CONDITION MONITORING APPROACHES OF A TRANSFORMER

saptarshi ROY[1] **Dr. p suresh BABU**[2]

[1]Research Scholar, Dept. of Electrical Engineering, NIT Warangal, INDIA, email id: saptarshi.roy.ju@gmail.com

[2] Assistant Professor, Dept. of Electrical Engineering, NIT Warangal, INDIA, email id: drsureshperli@nitw.ac.in

Abstract –*Equipments are deteriorating with respect to time. If the timing and causes of the equipment deterioration are known ,proper preventive measures can be taken and hence the life time of the equipment can be increased. In this context, several parameters can be analysed, e.g- pressure ,temperature, vibration ,flow etc by collecting data and following certain methodologies to indicate the status of condition of the equipment. In this way the reliability of the equipment can remain high and longevity also can be increased. This paper presents a survey on various condition monitoring approaches of transformer along with various practical case studies based on various site visits. It discusses the minute details about how the condition of a transformer can be assessed after several years of usage and operation. It also discusses what are the methodologies used for assessment of transformer's condition and necessary precautions to be taken to avoid errors in assessment of condition. Some practical case studies based on various site visits are also shown to emphasize the importance of the work.*

Index terms *: Preventive maintenance, Overhauling, Retrofitting, Condition monitoring , Polarization index , DGA ,Furan Analysis ,Tan delta ,degree of polymerization ,Sweep frequency response, Residual life.*

I.INTRODUCTION

Maintenance of transformer are of four kinds : 1)Breakdown maintenance 2) Preventive maintenance 3)Condition based maintenance 4) Strategic maintenance.

Condition based maintenance: Condition monitoring(CM) is nothing but health assessment of equipment. Like human being, the equipments also need a doctor for periodic check up of health in order to keep their health in good condition[1]. Overhauling and retrofitting are another two terms associated with condition based monitoring [1–3]. Using various process parameters , we can get certain indications about the health of the transformer and accordingly necessary actions to be taken to prevent failure and hence increase life time. It is a kind of preventive maintenance .

Diagnostics : Diagnostic is a term related to identify disease of human being. The same term is used in industry with respect to find any disorder in any equipment. The data extracted through various processes are grouped intelligently and after that with the help of the properties of the data, a complete knowledge is generated regarding the health condition of the transformer.

Overhauling : Overhauling means renovation. Any equipment like transformer, motor, generator , turbine etc are checked with respect to their present performance and possibility of its deterioration in future, and the weak or prone to damage parts are repaired or replaced [1].

Retrofitting : It is one is to one replacement of the spares of the equipment with duplicate one instead of original. e.g- previously bulk oil circuit breakers are mostly used in industry, but nowadays BOCB are obsolete and they are retrofitted by Vacuum circuit breakers [1].

Several works has been done based on various condition monitoring approaches of transformer from the past. [4] describes distribution transformer's condition monitoring of mechanical parts by using Sweep frequency response analysis.[5] describes a online condition monitoring approach for power transformer's bushing, tap changers and insulation

system.[6] demonstrates a technique for condition monitoring of transformer oil using thermal analysis.[7] describes a method for condition monitoring of transformer's insulation system.[8] describes condition monitoring of transformer insulation system by polarization and depolarization of current measurement.[10-12] describes various condition monitoring approaches of a transformer in different faulty conditions.[14] describes a transformer's condition monitoring approach using oil and winding temperature analysis.[15] describes a health index based transformer condition monitoring approach for distribution transformer.[16-18] describes the methods for transformer oil condition monitoring approaches. From the above literatures it is found that the practical exposures of the works are less. Almost no work is done based on practical site visits and on an working transformer in a substation. Most of the works are on a small part of a transformer (e.g- either insulation system, oil insulation or bushing, tap changers etc.). Integration of work is missing. Very minute details need to be remembered for the accuracy of the tests which can be known only while doing the work in the site or from the interaction with the experienced workers in the site. In this work we want to explore on various condition monitoring approaches of transformer based on various site visits. We observed the minute details of the tests in the site. All the salient points are discussed with the test results and interpretations.

