Study the Insulation System of Power Transformer Bushing

Amit Mehta, R. N. Sharma, Sushil Chauhan and S. D. Agnihotri

Abstract—**Bushings are a critical component in electricity transportation. They are used in substation buildings, transformers, locomotives, and switchgear. Bushings cause more than 15% of transformer failures. The main purpose of a bushing is to transfer load currents in and out of metal (grounded) enclosures at system voltages. The insulation system breaks down, causes bushing failure results in tank rupture, violent explosion of the bushing and fire .Clearly, the risk and likelihood of collateral and personnel damage is a major concern in such an eventuality. This research is undertaken to study the insulation system of transformer bushing and in-field measurement of power-factor and capacitance using the Doble M4000 insulation analyzer. The case studies on the two 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, Bushing, power factor, capacitance.**

I. Introduction

Large power transformers belong to the most expensive and strategically important components of any power generation and transmission system. A serious failure of a large power transformer due to insulation breakdown can generate substantial costs for repair and financial losses due to power outage. Therefore, utilities have clear incentive to assess the actual condition of their transformer, in particular the condition of the HV insulation system, with the aim to minimize the risk of failures and to avoid forced outages of strategically important units. Assessment of insulation quality in large H.V. power equipment at any point in time, also called 'Condition Monitoring' is an area of work currently be study the insulation system of transformer bushing pursued by many laboratories and utilities. Several techniques are available for monitoring of several parameters, which could indicate the condition on the insulation. From the literatures as well as field data it has been established that bushings are one of the major reasons for transformer failure [1], [2].

II. Bushing Monitoring Systems

A failure of transformer accessories such as condenser bushings sometimes leads to a transformer failure and long term outage. Often, moisture is a cause of explosion for service-aged bushings. On-line monitoring of insulation dryness in bushings through oil analysis is a difficult task and may not represent the moisture in the paper. 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 [3].Bushing failures are normally due to degradation and aging of cellulose and oil [4]. Life assessment of a bushing is crucial when it reaches the age of 20-25 years. The cellulose deterioration effects can be found in the oil and can be measured using degree of polymerization (DP) test and sampling the oil for furanic analysis (furfural method). Bushing 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 [5]. Mineral oil and insulation paper should have sufficient dielectric strength to withstand these faults. According to a study transformer/bushing 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 [6]. 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".

III. Measuring Technieques

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.

Manuscript received Febeuary 11, 2011; revised July 11, 2011

Amit Mehta, R. N. Sharma and Sushil Chauhan are with the Electrical Engineering Department of National Institute of Technology, Hamirpur, Himachal Pradesh, INDIA (mehtaamit5@gmail.com)

S. D. Agnihotri is with HPSEB as S.E. (Production).

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.

IV. 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. 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.

V. RESULTS AND DISCUSSIONS

According to the IEEE standards C57.19.00 [7] and C57.19.01 [8], condenser bushing rated 115 kv and above are provided with C1 (main) and C2 (tap) capacitances. Under normal operating condition,C1 is automatically grounded through the voltage tap cover connecting the tap stud with the mounting flange.C2 is therefore shorted and not subjected to any voltage stress. However if the bushing is applied with a potential device, the voltage tap will be connected to the potential device so that the C1 and C2 capacitance behave like a voltage divider. In this case, the voltage across C2 will be used for the potential device. The voltage tap can also be used for measuring the power factor and capacitance of C1 and C2.

The effect of applied voltage on power-factor at the 10% of rated voltage the power factor of the two bushings is practically the same. That means that off-line dissipation-factor or Doble power-factor tests at 10 kV will not show any defect in the bushings, but with increase of applied voltage the power-factor of the defective bushing rapidly grows. The higher applied voltage reflects in higher power-factor magnitude.

The M4000 analyzer is connected through the matching unit to the test taps of the bushings or the current transformers located on the same phase. This system uses residual current from a balanced (tuned) wye of the 3 phase leakage current to detect a change in any of the three HV, XV or TV bushing.

The following limits have been determined to identify questionable units [9]:

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

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

Case 1

Bushing C1

Table .1. 26.67MVA, 127KV, SR.NO. 8726/01
MATTAN SIDH, HAMIRPUR H.P.

Pha-se	Serial	Test kV	mA	Watts	% PF corr	CF	Cap. (pF)
H1	01062	0.5000	1.124	0.0300	0.27	1	358.70
H1	01062	5.002	1.124	0.0310	0.28	1	358.86
H1	01062	10.002	1.126	0.0320	0.28	1	358.78
X1	52006	0.5000	0.9360	0.0340	0.36	1	298.87
X1	52006	5.001	0.9360	0.0330	0.35	1	298.80
X1	52006	10.002	0.9370	0.0330	0.35	1	298.71

