' connection is also 'ground'.

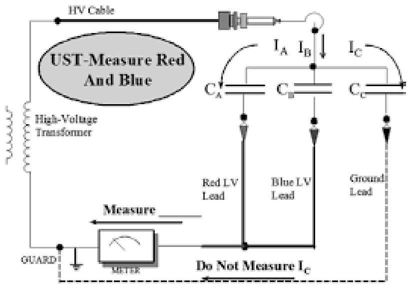


Fig. 1. Ungrounded Specimen Test(GST)

B. The Grounded Specimen Test (GST)

The Grounded Specimen Test (GST) is referred to as the measurement of an insulation sample that has one of its terminals grounded. To conduct a GST test, the measuring circuit of the instrument used must be ungrounded to make the measurement possible. As most pieces of electric power system equipment is grounded, the grounded specimen test must be used if the equipment is to be tested in the installed condition. GST is therefore the most important and most frequently used test. Most up-to-date test equipment also offer a grounded specimen test with guard-GSTg. This connection allows one to measure one component of a multi-component, grounded, insulation system.

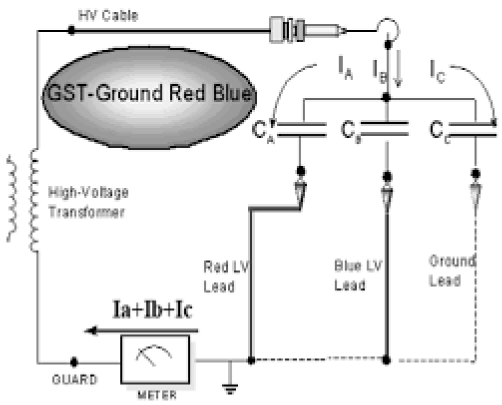


Fig.2 Grounded Specimen test

C. *Capacitance and Tan δ Measurement for Bushing*

Capacitance and Tan δ Measurement for Bushing provides an indication of the quality and soundness of insulation in the bushing. Portable capacitance and Tan bridge such as Schering bridge or transformer arm bridge, power supply and standard capacitor is used for measurement of Capacitance and Tan δ

Testing Procedure:

a) Ensure that test specimen is isolated from other equipments
b) Position the test set at least 6 feet (180 cm) away from test specimen to be tested.
c) To prevent damage to the test set always the capacitance multiplier dial to the SHORT position , the capacitance measuring dials to the "O" position.
d) Keep the UST-GST switch to UST position
e) Keep interference suppressor switches in off position
f) Connect the ground terminal of test set to low impedance earth ground
g) Connect control unit to the high voltage unit using two 5 feet long shielded cables
h) Connect the low voltage cable with red sheath to be " Cx" red terminal of the test set .Make sure the connector locks to the receptable.
i) Connect the external interlock cable to the interlock terminal of the test set
j) Connect the high voltage cable with black sheath to the high voltage terminal of high voltage unit.
k) For 3-ph auto-transformer, short together all 400KV, 220 KV and Neutral bushing

Measurement of C1 Capacitance and Tan delta:

a) Connect the crocodile clip of the HV cable to the top terminal of the shorted HV/IV bushing. Unscrew the test tap cover , insert a pin in the hole of the central test tap stud by pressing the surrounding contact plug in case of 245 KV OIP bushing and remove he earth strip from the flange by unscrewing the crew.
b) Connect the LV cable to the test tap of the bushing under the test to the capacitance and tan kit through a screened cable and earth the flange body. Repeat the test for all body by changing only LV lead connection of the kit to the test tap of bushing which is to be tested.

Measurement of C2 capacitance and Tan Delta

HV lead to be connected to the test tap of the bushing under test ad LV of the kit to be connected to the ground. HV of the bushing is to be connected to the guard terminal of the test kit.

Recording of test result

Make of Capacitance and tan kit -
ETEL AUTOMATIC TAN DELTA TEST KIT
Ambient Temp 26C

