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SARI / Energy

Training Module

on

Instrument Transformers

CONDITION BASED MAINTANANCE OF INSTRUMENT TRANSFORMERS

INTRODUCTION

- Instrument transformers play vital role in power system and their operational reliability is very important.
- There are frequent cases of **catastrophic** failure of Instrument Transformers.
- Explosive failure may cause damages to adjoining equipments causing considerable loss of asset & injuries (sometimes fatal) to the personnel.
- Failure of ITs leads to malfunctioning of system protection, controls, instrumentation and costly power outage.

Explosive failure is caused as the result of sudden pressure and heat developed due to huge arc formation, burning and vaporisation of oil/paper in small confined space.

INTRODUCTION

Large population of equipments commissioned during last 2 to 3 decades are ageing out which is cause of concern as the failure of aged CTs is not predictable.

-Looking at the consequences of failure, the focus has now changed from Conventional Maintenance to Condition Based Monitoring.

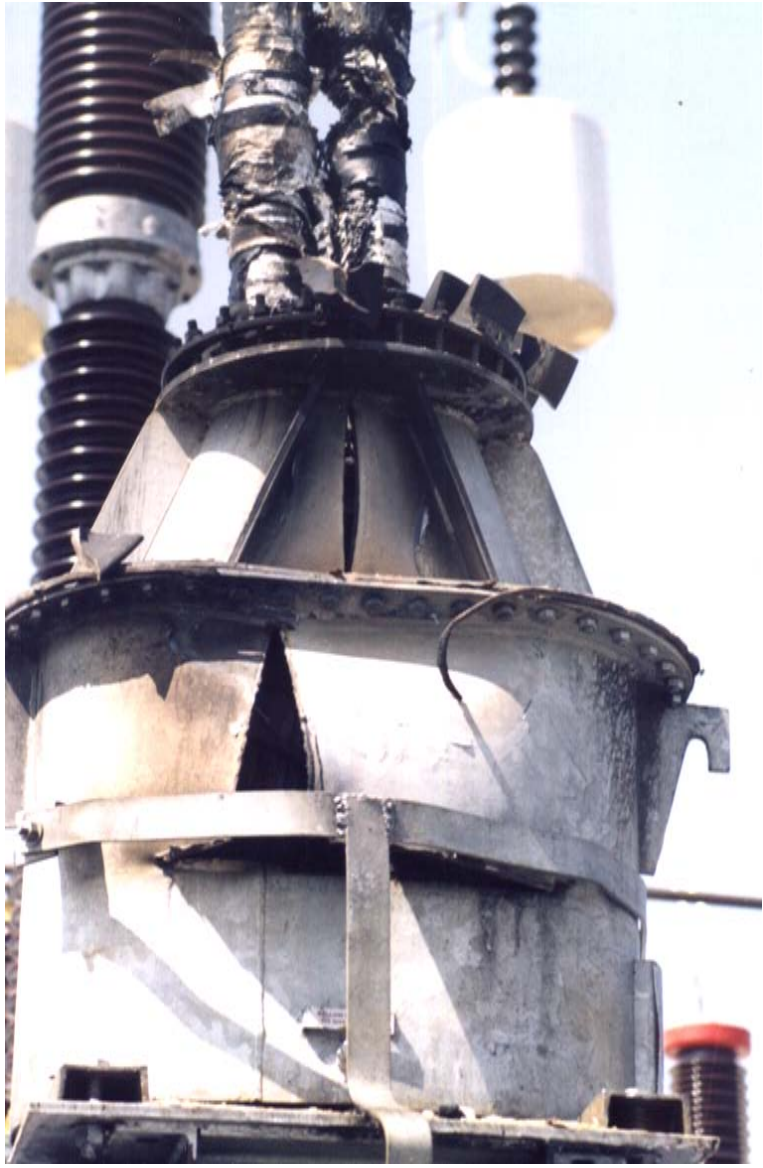
BATHTUB CURVE



Figure 1: Bathtub curve.

