Condition Monitoring of Insulation System in Power Transformers

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***Abstract*—The oil/cellulose insulation system is one component of the transformer which, once subjected to normal and/or abnormal loading conditions cannot be replaced. Power factor and capacitance measurement are routinely used in the condition assessment of oil/paper insulated high voltage equipment. It is generally accepted belief that moisture in the oil/paper insulation increases the power factor and capacitance. This research is undertaken to study the insulation system of transformer and in-field measurement of power-factor and capacitance using the Doble M4000 insulation analyzer. The case studies on the different transformers showed how the trend of moisture and dielectric properties changes with the variation of power factor and capacitance of insulation system.**

***Index Terms*—Insulation system; power transformer; power factor; capacitance.**

I. Introduction

Understanding the design of the transformer as well as the operational history is essential for making reliable diagnosis. The design of the components must enhance the life expectancy of the assembly as a whole [1]. Due to operations under extreme conditions, rapid aging and wear and tear will occur, thereby shortening the life of the transformer. Many of the components like tap changer contacts, bushings, pumps and fans can be replaced in a timely manner to extend the life of the transformer [2].Transformer failures are normally due to degradation and aging of cellulose and oil. Life assessment of a transformer is crucial when it reaches the age of 20-25 years. The cellulose deterioration effects can be found in the transformer oil and can be measured using degree of polymerization (DP) test and sampling the oil for furanic analysis (furfural method). Transformer failure is mostly attributed to the dielectric response of the insulation system. Through faults also have considerable effect on the integrity of insulation system and accelerate the aging phenomenon.[3] Mineral oil and insulation paper should have sufficient dielectric strength to withstand these faults. According to a study transformer failure rate due to insulation related problems is 11 % and is increasing. Insulation aging in transformer is a complex and irreversible phenomena. Stresses due to operation (normal to extreme), ambient conditions and contamination contribute to the deterioration of the insulation chain thus shortening the transformer design life [4]. In current scenario most of the in service transformers (around 65%**)** are of the age of 25 years and older. So Insulation is basically a layer of one or more dielectrics between plates. One plate is at a high potential and the other at a lower or ground potential. IEEE defines insulation as: “Material or a Combination of Suitable Non-Conducting Material that Provides Electrical Isolation of Two Parts at Different Voltages.” The main cause of transformer failure is due to failure of insulation as shown in the Table I.

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TABLE I: Causes Of Transformer Failure

Cause	% of failure
Insulation failure	26
Manufacturing problems	24
Unknown	16
Loose connections	7
Overloading	5
Improper maintenance	5
Oil contamination	4
Line surges	4
Fire/explosions	3
Lightning	3
Floods	2
Moisture	1

II. Measuring Techniques

A wide variety of electrical, mechanical and chemical techniques were used on transformer insulation samples. In most cases all the tests were applied to each set of samples, so that it is valid to compare and to correlate the test results for like samples.

A. Electrical Techniques

There are two main reasons why electrical techniques do not mostly provide good measures of the degradation of cellulosic insulation. The first, as has already been mentioned, is the dominant effect moisture has on most electrical properties. The second is that the electrical properties of oil impregnated paper and pressboard are probably more a function of the impregnating oil than of the cellulose. So the electrical results are not sensitive measures of the condition of the insulation.

B. Mechanical Techniques

Because of convenience, the mechanical properties of the cellulosic insulation were only studied using tensile strength (TS) measurements even though other measures such as folding strength and bursting strength may also be relevant. TS of paper is also very sensitive to moisture content

C. Chemical Techniques

Cellulosic paper is a blend of three components – cellulose polymer of high molecular weight, hemi-cellulose co-polymers of lower molecular weight, and lignins which are aromatic-based polymers. The degradation of paper is dependent on the environmental conditions and can involve hydrolytic, oxidative and thermal degradation. Degradation can cause changes in the molecular weights, the morphology, the chemical composition and the surface of the paper. Chemical Composition of Cellulose Degradation Products dissolved in the Oil - the well established technique of dissolved gas analysis (DGA) using gas chromatography yields quantitative data on the concentrations of the various gases (hydrogen, carbon mono and &-oxide, and hydrocarbons) caused by arcing and by degradation of oil and cellulosic paper. The DP will be measured for the paper. The use of HPLC techniques to determine the soluble concentrations in oil of furans to assess the extent of paper degradation (so called furans analysis) is a comparatively new technique being applied to power transformers.

