

# Transformer Condition Monitoring Practices with A Special Approach for Detection of Electric Arcs

## Introduction

Transformer is a high efficient static electrical device used for power transfer from one voltage level to the other and plays the vital role in electrical transmission and distribution system. From the day of this equipment in service, different stresses like electrical, mechanical, chemical, and environmental factors affect the condition of the transformer. At the initial stage, degradation of insulation quality occurs slowly. But this deterioration multiplies in due course of time and leads to final failure of the transformer. So, to overcome this situation, continuous monitoring of the condition and preventive measures is required for correct maintenance of the transformer.

The faults like partial discharge, electrical arcs, or hot spots generally deteriorate the condition of transformer in quick progression. Hence early detection of these faults is very important for saving transformer from any catastrophic failure. Basic theories of the deterioration of insulation due to these heat-generated faults are described below.

For the reasons like abnormal loading, imperfect/faulty design or environmental conditions on the transformer, the temperature of windings, core and insulations rises and results the faults like partial discharge, electric arc and hot spots. Now, because of this temperature rise and presence of oxygen in the insulations (both oil and solid insulations), the oxidation process is developed. The oxidation process is developed. The oxidation of oil results in the formation of oxidation products (alcohols, aldehydes, acids, esters). The solid matters that formed by oxidation and condensation of polymerization of oil are called sludge. This sludge is usually deposited on the paper insulation and closes the pores on it. Hence, the cooling of windings by oil is affected which hampers the performance of the equipment<sup>1,2</sup>.

Similarly the presence of oxygen and acid in the solid insulation (Cellulose) also results the oxidation leads to the formation of carbon dioxide, carbon monoxide, water and the other products.

Solid insulation (heat) free glucose molecules, H<sub>2</sub>O, CO<sub>2</sub>, CO cellulose with reduced chain, 2 furans.

These products being dissolved in oil, deteriorate the condition of insulation in turn the performance of transformer. From the above discussion it concludes that primitive and effective condition are required for transformer.

## Environmental Conditions

These conditions are described with following factors.

- System voltage, frequency,
- Short circuit forces,
- Over fluxing,
- % Impedance,
- Harmonics,
- Inrush current,
- Abnormal operational condition,
- Losses.

## Benefits of Condition Monitoring

- Timely field measurement.
- Confirmation of the presence of fault.
- In time proactive decisions.
- Reduction of unplanned outage.
- Predictable and reliable maintenance schedule.
- Prevention of catastrophic failure and destruction of peripheral equipment.
- Reduction of maintenance cost.
- Provision of obtaining quality control features.
- Increment of the system stability.

- Minimises the severity of any damage and eliminates consequential repairs
- Increase safe working environment.
- Information for future plan, regarding up rating, and refurbishment of equipment.
- Use of equipment for maximum economical efficiency.
- Managers and extends the life of equipment with efficient and cost effective maintenance

### Methods Used For Condition Monitoring<sup>2, 4,5</sup>

Initial days, the population of transformers and traffic of the transmission lines were very less. So, complexities in the electrical environments were also within the limit of control. But recent days, the interconnection complexity of transformer lines, and need of key transformers to the system are