- The curve is a general representation of failure pattern of electrical equipments from the initial years of commissioning to the end of operating life.
- Failure during first few years are usually due to manufacturing defects,transit damages,installation problems,leakages etc as explained in detail ahead.
- Random failure mode includes failures due to service condition,system switching surges,lightening impulses,ineffective maintenance etc.The rate of failure during this period is quite low.
- Wearout failures includes natural aging process resulting into dielectric degradation. Failures during this period are sudden and unpredictable.
- The failure rate during this period is quite high.This period as experienced by utilities starts after two decades.

CATASTROPHIC FAILURE



Failure



Pressure buildup in metallic bellow





HV creepage inside the insulator



Factors responsible for failure

- -Life of IT is expected to be more than 20 years.
- -Early failures due to manufacturing defects are low compared to aged out transformers.
- - Failure of aged out transformers is often sudden and catastrophic.
- -Level of deterioration in such equipments has to be properly diagnosed and timely action be taken.
- Following factors are some of the main causes responsible for degradation of insulation.

Factors responsible for failure

Manufacturing defects –

- Residual Moisture-inadequate drying of insulation
- Over stressing- electrical stress
- Partial Discharges
- Dielectric loss –overheating of insulation
- Selection of R.M.
- Improper insulation design
- Overheating due to I^2R loss in primary
- Poor quality control
- Poor hermetic sealing
 - moisture ingress
 - air ingress

Factors responsible for failure

Service Condition

- Mishandling and damage during transit/installation
- Contacts of terminal connectors
- Unattended leakages-moisture ingress
- Leakage of N₂ gas
- Leakages through pressure release device aging out
- Old installation, frequent interruption / over-currents
- Lightening and switching surges
- Ferroresonance
- Polluted atmosphere
- Poor maintenance program

FACTORS RESPONSIBLE FOR FAILURE

Natural Ageing

-Stresses like dielectric, electromechanical, thermal, mechanical and chemical are continuously acting on paper and oil insulation.

-The stresses cause the natural aging process of degradation of insulation.

-THE EFFECT OF ABOVE FACTORS ON INSULATION SYSTEM IS EXPLAINED IN DETAIL AS FOLLOWS.

DEGRADATION PROCESS OF INSULATION

- Oil impregnated paper (OIP) is standard and proven insulation system used in design of HV equipments.
- The combination has much more better insulation strength.
- Insulation paper is made from cellulose fibre.
- Paper is very hygroscopic by nature & readily absorbs moisture from the surrounding.
- Aging is influenced by degradation of cellulose and oil as the result of different stresses and accelerate in presence of oxygen and moisture.

DEGRADATION PROCESS OF INSULATION

- Thermal degradation causes oxidation & reduces strength of paper (degree of polymerization).
- It produces mainly H₂, CO₂, CO, Methane (CH₄), H₂O, acids and sludge.
- Water formed acts as catalyst to accelerate further degradation
- Oxygen mainly affects the oil causing oxidation

DEGRADATION PROCESS OF INSULATION

Effects -

- Production of components like H₂, CO₂, CO, methane, H₂O, sludge and acids
- Reduces tensile strength of paper (degree of polymerization)
- Affects resistivity & insulation properties of oil & paper
- Increases tan delta, which in turn increases dielectric heating
- Tan delta of 0.5% produces 20 watts in 245 kV insulation & 100 watts in 420 kV CT insulation as dielectric loss (heat **loss**)

DEGRADATION PROCESS OF INSULATION

- With low dissipation rate of heat, there may be thermal breakdown of insulation.
- Thus, it can be seen that presence of moisture and O₂ can cause speedy degradation of insulation.
- A poorly dried transformer with higher moisture content and gas (particularly O₂) drastically reduces life expectancy.
- A well-dried but leaking transformer can easily absorb moisture & O₂ from atmosphere.
- Initial moisture and O₂ causes early degradation reducing life expectancy.