The paper is organized as follows. Section I describes the introduction part. In introduction part different kinds of transformer maintenance, basic terminologies used and literature survey is described. Section II consists of the names of the different condition based monitoring methodologies of transformer. Section III to Section VIII describes the most important methodologies used in transformer condition monitoring approaches with at least one practical case study based on various site visits. Section IX to Section XII describes other approaches used in transformer condition based monitoring in a nutshell. Section XIII describes the general cautions to be followed during conduction of condition monitoring tests of transformer in the site practically. Section XIV describes the advantages of the proposed work compare to previous works. Section XV describes the conclusions followed by acknowledgement, nomenclature and references.

II.CONDITION BASED MONITORING METHODOLOGIES :

Condition monitoring of transformer is very effective in case of large size power transformers which is having rating in terms of 100,200,300 MVA or even more. A standard 315 MVA transformer costs in terms of crores , may be 5-6 crores with on an average life span 15-20 yrs. Instead of replacing the whole transformer with erection, testing and commissioning costs after the effective life time, it is suggested to do condition monitoring and increase its effective life time up to its optimum usage. Prone to damage spares are needed to be replaced and obsolete spares are needed to be replaced with spares with updated features. It is seen from the experiences if the user invests just 10% of the transformer's cost on the account of its condition monitoring the effective life time increment of transformer will be of about 25%, 30% or even more[13]. So, condition monitoring of transformer is a very very important aspect w.r.t its maintenance and it is expected that this article will be very helpful for all industry practitioners to create a general awareness about its different methodologies with practical examples. Fig 1 refers to the flow chart of the proposed work and Fig 2 shows an automatic ratio meter, which is an associated test kit during the testing. The several methodologies used in transformer's condition monitoring approaches are as follows :

1)Tan delta on winding.
2)Test of oil samples.
3)Polarization Index.
4)Dissolved Gas Analysis
5)Furan Analysis
6)Degree of Polymerisation
7) Partial Discharge Test.
8)Frequency Response Analysis
9) Radio Influence Voltage Test .
10) Infra-red Temperature Measurement .
11) Residual Life Assesment etc.