III. Condition Monitoring

In-field measuring exploits the advantages of power-factor testing under real operating conditions (at rated voltage, at variable operating temperature) and consequently, to extend the range of diagnostic characteristics using: change of power factor with temperature, with voltage, with time, as well as correlation between power-factor, capacitance, sum current and leakage current in case if an internal fault occurs that involves short-circuits between layers.

The M4000 Insulation Analyzer is used to determine the condition of high-voltage power apparatus in the field. This portable test set incorporates automated testing with high accuracy and sensitivity, over a wide range of values and with minimal susceptibility to electrostatics interference and noise. The M4000 uses an internal sine wave generator and a 3 kVA power amplifier to generate an isolated 0-12 kV test signal. The M4000 then measures the voltage and current of the specimen using reference impedance. The instrument calculates and reports test results by converting the sampled data into vector (magnitude and phase) quantities and applying conventional AC circuit theory. All reported results including power loss, power factor and capacitance are derived from the vector voltage and current.

IV. Results And Discussions

Measurements can be performed between high and low voltage windings (so called CHL measurements where indexes H and L indicate high voltage and low voltage windings respectively) or between windings and the ground (CH and CL). In CHL measurements, the voltage usually is applied to the transformer HV side and the resulting current is measured on the LV side. If the guard cable is connected to the grounded transformer tank and no other elements are connected to the bushings, the whole current flows across the main insulation between windings, following the desired current path. The capacitance and the losses of the insulation between the HV and LV windings can be characterised well. Guarded CHL measurements minimize the influences from additional loading capacitances to ground as well as from internal and external leakage. In CHT measurements the capacitance and the losses of the insulation between the HV winding and the tertiary. Changes in these values as the transformer ages and events occur, such as nearby lightning strikes or through faults, indicate winding deformation and structural problems such as displaced wedging and winding support.

The following limits have been determined to identify questionable units [5]:

Normal condition:	PF < 0.5%
Warning:	$0.5 \leq$ PF ≤ 0.7 %
Alarm:	PF > 0.7 %
Remove from service	PF > 2.0%

The different transformers tested for measurement of power factor, losses and capacitance and case studies result are shown as under:

CASE I

TABLE II: 26.67MVA, 127KV, SR. NO. 8726/01
MATTAN SIDH, HAMIRPUR H.P

Meas.	Test kV	mA	Watts	%PF corr	CF	Cap. (pF)
CH + CHT	10.002	13.84	0.279	0.2	1	4411.8
CH	10.002	7.523	0.138	0.18	1	2398.3
CHT (UST)	10.002	6.311	0.132	0.21	1	2011.8
CHT		6.317	0.141	0.22	1	2013.5
CT + CHT	10.002	16.725	0.404	0.24	1	5331.4
CT	10.002	10.413	0.272	0.26	1	3319.3
CHT (UST)	10.002	6.309	0.133	0.21	1	2011.1
CHT		6.312	0.132	0.21	1	2012.1

The variation of power factor in Fig.1 showed normal trend which indicated that the quantity of moisture in transformer insulation is in acceptable limits.