MOISTURE TRANSITION BETWEEN OIL & PAPER INSULATION

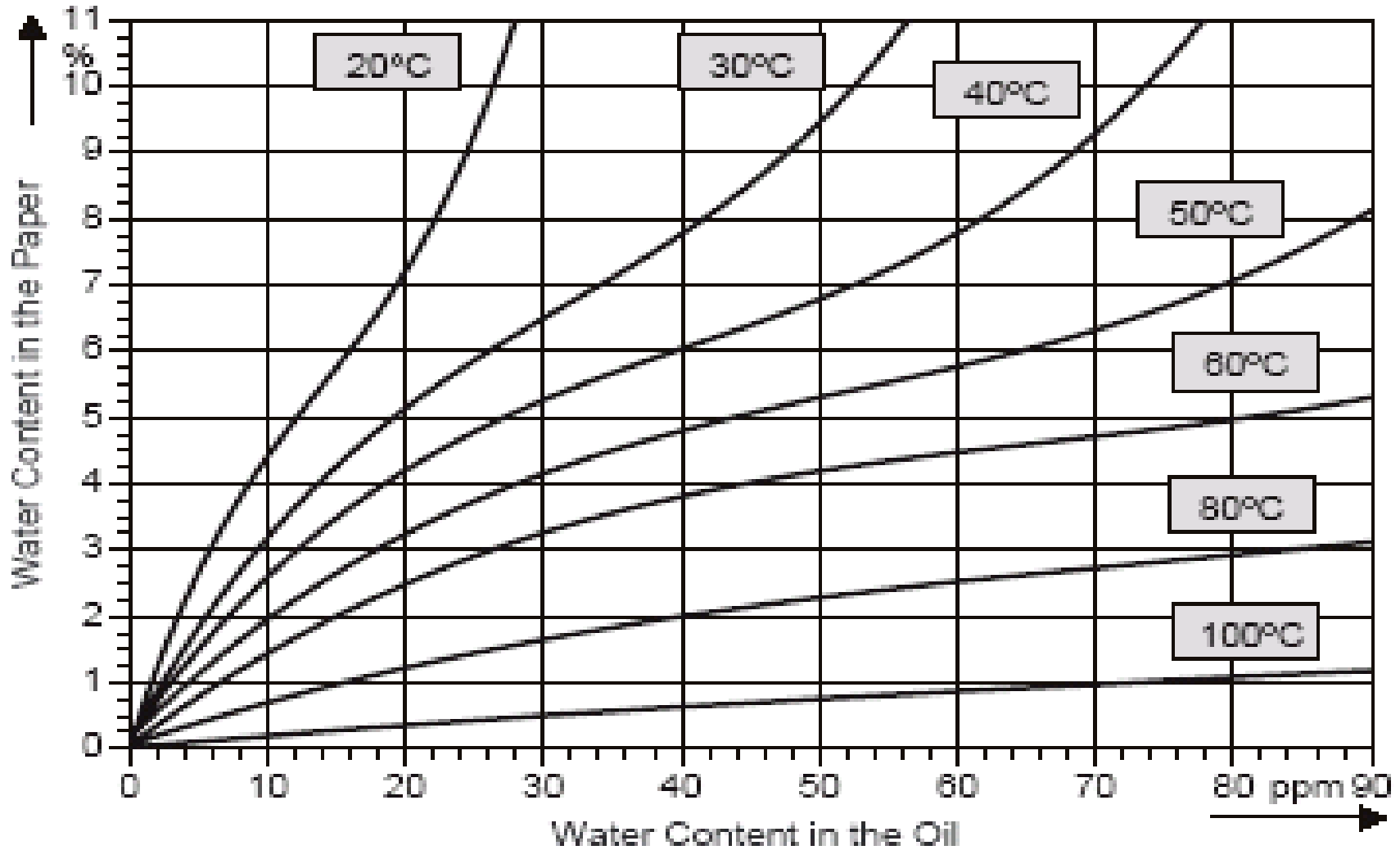
- Moisture present in CT is absorbed by paper and oil in a proportion depending on temperature
- There is always equilibrium between moisture in cellulose of paper and oil in an insulation system at any given constant temperature.
- With change in temp, the equilibrium is disturbed and transition of moisture takes place between oil & paper.
- At higher temperature, the water absorption in oil increases and that of paper reduces

MOISTURE TRANSITION —cont.