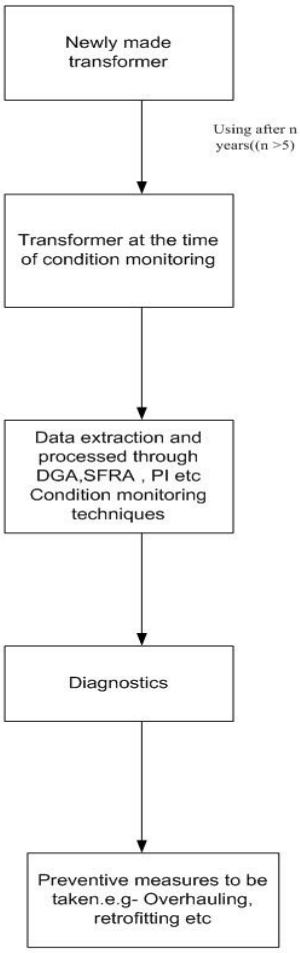

Fig 1: Flow chart of the proposed work

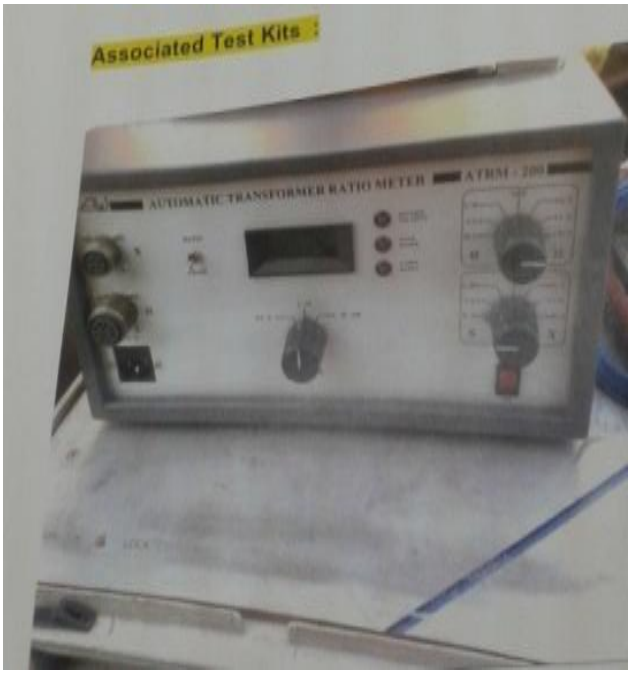

Fig 2: Automatic Ratio meter

III.POLARIZATION INDEX TEST :

The insulation resistance readings change with respect to time because of dielectric absorption . The direct ratio of two certain times can indicate the condition of the insulation system. The ratio is called the "Polarization Index" .Therefore ,

$$P.I = \frac{R(t_2)}{R(t_1)} \qquad (1)$$

$R(t_1)$ = Insulation resistance after t_1 times of applying d.c voltage. $R(t_2)$ = Insulation resistance after t_2 times of applying d.c voltage. Generally we use t_1 =10 sec t_2 =60 sec P.I gives an idea of the cleanliness of the insulation system .

P.I < 1.3 – not good. 2 < P.I <5 - permissible

P.I < 2- dirty or moist insulation . P.I > 5- Very dry, brittle insulation system.

Exceptions : HV Vacuum pressure impregnated system may yield a P.I between 1&2,for a perfectly good winding .

i)Case Study :

Site : Bhushan Power and Steel Limited, Jharsuguda ,Orissa Date : 08-12 Sept.,2016.The results shown are tested on a 16 MVA CG make transformer. sl. No. 7184/05 ,Voltage Class 6.6 KV /433 Volt .

TABLE-I describes the polarization index test results. The analysis of the results and recommended actions are also discussed .

TABLE-I :Polarization Index test results

Connection	I.R at 10 sec(Mega Ohm)	I.R at 10 sec(Mega Ohm)	P.I
Ph- Earth	2.2	2.48	1.12
Ph-Earth	1.11	2.18	1.96
Ph-Ph	1.04	2.08	2.00

ii)Recommended Action :

1)The insulation is okay .
2)But little bit of oil purification will make its condition better .If P.I value is very high, even if >5 ,then it is not a matter of concern. But it is really harmful , if its value is very low ,specially below 1 . It indicates the insulation contains moisture . Moisture content make it conducting and thus degrade its insulation property .
During inspection of transformers , it is found that , the tank is not well covered . The I.R value between live part (i.e winding) and ground was found to be zero .In those case ,if we apply Meggar test for long time , then two types of results are noticed in two cases :

i)I.R remains at zero :We can conclude that probably there is some short circuit between tank body and live part. Need proper inspection of core coil assembly .

ii)I.R increases slightly but not enough : We can conclude that it indicates Oil BDV(Break down voltage) problem. Needs proper purification and sampling .If P.I not increases even after applying the above methodologies, we can take the help of some other processes. e.g- Nitrogen Purging , Induction heating etc .

IV.DGA (DISSOLVED GAS ANALYSIS) :

It is very important for assessment of condition of transformer's oil insulation. Generally oil samples from Buchhloz relay are collected , gas extracted , then they are separated , then analysed , then the interpretations are made from collected data .

i) Some interpretations from DGA :

Free Gas –

i)Colourless and odourless : Trapped air .
ii)Greyish with pungent smell: non-flammable overheating of insulation and insulation board .
iii) Yellowish inflammable : decomposition of wood
iv)Dark Grey : Flash over in oil / Overheat .

ii)Case Study :
Site : Purnea ,Bihar State Electricity Board

Date: 12 Oct, 2016
DGA Test lab : Insulating oil testing laboratory , Powergrid , Durgapur .
The results are shown on a 50MVA Transformer , 132/33 KV, Sr. No. T 9408/05 .

TABLE-II shows DGA Test results.