Bushing	Capacitance			
	PREVIOUS VALUES		PRESENT VALUES	
	2 KV	10 KV	2KV	10KV
400 KV BUSHINGS				
R ph	469.85 pF	469.73pF	469.61pF	469.60 pF
Y ph	462.53pF	462.55pF	462.51pF	462.50pF
B ph	465.45pF	469.23pF	465.36pF	469.61pF
220 KV BUSHINGS				
R ph	382.5 pF	382.12pF	382.45pF	382.43pF
Y ph	417.48 pF	417.58 pF	417.66 pF	417.78 pF
B ph	380.68 pF	380.69pF	380.94pF	380.94pF
52 KV bushing				
Rph	207.58 pF	207.74pF	207.22pF	207.23pF
Yph	190.22 pF	190.53pF	190.34pF	190.34pF
Bph	207.65 pF	207.54pF	207.24pF	207.24pF
	Tan Delta			
	PREVIOUS VALUES		PRESENT VALUES	
	2KV	10 KV	2KV	10KV
400 KV BUSHINGS				
Rph	.0033	.0033	.0034	.0034
Y ph	.0032	.0032	.0034	.0034
B ph	.0033	.0032	.0034	.0032
220 KV bushing				
R ph	.0037	.0035	.0037	.0037
Y ph	.0060	.0055	.0062	.0058
B ph	.0036	.0035	.0037	.0037
52 KV Bushing				
R ph	.0044	.0045	.0047	.0047
B ph	.0036	.0034	.0035	.0035
Y ph	.0046	.0045	.0047	.0047

Comments

The tan delta value has not exceeded the acceptable limit of 0.7%

The main capavitance (C1) variation of the bushing i.e, the capacitance between high voltage terminal and test tap is within + 10% -5%

Rate of rise of tan delta is not more than .001 year

Hence bushings are healthy

D. *Capacitance and Tan δ Measurement for Winding*

The purpose of Capacitance and Tan δ Measurement for winding is to carried out to a certain the general condition of the ground and inter winding insulation of transformer

Testing Procedure

a) Measurement should be made between each inter winding combination with all other winding grounded to the tank or ground he entire windings guarded.
b) For two winding Transformer , measurement should be made between each winding and ground with remaining winding grounded
c) For three winding Transformer , measurement should be made between each winding and ground with one remaining winding guarded and second remaining winding grounded.
d) Finally measurement should be made between all windings connected together and the grounded tank
e) Removal of jumpers from bushing for capacitance and tan measurement windings
f) Rest all procedure is same of Capacitance and Tan δ Measurement for bushing

Recording of test result

Make of Capacitance and tan kit
ETEL AUTOMATIC TAN DELTA TEST KIT
Weather : Clear, Oil Temp: 35 C

TEST VOLTAGE	2KV			
TEST MODES	PREVIOUS VALUE		PRESENT VALUE	
	CAPACITANCE	TAN	CAPACITANCE	TAN
HV-LV in UST mode	16985 pF	.0022	16998pF	.0023
HV-Ground in GST mode	27501pF	.0024	27513pF	.0026
LV-Tank in GST mode	24323pF	.0020	2432pF	.0023
TEST VOLTAGE	10 KV			
TEST MODES	PREVIOUS VALUE		PRESENT VALUE	
	CAPACITANCE	TAN	CAPACITANCE	TAN
HV-LV in UST mode	16999pF	.0022	17011pF	.0024
HV-Ground in GST mode	27500pF	.0025	27511pF	.0027
LV-Tank in GST mode	24366pF	.0022	24370pF	.0024

Comments

a) The tan delta value has not exceeded the acceptable limit of 0.7%
b) The main capacitance (C1) variation of the winding is within + 10% -5%
c) Rate of rise of tan delta is not more than .001 year
d) Hence bushings are healthy

III. MAGNETIZING CURRENT TEST

Magnetising current test is performed to locate defect in magnetic core structure, shifting of windings, failure in turn to turn insulation or problem in tap changers. These conditions change the effective reluctance of magnetic circuit thus effecting the current required to establish flux in the core.

Testing Procedure

a) The test comprises a simple measurement of single phase current in one side of the transformer usually the low voltage side
b) 3 phase transformers are tested by applying 3 phase ac supply HV terminals Keep the tap position in the lowest position
c) Measured the voltage applied on each phase and current in each phase of HV terminal
d) After completion of the above steps keep the tap position in normal position and repeat the above steps
e) After completion of the above steps keep the tap position in Highest position and repeat the above steps
f) keep the tap position in Highest position and Keep LV and HV terminal open
g) Measure the phase to phase voltage between the IV terminal and current on each IV terminal
h) Record the test result

Recording Of Test Result

Apply 3 –Phase ac supply on HV terminal and Keep IV and LV open

Tap position	Voltage Applied		Current Measured	
	Between	(Volts)	In	(mA)
Lowest	R-Y	406	R phase	17
	Y-B	391	Y phase	16
	B-R	413	B phase	16
Normal	R-Y	404	R phase	18
	Y-B	390	Y phase	20
	B-R	410	B phase	20
Highest	R-Y	403	R phase	23
	Y-B	390	Y phase	23
	B-R	410	B phase	22