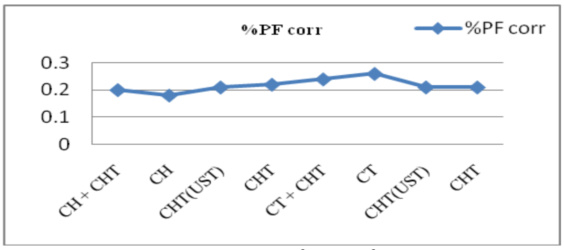

Fig. 1.Variation of power factor

The trend of capacitance and loses in Fig. 2 showed no change in the dielectric properties of the transformer insulation.

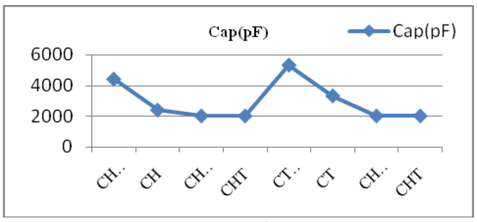

Fig. 2. Variation of capacitance

CASE II

TABLE III: 52 MVA, 132/11KV, SR.NO. 201390 (GT-2)
LARJI POWER HOUSE, KULLU H.P.

Meas.	Test kV	mA	Watts	%PF corr	C F	Cap. (pF)
CH + CHL	1	36.428	1.43	0.39	1	11611.6
CH	1	17.618	0.881	0.5	1	5615.9
CHL (UST)	1.001	18.812	0.635	0.34	1	5996.4
CHL		18.81	0.549	0.29	1	5995.7
CL + CHL	1.001	53.239	1.941	0.36	1	16970.6
CL	1	34.429	1.354	0.39	1	10974.8
CHL (UST)	0.999	18.81	0.624	0.33	1	5996.1
CHL		18.81	0.587	0.31	1	5995.8
CH'		17.618	0.881	0.5	1	5615.9
CL'		34.429	1.354	0.39	1	10974.8

The variation of power factor in Fig.3 showed warning trend between high voltage winding and ground where as other results showed a normal trend. This warning trend showed small amount of moisture in the insulation.

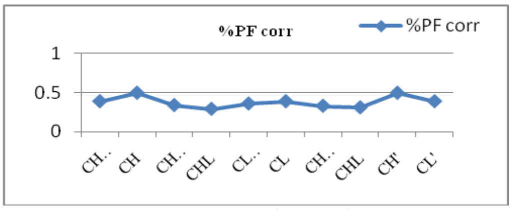

Fig. 3.Variation of power factor

The results of capacitance between high voltage winding and ground in Fig. 4 showed change in physical properties and small amount of moisture.

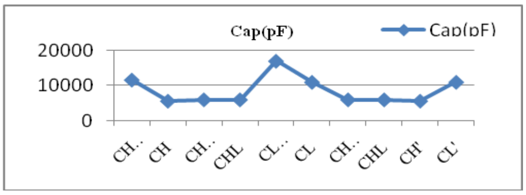

Fig. 4.Variation of capacitance

CASE III

TABLE IV: 52 MVA, 132/11KV, SR.NO. 2013903 (GT-1)
LARJI POWER HOUSE, KULLU H.P.

Meas.	Test kV	mA	Watts	%PF corr	C F	Cap. (pF)
CH + CHL	1.002	41.308	1.632	0.4	1	13167.1
CH	1.001	22.391	1.164	0.52	1	7137.1
CHL (UST)	1.001	18.918	0.497	0.26	1	6030.2
CHL		18.917	0.468	0.25	1	6030
CL + CHL	1.002	51.181	1.46	0.29	1	16313.8
CL	1.001	32.504	0.966	0.3	1	10361.1
CHL (UST)	1.002	18.684	0.494	0.26	1	5955.6
CHL		18.677	0.494	0.26	1	5952.7
CH'		22.391	1.164	0.52	1	7137.1
CL'		32.504	0.966	0.3	1	10361.1

The variation of power factor in fig. 5 showed warning trend between high voltage winding and ground whereas other results showed a normal trend. This warning trend showed small amount of moisture in the insulation.