TABLE-II : DGA Test results

Test Values	Top Sample	Bottom Sample-I	Bottom Sample-II
BDV(KV)	54.2	55	57
Water content(ppm)	13	12	12
DGA	Results		
TGC(%)	7.1	7.2	7.2
N_2(%)	5.11	5.23	5.19
O_2(%)	1.51	1.49	1.53
H_2(ppm)	1111	1159	1164
CH_4(ppm)	450	455	455
C_2H_4(ppm)	1037	1031	1035
C_2H_6(ppm)	26	26	26
C_2H_2(ppm)	954	955	958
CO(ppm)	141	145	147
CO_2(ppm)	642	627	631

iii) Recommended Action :

i)Content of H_2,CH_4 indicates partial discharge,C_2H_2 indicates arcing ,Content of C_2H_4 and C_2H_6 indicates decomposition of oil (Kitone formation).

ii) The DGA shows high temperature arcing problem of the transformer . Some part of oil is also decomposed. Need proper internal inspection of the transformer, whether internal condition of winding insulation is o.k or not .

iv)Comments :

i)During DGA , if the content of C_2H_2 is low, we recommend proper filtration of oil.

ii) If content of C_2H_2 is high then proper internal inspection of insulation is required .

V.TAN DELTA TEST :

Fig 3: Tan Delta kit

Tan delta test indicates the dielectric strength , dielectric loss and the moisture content of the solid and liquid insulation. Delta is the angle between ideal capacitive current and lossy capacitive current. Fig 3 shows the picture of the Tan delta kit used for our work. TABLE-III and TABLE-IV shows the test results.

.i)Limit of Tan Delta Values:

For good transformer ==< 0.5%

Acceptable ==0.5%-2.0%

Unacceptable ==2.0%

ii)Case Study :

Site : Rourkella ,NSPCL , January 2016.Results shown on a 138/11.5 KV Transformer , 16.5/33/82.5 MVA ,Ynd11 , Sr. No. 24539.

TABLE-III: Tan Delta measurement of the winding :

Test Condition	Voltage(KV)	% Tan Delta	Capacitance(Pf)
HV-LV+Gnd(GST)	10	0.415	11433.48
LV-Gnd (GSTg)	5	1.187	15325.46
HV-Gnd(GSTg)	10	0.401	4133.06
HV-LV(UST)	10	0.402	7301.83

UST means Ungrounded specimen test . GST means Grounded specimen test .
GSTg means Grounded Specimen test with guard .

TABLE-IV:Tan Delta measurement of the Bushing :

Bushing	Voltage(KV)	% Tan Delta	Capacitance(Pf)
1U	10	0.48	252.25
1V	10	0.60	254.53
1W	10	0.36	256.34

iii)Diagnosis :

1)Tan Delta value of LV-Gnd indicates wet insulations .

2) Tan Delta value of HV bushing (1V)slightly exceeds the limits .

iv)Recommendations :

Although tan delta values are in acceptable limit , it has been seen tan delta value of LV winding is high. So, drying out of transformer , cleaning of HV bushings are suggested. Tan delta should be measured in mid day. If it is measured in morning or evening ,it may give erroneous results due to moisture content in the air .

VI. SFRA (SWEEP FREQUENCY RESPONSE ANALYSIS) TEST :

It assesses the structural health of core and winding. It indicates the response of transformer winding to variable supply frequency. Original SFRA result of newly made transformer should be provided by the original equipment manufacturer (OEM). It will be compared with the transformer SFRA result at the time of condition monitoring.

i)Recommendations :

Fig 5 picture shows the distortion with original figure(Fig 4), indicates displacement of winding with respect to original place of core – coil assembly at first. It needs lifting of core coil assembly and refit .