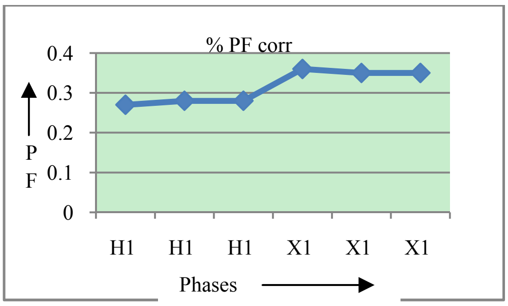

Fig.1.Variation of power factor in different phases

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

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

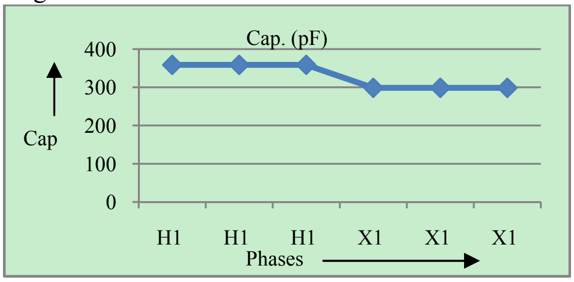

Fig.2.Variation of capacitance in different phases

Bushing C2

Table.2. 26.67MVA, 127KV, SR.NO. 8726/01 MATTAN SIDH, HAMIRPUR H.P.							
Pha-se	Serial	Test kV	mA	Watts	% PF corr	CF	Cap. (pF)
H1	01062	0.5000	2.668	7.325	27.46	1	818.55
H1	01062	0.5000	2.661	7.151	26.87	1	817.99
X1	52006	0.5000	1.854	0.0460	0.25	1	591.90
X1	52006	1.002	1.857	0.0530	0.29	1	591.84
H1	01062	0.5000	2.759	9.097	32.97	1	830.75
H1	01062	1.000	2.792	10.085	36.12	1	829.44

The variation of power factor in figure 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 bushing.

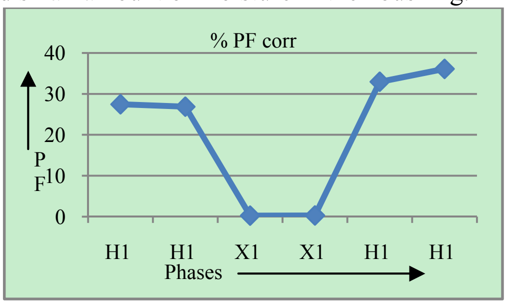

Fig.3.Variation of power factor in different phases

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

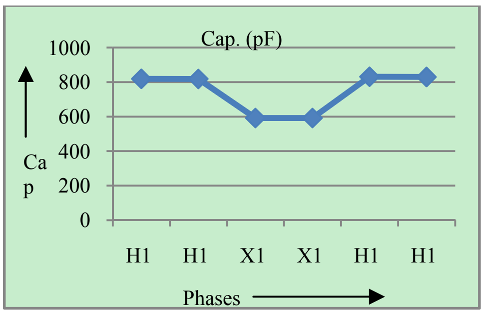

Fig.4.Variation of capacitance in different phases

Case 2 Bushing C1

Table.3. 31.5 MVA, 220/33/6.715 KV, SR.NO. 24441 JASSURE, KANGRA H.P.							
Pha-se	Serial	Test kV	mA	Watts	% PF corr	CF	Cap. (pF)
H1	821149	0.5000	0.7520	0.024	0.32	1	240.01
H1	821149	10.002	0.7530	0.025	0.33	1	239.87
H2	821148	0.5000	0.7550	0.024	0.32	1	240.91
H2	821148	10.002	0.7550	0.025	0.33	1	240.78
H3	830265	0.5000	0.7480	0.023	0.31	1	238.69
H3	830265	10.002	0.7480	0.023	0.31	1	238.58

The variation of power factor in figure 5 showed normal trends which indicated that the quantity of moisture in transformer bushing is in acceptable limits

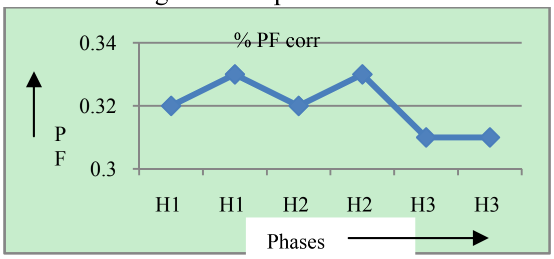

Fig.5. Variation of power factor in different phases

The trend of capacitance and loses in figure 6 showed no change in the dielectric properties of the bushing insulation

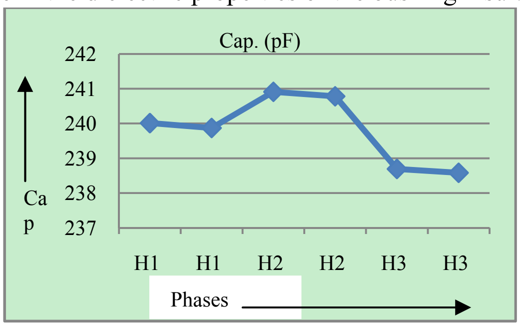

Fig. 6.Variation of capacitance in different phases

Bushing C2

Table .4. 31.5 MVA, 220/33/6.715 KV, SR.NO. 24441 JASSURE, KANGRA H.P.							
Pha-se	Serial	Test kV	mA	Watts	% PF corr	CF	Cap. (pF)
H1	821149	0.500	2.320	0.055	0.24	1	740.64
H2	821148	0.500	2.259	0.075	0.33	1	721.09
H3	830265	0.500	2.298	0.079	0.34	1	733.40