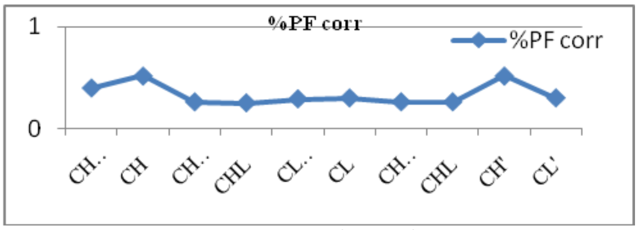

Fig. 5. Variation of power factor

The results of capacitance between high voltage winding and ground in Fig. 6 showed change in physical properties and small amount of moisture

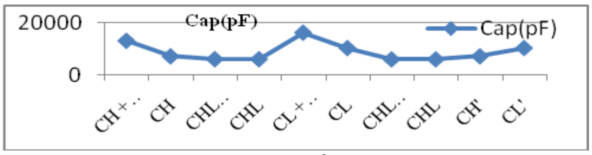

Fig. 6. Variation of capacitance

CASE IV

TABLE V: 31.5 MVA, 220/33/6.715 KV, SR.NO. 24441
JASSURE, KANGRA H.P.

Meas.	Test kV	mA	Watts	% PF corr	CF	Cap.(pF)
CH + CHL	10.002	22.716	0.664	0.29	1	7241
CH	10.002	10.988	0.358	0.33	1	3502.4
CHL (UST)	10.002	11.719	0.289	0.25	1	3735.5
CHL	10.002	11.728	0.306	0.26	1	3738.6
CL + CLT	10.003	42.373	1.59	0.38	1	13506.6
CL	10.002	3.593	0.184	0.51	1	1145.3
CLT (UST)	10.002	38.764	1.4	0.36	1	12356.8
CLT	10.002	38.78	1.406	0.36	1	12361.3
CT + CHT	5.001	37.643	1.314	0.35	1	12016.4
CT	5.002	36.988	1.299	0.35	1	11807.2
CHT (UST)	5.001	0.656	0.017	0.26	1	209.53
CHT	5.001	0.655	0.015	0.23	1	209.2
CH+CL+ CT	5.001	51.591	1.929	0.37	1	16468.7

The variation of power factor in Fig. 7 showed warning trend between low voltage winding and tertiary where as other results showed a normal trend. This warning trend showed small amount of moisture in the tertiary winding.

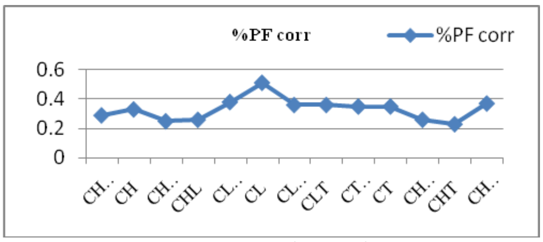

Fig. 7. Variation of power factor

The results of capacitance between low voltage winding and tertiary in Fig. 8 showed change in physical properties and small amount of moisture in the tertiary winding.

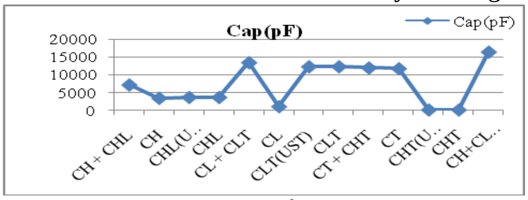

Fig. 8. Variation of capacitance

V. Conclusion

The above case studies on the different transformers showed how the trend of moisture and dielectric properties changes with the variation of power factor and capacitance of insulation system. The power factor is a measure of the energy dissipated and confirms insulation integrity and quality of the insulation. The moisture impurity and aging of the insulation will normally cause an increase in the power factor. Change in the capacitance could be due to change in the dielectric properties of the insulation which can be affected by the presence of moisture and other impurities or shorting out some of the paper layers by conducting paths. Capacitance testing also measure physical changes that may have occurred to the apparatus.

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