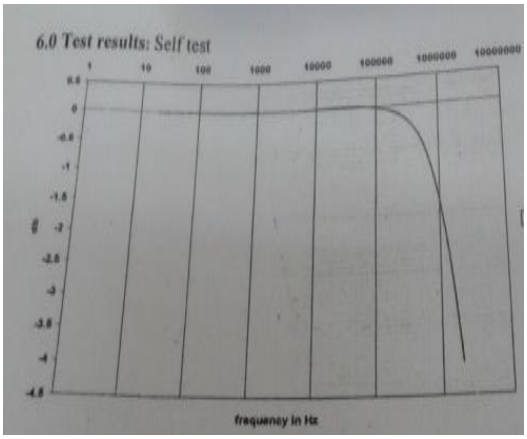

Fig 4: Frequency Response of newly made transformer

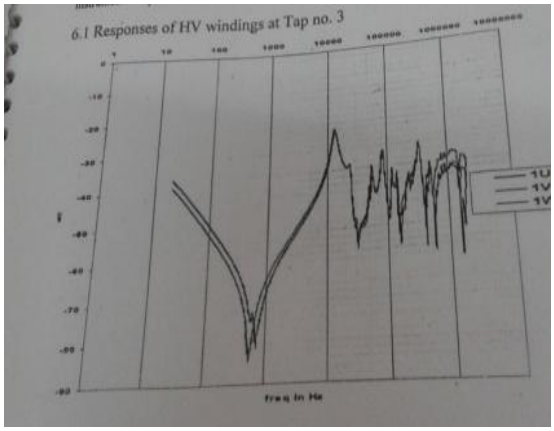

Fig 5: Frequency Response at the time of CM

VII.FURAN ANALYSIS :

Furan is derivative of an aromatic compound formed due to paper degradation. Derivatives of Furan soluble in oil are :Furaldehyde , Acetyl Furans, Methyl Furaldehyde , Furfuryl alchohol , Hydroxy Methyl Furaldehyde .

TABLE-V shows the Furan analysis test results.

i)Limit:

Acceptable : Total Furan < 100 ppb

Questionable : 100ppb < Total Furan < 250

ii)Case Study :

Site : Rourkella , NSPCL , January 2016.

Transformer Details : 138/11.5 KV ,16.5/33/82.5 MVA ,Sr. No. 24539 ., Ynd 11.

Test Report :TABLE-V

Analysis of Furanic Compounds	Obtained Value (ppb)
5-Hydroxymethyl-2-Furfural	ND
2-Furfuryl Alchohol	ND
2-Furfural	258.8
2-Acetyl Furan	ND
5-Methyl-2-Furfural	ND
Total Furan content in Oil	258.8

ND: Not Detected.

iii)Recommendations :

The transformer is having furan level 258.8 ppb , which indicates normal aging of transformer .

iv)Comments :

i)Furan concentration may mislead the result because of the history of the transformer .

ii)There are leakages on the transformer and oil was topped up for 3-4 times before actual test . So, furanic compounds are diluted .

VIII.DEGREE OF POLYMERISATION TEST :

It requires paper samples. Aging of paper leads to loss of tensile strength and reduced life of electrical equipments. Insulation is long chain of hydro-carbons . With respect to time , it will deteriorate. TABLE-VI shows degree of polymerization test results. Fig 6 shows degree

of polymerization vs transformer residual life assessment curve. In practice this curve should be provided by original equipment manufacturer (OEM).

i)Diagnosis :

New Kraft paper D.P – 1100 to 1500
After Factory drying D.P-800 to 1000 (Exceptional Decay) D.P at the end of life -150
D.P of partial rewinding – 250

ii)Case Study:

Site : Rourkella ,NSPCL, January 2016.Transformer Details : 138 /11.5 KVMVA Class : 16.5 /33 /82.5 MVA
Sr. No. 24539 Vector Group: Ynd11.

iii)Test Results :

The insulation paper samples were taken for measurement of D.P from various locations .The sample details and result as below :

TABLE –VI : DP Test results

Paper Samples taken from	D.P Value
HV lead ,top	650
HV lead,bottom	600
LV lead,center	563
LV lead ,bottom	576
LV lead , top	580
HV lead , Center	669

N.B: DP Values are based on the viscometric method .