Apply 3 phase ac supply on IV terminal and keep HV and LV terminal open

Tap position	Voltage Applied		Current Measured	
	Between	(Volts)	In	(mA)
Normal	R-Y	409	R phase	92
	Y-B	399	Y phase	90
	B-R	417	B phase	94

Comments
The set of readings for current measurement in each of tap position is found to be equal . It indicated healthy winding

IV. MOISTURE MEASUREMENT

Moisture on the transformer affects dielectric strength and ageing of insulation and sometimes result in sudden failure due to bubble evolution on increased loading. Moisture in insulation being measured indirectly by measuring moisture content in oil. As water concentration in oil is highly temperature dependant , moisture in oil not a reliable indicator of dryness of cellulose.. New transformers should have less than 0.5% of moisture in paper by weight. Maximum amount of water in the transformer is present in the paper. When the oil temperature increases, more water is dissolved in the oil. Thus water content in the oil together with the temperature can give an estimate of water present in the paper.

Moisture in paper	Classification
<0.5	New Transformer
0.5-1.5	Dry insulation
1.5-2.5	Medium wet insulation
2.5-4	Wet insulation
>4	Very wet insulation

A. *Moisture measurement through domino*

DOMINO test is used to determine the moisture content of the oil in Transformers and reactors. The sensor is made of Thin polymer film which measure capacitance.
T he capacitances changes proportional to the change in saturation of water in oil.

DOMINO Principle
Relative saturation RS= Wc * 100/S(%)
Wc = Concentration of water in oil
S= Solubility of water in oil that can be held at a given temperature
Solubility of water in oil at given temperature, Log S= -1567/K+ 7.0895

V. FURAN ANALYSIS

The mechanical properties of insulating paper can be established by direct measurement of its tensile strength or degree of polymerization (DP). These properties are used to evaluate the end of reliable life of paper insulation. It is generally suggested that DP values of 150-250 represent the lower limits for end-of-life criteria for paper insulation; for values below 150, the paper is without mechanical strength. Direct measurement of these properties is not practical for in-service transformers Analysis of paper insulation for its DP value requires removal of a few strips of paper from suspect sites. This procedure can conveniently be carried out during transformer repairs. The results of these tests will be a deciding factor in rebuilding or scrapping a transformer. Note: Since it is usually not practical (and often dangerous to the transformer) to obtain a paper sample from a de-energised, in service transformer an alternative method has been found. When a cellulose molecule de-polymerises (breaks into smaller lengths or ring structures), a chemical compound known as a furan is formed.

By measuring the quantity and types of furans present in a transformer oil sample, the paper insulation overall DP can be inferred with a high degree of confidence. The types and concentration of furans in an oil sample can also indicate abnormal stress in a transformer, whether intense, short duration overheating or prolonged, general overheating. Furan analysis can be used to confirm Dissolved Gas Analysis where carbon monoxide present indicates problems with solid insulation.

Furan derivatives

2- Furaldehyde	2 FAL
Furfuryl alchol	2 FOL
2-Acetylfuran	2 ACF
5-Methyl -2-Furaldehyde	5MEF
5-Hydroxymethyl-2-Furaldehyde	5HMF

2- Furaldehyde is the most abundant of furan derivatives but the other four are occasionally found in large concentration to indicate significant paper degradation

Approximate Relation Between DP And Total Furans

2 FAL(ppm)	DP= (1.5-log(2FAL))/.0035	2FAL ppm	DP=1850/(2FAL+2.3)
0.1	714	0.1	770
0.5	514	0.5	660
1	428	1	560
2	342	2	430
3	292	3	349
4	256	4	293
5	228	5	253

A. *Life Assessment of equipment by Furan Analysis*

Life of the equipment is generally the life of solid insulation itself, the remaining can be predicted from DP value
% Life (remaining) = 100 * (DP-200)/(1200-200)
We say % age life ,it is rather the % age reliability of the equipment to understand short circuit forces, overloading etc

Table 2

Furan Content (ppm)	DP Value	Significance
0-0.1	1200-700	Healthy transformer
0.1-1.0	700-450	Moderate deterioration
1-10	450-250	Extensive deterioration
>10	<250	End of life criteria

VI. DISSOLVED GAS ANALYSIS

DGA is probably the most powerful tool or detecting fault in electrical equipment in service. Thermal and electrical distributions in the operating transformer are two most important causes of dissolved gases in oil. The gases produced from thermal decomposition of oil and solid insulation are because of losses in conductors due to loading. Also decomposition occurs in oil and solid insulation is due to occurrence of arc. In case of electrical disturbances the gases are formed principally by ionic bombardment. The gases are generated mainly because of cellulose and oil insulation deterioration. In the normal operation of the transformer, gases such as Hydrogen (H_2), Methane (CH_4), Ethylene (C_2H_4), Acetylene (C_2H_2), and Ethane (C_2H_6) and so on are released

A. Doernenburg ratio method

This method utilizes the gas concentration from ratio of CH4/H2, C2H2/CH4, C2H4/C2H6, C2H2/C2H4.