- As temperature reduces moisture migrates from oil to paper.
- It is also established that oil to paper migration is faster than that from paper to oil
- During sunny days with higher loads, temp is high and migration of water takes place from paper to oil
- During cool nights the reverse takes place & moisture migrates from oil to paper
- With high variations in the temperature the concentration of the moisture in any of the media may become critical and break down may take place.



Moisture equilibrium in OIP insulation



MOISTURE TRANSITION contd....

Illustration from the experimental graph.

- At 60°C with moisture of 20 ppm in oil, the paper contains 2.5% moisture by weight
- At 20°C with moisture of 20 ppm in oil, the paper contains 7% of moisture by weight.
- The paper with higher percentage of total moisture present in CT may cause reduction of dielectric strength significantly and leads to insulation breakdown.
- Above experimental finding supports the failure pattern of ITs during cool nights of hot summers in India.

MOISTURE TRANSITION –cont.

Thus, it is important to observe following:

- In new transformers, the paper and oil must be perfectly dried to minimise the initial moisture content. (preferably 5 ppm in oil and max 0.5% in paper.) The moisture accelerates the degradation process during initial years.
- It should be noted that ITs are minimum oil equipment and oil is not changed during its lifetime.
- Transformer must be hermetically sealed preferably with metallic bellows.
- If nitrogen cushioned sealing is provided, the required pressure should be monitored and maintained during operating life.
- Leakages must be attended immediately.
- With above precautions, the risk of absorption of external moisture will be minimum.

DIAGNOSTIC TESTS AND CONDITION MONITORING

- Condition monitoring may be defined as a process of monitoring the characteristics of operation of equipment and find out the changes and trends of the characteristics of the insulation system which can be used to predict the need for maintenance before serious deterioration occurs.
- Thus it determines the health of the equipment and routine maintenance can be rescheduled as required. This reduces the unnecessary cost of maintenance.

To assess the condition of insulation, diagnostic tests as detailed below can be performed.

- Electrical Diagnostic Tests
 - Test for Insulation Resistance
 - Polarization Index
 - Tan Delta and Capacitance Measurement
 - Resistivity, $\tan\delta$ and BDV of oil
 - Partial Discharge Test on site
- Chemical Analysis
 - (A) -Test for Water content
 - Dissolved Gas Analysis (DGA)
 - IFT
 - (B) -Degree of Polymerization (DP)
 - Furan Analysis
- Other Tests and Inspection
 - Infrared Thermograph
 - Visual inspection for leaks, polluted insulators, corona discharges.

- Insulation Resistance Test

- Initial screening test for equipments.
- To use high range 1000,000 m Ω , 5 to 10 kV IR tester
- Test during fair weather condition.
- Frequency of test may be high for better results.
- Gives initial warning to engineers to decide further investigation.
- Normally useful for medium and low voltage trans upto 72.5 kV.

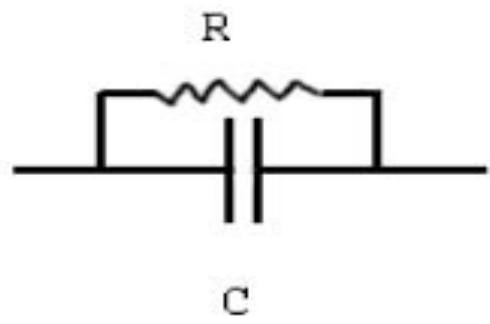
Polarization Index

- Ratio of IR values at end of 600 seconds and 60 seconds.
- Possible only with high range meggar.
- Value of 1.3 to 2.0 indicates good insulation for instrument transformers.