Estimation of remaining life of transformer is as per the given table :TABLE-VII :Furan , DP and % life used

55^0C Rise Transformer (ppb)	Estimated degree of polymerization(DP)	Estimated percentage of Remaining life	Suggested Interpretations
58	800	100	Normal aging rate
130	700	90	Normal aging rate
292	600	79	Normal aging rate
654	500	66	Accelerated aging rate
1464	400	50	Accelerated aging rate
1720	380	46	Accelerated aging rate
2021	360	42	Accelerated aging rate
2374	340	38	Excessive aging danger
2789	320	33	Excessive aging danger
3277	300	29	Zone
3851	280	24	High risk of failure
4524	260	19	High risk of failure
5315	240	13	End of expected life of paper insulation and of the transformer
6245	220	7	End of expected life of paper insulation and of the transformer
7337	200	0	End of expected life of paper insulation and of the transformer

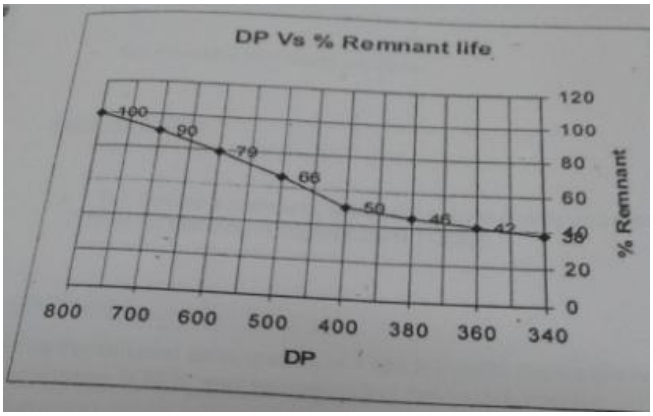

Fig 6: Degree of Polymerization vs Residual life

iv)Analysis of D.P results :

1)The furan level corresponds to 650D.P unit shows the remaining life of the transformer 80%(ref. Fig 6).
2) The average D.P value of thin insulation(paper) is 606 with minimum life consumption. The D.P value 606 ,shows normal aging of paper insulation
3)Average D.P 606 corresponds to remaining life near 79%.
4) The lowest DP value 563 ,corresponds to remnant life 72%.
5) The average DP value shows normal aging of solid insulation .
6) The discussed transformer contains significant moisture. It needs the proper drying under supervision of transformer original equipment manufacturer (OEM).

TABLE-VII describes degree of polymerisation and estimated remaining life percentage data.

v)Comments :

1)The Furan level corresponds to 650 D.P units shows the remaining life of transformer is 80% ,may be misleading due to job history .
2) Residual life assessment (RLA) does not predict a definite time of a transformer , rather it indicates an increasing probability of failure .

IX.PARTIAL DISCHARGE TEST :

Partial discharge means localised dielectric breakdown of a small portion of a solid /liquid electrical insulation system under HV stress . Normal range of partial discharge from a transformer is in terms of pico-coulomb .

X.SATURATION OF CORE TESTING FOR TURRET CT OF TRANSFORMER :

It is helpful for the determination of knee point and saturation point voltage of CT core.

XI. RADIO INFLUENCE VOLTAGE MEASUREMENT :

Localized breakdown of insulation(micro-volt) can be measured by RIV signal. It reconfirms poor tan delta value of insulation .

XII.INFRA-RED TEMPERATURE MEASUREMENT :

It is used for thermal imaging of hot spot and non-contact type localised temperature measurement .

XIII. GENERAL CAUTIONS :

Some general precautions regarding the condition monitoring of transformers are as follows :
1) Transformer should never be kept open, otherwise oil may get contaminated and oil BDV (Break down voltage) may fall down.
2) During Overhauling Low voltage AC test should be done first rather than DC test for more correct result .
3) Tan delta test should be done neither in very early morning nor in late evening or night. Otherwise the moisture content in the environment may affect the accuracy of the result. It is always suggested to do tan delta test in the mid-day.
4) Proper grounding of the instrument is required for carrying out any test .

5) **Capacitive voltage of transformer :** Voltage between Neutral and Earth . It has no relation with the actual health of the transformer. Sometimes it is referred as the floating voltage of transformer also.
6) During condition monitoring of the transformer some general tests also suggested to be done. E.g- Magnetic voltage balance test, Magnetic current balance test etc.