M	N	O	P	
CH_4/H_2	C_2H_2/C_2H_4	C_2H_6/C_2H_2	C_2H_2/CH_4	Suggested Fault Diagnosis
>0.1	<0.75	>0.4	<0.3	Thermal Decomposition
<0.1 <0.001	>0.75	<0.4	>0.3	Corona (Low Intensity PD)
<0.1	<0.75	>0.4	<0.3	Arcing(High Intensity PD)

B. *Roger's ratio method*

According to the IEC standards, the extended Rogers method is used to produce a three digit code. The code is determined based on the three gas ratios of C_2H_2/C_2H_4, CH_4/H_2, and C_2H_4/C_2H_6

Gas ratio	Value	Code
X= C2H2/C2H4	X<0.1	0
	0.1<X<3	1
	X>3	2
Y= CH4/H2	Y<0.1	1
	0.1<Y<1	0
	Y>1	2
Z=C2H4/C2H6	Z<1	0
	1<Z<3	1
	Z>3	2

Sl. No.	Code			Kind of fault	Grouping of fault
	X	Y	Z		
1	0	0	0	No fault	F1
2	0	1	0	Partial discharge with low intensity discharge	F2
3	1	1	0	Partial discharge with high intensity discharge	F3
4	1 or 2	0	1 or 2	Partial discharge with low intensity discharge	F2
5	1	0	2	Partial discharge with high intensity discharge	F3
6	0	0	1	Thermal fault with temperature less than 150°C	F4
7	0	2	0	Thermal fault with temperature between 150° C to 300° C	F5
8	0	2	1	Thermal fault with temperature between 300 °C to 700° C	F6
9	0	2	2	Thermal fault with temperature greater than 700°C	F7

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B. *Case Study*

DGA result of TATA STEEL, Jamshedpur (Tata Nagar).
Equipment: 15/18.75 MVA
Make BHEL
Rated Voltage: 420/220/33 KV
Rated current: 434/526.6/837.03 Ampere

FAULTY GASES							
Sl. No.	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
1	21	11.5	65.3	50.6	0	327	5892
2	178	506	176	583	11.7	151	1844
3	502	646	194	690	14	175	2267
4	695	1340	629	2720	2.5	335	5655
5	684	1475	635	2970	5.5	377	6413
6	26	35.8	34.5	224	3.94	105	1096
7	408	567	354	2217	83.6	74	1912
8	397	436	354	1771	60.5	70	1867
9	21	47.9	37.7	72	0	154	1714

ROGER'S RATIO							
Fault Gases(IEC STANDARD)							
	RATIO			CODES			
S. No.	X	Y	Z	**X**	**Y**	**Z**	Kinds of Faults
1	0	0.561	0.774	0	0	0	No Result
2	0.02	2.842	3.312	0	2	2	Thermal fault with temp >700°C
3	0.02	1.286	3.556	0	2	2	Thermal fault with temp >700°C
4	0.04	1.928	4.324	0	2	2	Thermal fault with temp >700°C
5	0.002	2.156	4.677	0	2	2	Thermal fault with temp >700°C
6	0.018	1.365	6.480	0	2	2	Thermal fault with temp >700°C
7	0.038	1.389	6.262	0	2	2	Thermal fault with temp >700°C
8	0.034	1.098	5.002	0	2	2	Thermal fault with temp >700°C
9	0	2.270	1.912	0	2	1	Thermal fault with temp bet. 300°C & 700°C

ROGER'S RATIO							
Fault Gases(IEC STANDARD)							
	RATIO			CODES			
S. No.	X	Y	Z	**X**	**Y**	**Z**	Kinds of Faults
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8	0.034	1.098	5.002	0	2	2	Thermal fault with temp >700°C
9	0	2.270	1.912	0	2	1	Thermal fault with temp bet. 300°C & 700°C

VII. CONCLUSION

In this paper the analysis of life assessment of transformer is done so that due to failure of transformer there should not be any type of fault occur in electrical systems. Various methods are explain in the paper like Tan & and capacitance measurements for windings, Degree of Polymerisation, Effect of moisture, Furan testing, Dissolved gas Analysis, Partial Discharge measurement, Magnetising current measurement along with their cases studies and results

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