The variation of power factor in figure 7 showed normal trends which indicated that the quantity of moisture in transformer bushing is in acceptable limits

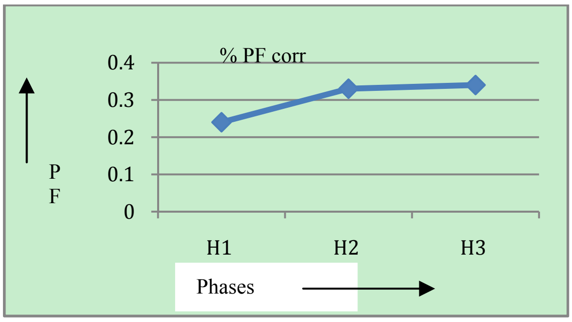

Fig.7.Variation of power factor in different phases

The results of capacitance between high voltage winding and ground in figure 8 showed change in physical properties and small amount of moisture.

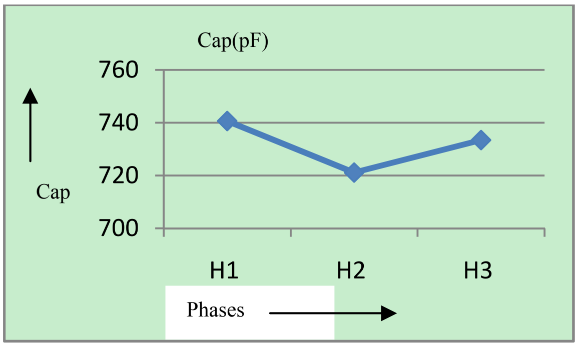

Fig.8.Variation of capacitance in different phases

VI. Conclusion

The above case studies on the two different transformer bushings 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.

Acknowledgment

The authors are thankful to Technology Information Forecasting & Assessment Council and Centre of Relevance & Excellence (TIFAC-CORE) on "Power Transformer Diagnostic" at NIT Hamirpur H.P. INDIA for providing necessary infrastructural facilities for caring out the research work.

References

[1] [1] V. Smekalov "Bushing insulation monitoring in the course of operation" a transaction in CIGRE 1996: 12-106.

[2] S. D.Kassihin, S.D. Lizunov, G.R. Lipstein,A.K.Lokhanin, and T.I.Morozova "Serviceexperience and reasons of bushing failures of EHV transformers and shunt reactors" atransaction in CIGRE 1996:12-105.

[3] B Richardson, Transformer life management: Bushings and tap changers, IEE Colloquium (Digest) IEE, Stevenage, Engl. P 8/1-8/4, 510, 1998.

[4] D. M. Getson, "High voltage bushing" ABB Germany,Germany,2002

[5] Tailin Xue, Bing Xie, Yuncailu Lu:"Study on the Insulation Life Models of Power Transformer ", IEEE, 2008.

[6] K.B.Liland , M.H.Ese , L.Lundgaard And M.Kes :"Oxidation of Cellulose",IEEE,2008

[7] IEEE standard C57.19.00,"General requirements and test procedure for power apparatus bushings", 2004.

[8] IEEE standard C57.19.01,"Performance characteristics and dimension for outdoor apparatus bushing", 2000.

[9] Doble Engineering Company "Reference Book on Insulating Liquids and Gases" RBILG-391.1

Mr. Amit kumar Mehta, was born on March 25, 1969. He obtained his bachelor degree in electrical engineering from Bangalore University in the year 1993 and master in power engineering from Punjab technical university in year 2008. Presently he is pursuing his Ph.D. from NIT Hamirpur H.P.

Dr R. Naresh, was born in Himachal Pradesh INDIA in 1965. He received BE in electrical engineering from Thapar Institute of Engineering and Technology, Patiala, India in 1987, ME in Power Systems from Punjab Engineering College, Chandigarh in 1990 and Ph D from the University of Roorkee, Roorkee (now IIT Roorkee), India in 1999. Presently he is working as Head in the Electrical Engineering Department, National Institute of Technology, Hamirpur, HP.

Prof. Sushil Chauhan, was born on August 22, 1963. He obtained his bachelor degree in electrical engineering from Madan Mohan Malviya Engineering College Gorakhpur in the year 1986 and master in Power System Engineering from IIT Roorkee in the year 1988. He obtained his Ph.D. in ANN based Power System Security Assessment in the year 1999 from IIT, Roorkee Presently he is Dean Academics at NIT Hamipur H.P.