XIV . ADVANTAGES OF THE PROPOSED WORK :

During literature survey, it is found that most of the work done previously are concentrating on a particular area on a transformer. E.g- [4] Concentrates only on mechanical part ; [5],[7],[8] concentrate on transformer insulation system ; [6],[14],[17] concentrates on transformer oil etc. But here we concentrated on all the aspects of condition monitoring of transformer. In previous works many practical aspects are missing . But in our work, we practically visited many sites for collecting data and all the tests are done on working transformers in a substation. Some general precautions are needed to be maintained for the accuracy of the test results. These general precautions can be known only if someone works in sites. We discussed all those minute details in our work.

XV . CONCLUSION

The main purpose of this survey paper can be summarized as follows :

This paper discusses the various condition monitoring approaches of transformer used in Industry with practical case studies . This paper gives a vivid idea about how the condition of a transformer can be assessed and how to improve its operation and as well as effective life span. Each method contains description as well as at least one practical case study with interpretations and comments. Several general precautions are also discussed which can affect the accuracy of the results. The advantages of the proposed work with previous work are also discussed before the conclusion.

As a future scope, it can be suggested to explore on the new condition monitoring techniques of transformers. e.g- Saturable pulse transformer (SPT) testing technique, high performance liquid chromatography technique etc .We hope this survey paper will definitely be helpful for Industry practitioners to maintain proper performance of transformer.

ACKNOWLEDGEMENT :

This survey gives a complete overview about health assessment and condition based monitoring of the transformer. It shows practical data and results with interpretations. This survey is prepared based on a number of site visits including Bhushan Power & Steel Ltd, Jharsuguda ; Grid Substation, BSEB ; HINDALCO, Belur ; TISCO, Jamshedpur ;W.B.S.E.T.C.L, Mahachhanda ; Damodar Ispat ,Nabagram ; PGCIL,Subhasgram,; NSPCL,Rourkella . Special thanks to Mr. P.Mukhopadhyay , Ex-Sr. Manager ,Crompton Greaves limited for his valuable guidances ,Co-operation and encouragement during our survey work .

NOMENCLATURE

CM – Condition Monitoring
BOCB – Bulk Oil Circuit Breaker
P.I- Polarization Index
DP- Degree of Polymerisation
ppm – Parts per Million
ppb-Parts per billion
SFRA- Sweep Frequency Response Analysis
BDV – Break Down Voltage
DGA- Dissolved Gas Analysis
RIV –Radio Influence Voltage
SPT- Saturable Pulse Transformer
TGC- Total Gas Combustible
Gnd- Ground
UST – Ungrounded Specimen Test
GST- Grounded Specimen Test
GSTg- Grounded Specimen Test with Guard
IR-Insulation Resistance
OEM- Original Equipment Manufacturer
BSEB-Bihar State Electricity Board
HINDALCO-Hindustan Aluminium Company
TISCO- TATA Iron and Steel Company
WBSETCL- West Bengal State Electricity Transmission Company Limited
PGCIL- Power Grid Corporation of India Limited
NSPCL- NTPC-SAIL Power Company Private Limited.

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Saptarshi Roy: Received the B.E degree in Electrical Engineering from Jadavpur University, West Bengal, India in 2009. Received M.Tech degree from NIT WARANGAL in 2014. Currently he is pursuing PhD in Electrical Engineering in the department of Electrical Engineering, National Institute of Technology, Warangal, India. His areas of interest are power system protection, Phasor Measurement Unit applications in power systems, Synchrophasors applications in power systems. He has published more than 15 research papers in National, International conferences and Journals. He is a regular reviewer of IEEE systems Journal .

Dr. Suresh Babu Perli: Currently he is working as an Assistant Professor in Department Of Electrical Engineering, National Institute of Technology, Warangal. His areas of interest are Power System Protection with digital multifunction relays, Development of Adaptive protection schemes and Digital filtering algorithms.