Tan δ and capacitance Test

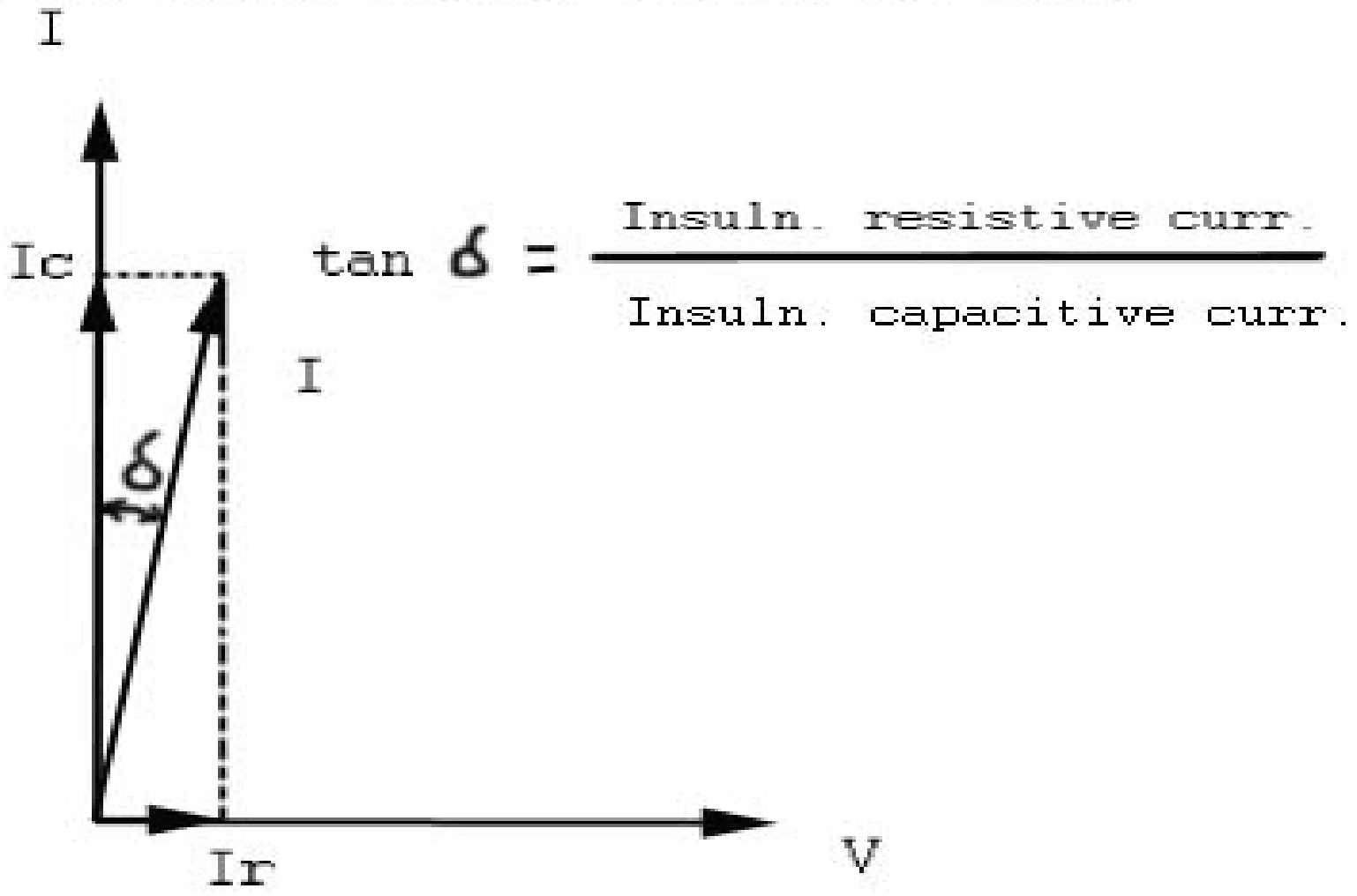
- One of the best diagnostic test to monitor insulation condition.
- Concept of $\tan\delta$ can be explained by considering insulation as capacitor.
- An ideal capacitor carries only capacitive current (I_c) which leads the voltage by 90° .
- But actual capacitor formed by transformer insulation conducts resistive current (I_r) due to moisture and impurities. The angle between I_r and voltage is less than 90° .

Fig A) Effective circuit of insulation



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Fig B) The Vector diagram showing Tan Delta



Tan-delta rest

Higher $\tan\delta$ indicates degraded insulation.

- Comparison between periodic measurements reveal trend in deterioration of insulation.
- Increase in $\tan\delta$ may be due to Moisture, contaminated oil, internal PDs etc.
- Rise in $\tan\delta$ with rise in voltage indicates high moisture /deterioration and steeper rise indicates major defects.
- Higher $\tan\delta$ increase dielectric losses producing losses and heat, thus causing more degradation.
- Normal value for new CTs can be 0.15 % to 0.4%

Tan-delta test --cont..

- Old equipment with more than 0.8% should be closely monitored.
- Higher $\tan\delta$ produces higher dielectric loss and if paper-oil insulation do not dissipate the heat it will lead to thermal breakdown.

Partial Discharge Test at Site

- More advanced site test—off line or online.
- Direct online method receives signals from PF terminal of CT.
- Signals are mixed with unwanted external discharges.
- Special filters and microprocessor base instruments for separating internal discharges from external.
- Identifies fault in insulation.

Resistivity, $\tan \delta$ and BDV ,IFT,Acid Number of oil

Tan-delta increase indicates oxidation,contamination and suspended water particals.

Low BDV indicates moisture, contamination due to oxidation.

Low resistivity indicates presence of suspended water, acidic oxidation etc.

-Decrease in Resistivity with increase in $\tan \delta$ indicates soluble contaminants and aging.

-Satisfactory resistivity at 90° compared with low resistivity at ambient temperature indicates moisire.

IFT detects contaminants and oxidation products in insulating oils.



CHEMICAL ANALYSIS TESTS (expln)

- Water Content Test
 - water content in oil should be less than 10 ppm, target to be 5ppm.
 - High content results into lower BDV and higher $\tan \delta$ and conductivity.
 - Moisture in oil may provide some information about moisture content in paper insulation, but it may not be always true. Temperature at which samples taken is important.(expl)
 - This test in addition to DGA and Furan can give more reliable information about insulation condition.

- Dissolved Gas Analysis (DGA)
 - Detection of incipient faults in equipment.
 - Incipient faults cause PDs, Corona, & Arching and generates heat with very high range of temperatures in affected section.
 - Oil and cellulose insulation decomposes and produces different gases at different temperatures.
 - Significant gases due to oil decomposition are H₂, methane (CH₄), ethane (C₂H₆), ethylene (C₂H₄) and acetylene (C₂H₂).
 - CO₂, CO and O₂ are produced as the result of degradation of cellulose during aging process and due to hotspot in insulation. ■

Dissolve Gas Analysis -- cont

- IEC 60599, IEEE C. 57.104 and other standards provides method to establish nature of faults on basis of gasses generated.
- By taking periodic tests, trend in degradation of insulation can be determined.
- In hermetically sealed ITs, the oil movement is very slow and the dissolve gas may move to sample collection point after several days. Hence the test results may not give the status of present insulation condition.



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Degree of Polymerization Measurement

(IEC 450) DP

- Determines thermal aging of solid cellulose insulation.
- Quality of cellulose is measured in DP.
- Measures indicate tensile strength of paper.
- New Kraft paper has DP = 1000 to 1500.
- With long service DP maybe = 200 to 250.
- DP value of 150 to 200 indicates mechanical strength of only 20% of initial strength and is considered to be the end of insulation life.
- Most accurate test, but sample of paper must be obtained which is impossible for IT.
- Use to verify remaining life of the equipment.
- May be performed to establish cause of failure in failed equipments.

Furan Analysis

- Furans form as degradation product of solid insulation and are soluble in oil.
- Furan analysis is performed by drawing sample from oil from operating transformer.
- Easy test as compared to DP test as transformer is not required to be opened.
- Interpretation of results are not as reliable as DP.
- No universal correlation established between DP and Furan yet.
- Furan analysis, DGA Test & DP Test combined offers very reliable conclusion.



MAINTENANCE PROGRAM

A simple program may be devised for condition monitoring by users as under:

1. Regular measurement of IR, PI, $\text{Tan}\delta$, and capacitance be made at suitable intervals in fair dry weather and recorded. Their correlation can be determined.
2. The variations from each periodical test be recorded in a computerized database and the trend of deterioration determined.
3. If the trend is indicative of progressive deterioration, then oil sample should be drawn for Moisture content, IFT, Acid numbers, DGA and Furan test.
4. If oil tests confirm the deterioration, the instrument transformer should be removed from services as early as possible to avoid catastrophic failure.

Maintenance program— cont.

- For small and medium voltage equipments where population is in thousands, IR, PI, $\text{Tan}\delta$ tests may be taken as indicator to replace them.
- The transformer up to 145 kV may be sent for recondition to departmental workshop. The transformers of 245 kV and above should be sent for further investigations to manufacturer of instrument transformers where Partial Discharge test can be performed. The transformer may be re-processed only if there is reasonable remaining life left.
- For 420 kV class transformers, where population is not high comparatively, should be regularly tested on-site for Moisture, DGA and Furan along with electrical tests listed in step 1.

ONLINE CONDITION MONITORING

As a result of compelling need felt by many utilities, **online** monitoring systems have been developed for transformers in more advanced countries to avoid unexpected failures. On-line monitoring of critical network assets provides information previously unavailable. This in turn allows better asset management. It is fast maturing into a serious and reliable network tool.

Normally dissipation factor and partial discharge tests are conducted on line using specially developed instruments. Technique of on-line monitoring of DGA and evolved gases is also developed, however it is mostly used for very costly equipments like power transformers presently.

ONLINE CONDITION MONITORING--cont

The key advantages are:

1. Relevant data collected and made visible on network.
2. Major help in delaying routine maintenance as long as possible hence driving down costs.
3. Costly and not easy to replace equipments are prime candidates for on-line monitoring.
4. Damage to the asset is minimized.
5. Equipment need not be taken out of service



INFRARED THERMOGRAPHY

- Infrared systems can measure temperature of exposed parts of equipment online.
- Can be used on routine basis by maintenance engineers.
- Infrared thermal imaging system is a technique involving infrared camera, software and computer.
- Camera senses infrared radiation from heated components of equipment in yard. A computer processes this information and displays the images of components with different colors depending upon the temperatures.
- By comparing the difference in similar parts in the equally loaded CTs in different phases, abnormally heated component is pointed out.
- Further investigation, corrective action is taken avoiding further damages.

CONCLUSIONS

- The degradation and subsequent failure of transformers is the result of aging of cellulose from paper insulation at elevated temperatures.
- Use of proper material and best manufacturing practice is the first step to minimize the degradation of insulation.
- However, for the instrument transformer to live its full life of 25-30 years, it is important to adopt efficient maintenance management by monitoring the condition of insulation at site by the user.

Conclusions

- In our country, very few utilities may be using some or all of the diagnostic techniques.
- Therefore, increased awareness and adoption of these essential techniques is highly desirable
- Effective condition-based maintenance practices for substation plant assets will result in reduced controllable operating costs and improved utility performance.
- **Proper investigations and analysis of failure of the equipments, carried out worldwide has resulted into improvement in electrical equipment design.**
- It has also revised systems and developed new equipments for health monitoring.

CONTD...

- Presently On-line monitoring is becoming main focus area for utilities mainly in developed countries to evolve new techniques for reliable operation of power equipments.
- It is highly desirable that the utilities and equipment manufacturers in our country have collaborative efforts in bringing together the resources in form of their experiences/data on failures, ideas, personnel, skill and fund to have common guidelines on the subject of condition monitoring.

THANK YOU

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