<b>Methods Used for Condition Monitoring</b>			
<b>Methods/Techniques/ Tests</b>	<b>Procedures</b>	<b>Condition Monitoring Involvement</b>	<b>Convenience</b>
1.IR measurement and PI value	Application of DC voltage from the instrument (Megger) and comparative study of IR values at different time (15 sec 60 sec, 600 sec) gives rise the idea of the insulation.	Condition of the insulation (Oil and solid)	1. Easy procedure. 2. OFF line. 3.Indecisive for fault location but provides condition assessment 4.Routine/ investigation
2.Capacitance and tanδ measurement	By the use of Schering bridge technique and other available methods, the capacitance of dielectric materials and associated factors (Dissipation factor, Tanδ factor) are calculated.	Condition of the insulation (Oil and solid)	1. Easy procedure. 2. OFF line / On line. 3. Indecisive for fault location but provides condition assessment 4. Routine/ investigation
3.Low voltage injection tests (Voltage Ratio, Voltage Balance, Excite current, SC current etc)	Supply of Low voltage to one side of transformer and measurement of different electrical parameters on open condition and short condition, gives rise the idea for diagnosis.	Overall conditions of Transformer core and winding	1. Easy procedure. 2. Offline 3. Partial decisive for fault location 4. Routine / Fundamental Investigation
4.Dissolve Gas Analysis	Because of the insulation decomposition, different characteristic gasses evolve and dissolve in oil. The concentrations of these gases are regarded as the primary diagnosis for obtaining the condition of the insulation as well as the diagnosis of fault.	1. Condition of insulation 2. Primary diagnosis of fault.	1. Easy procedure. 2. Offline 3. Partial decisive for fault location 4. Routine/ Investigation.
5.Laboratory Testing of In-service Oil (Water content, Acidity, Inhabitation content, Interfacial tension, Flash point, Pour Point, Viscosity, Dielectric strength, sp. resistance	According to the IS Methods, Oil tests are conducted to obtain different electrical, physical and chemical properties for comparison of the same with the standard values.	Condition of Transformer oil.	1. Simple procedure 2. Off line 3.Indecisive for fault location but primary detection of faulty portion. 4. Routine
6.Turns Ratio Test	By the use of reference transformer, the testing transformer turns are compared. The ratio meter has null detector. According to the voltage excitation and current through the windings of the transformers, adjustments are tried to obtain null deflection for turn's ratio. Now a days digital ratio meters are also available for finding the ratio	1. Condition of windings 2.Condition of Tap Positions.	1. Simple procedure 2. Off line 3.Indecisive for fault location but primary detection of faulty portion. 4. Routine/Primary Investigation

Winding Resistance Measurement	Basic method is voltmeter ammeter principle. Some cases Kelvin's double bridge principle is also used for finding the DC resistance of the winding.	1. Condition of windings 2. Condition of Tap Positions.	Same as above Testing No. 6 (Turns Ratio Test) as above
Partial discharge measurement	1. Electrical detection method – By the application of Power frequency voltage, called PDIV (Partial Discharge Inception Voltage), certain charge is allowed to develop, across the insulations. Then the developed charge is discharged by decreasing the voltage called PDEV (Partial Discharge Extinction Voltage). According to the pattern of PDIV and PDEV; the status of insulation is determined. 2. Acoustic Method – Because of the fault in the transformer, the solid insulation parts being heated, produce acoustic waves. By this method the sensors that fixed on the inner wall of the transformer, receive the signals for analysis of the fault by computing machines.	Condition of Insulation (Solid)	1. Easy/Simple procedure 2. Off line 3. Acoustic method is decisive for fault location 4. Investigation
Polarization spectrum technique / Recovery voltage measurement (RVM)	It is similar to PD Electrical detection method. But charging and discharging of the insulations are done for a certain pre-determined time. According to the recovery voltage that obtained during discharge condition, the status of insulation is determined.	Moisture Trend analysis of winding and paper insulation.	1. Expensive 2. Offline 3. Indecisive for fault location but primary detection of faulty portion. 4. Investigation
FRA (frequency Response Analysis)	By the use of standard spectrum analyzer, sweep frequency sinusoidal source of approx. 2V RMS is applied across the winding terminals. For different range of frequency, the impedance is measured. The curve (Impedances versus frequency) becomes indicative to know the status of the winding. The other curves for voltage ratio versus frequency are also used.	1. Mechanical displacement of winding. 2. Dynamic response of winding.	1. Expensive 2. Offline and disconnection required 3. Partially decisive for fault location 4. Investigation
DP measurement	By this method DP (Degree of Polymerization) value is counted for determination of the status of solid insulation and accordingly the assessment of residual life of transformer. Note: 1. D.P. Value: - It is average number of glucose rings in cellulose molecule. 2. D.P. value for new paper 1000-1400	1. Condition of Solid Insulation. 2. Residual life assessment.	1. Expensive 2. Offline 3. Indecisive for fault location but only assess the condition of the insulation. 4. Routine.
ARY-MAP Analysis	The graphic representation of the amount of (CO + CO <sub>2</sub> ) gas versus the service period transformer represents the degree of ageing of insulation.	1. Condition of Solid Insulation. 2. Residual life assessment.	1. Expensive 2. Offline 3. Indecisive for fault location 4. Routine.
FFA (Furfuraldehyde Analysis)	By HPLC (High Performance Liquid Chromatography), furan compounds are detected and according to the concentration and rate of generation of 2-furfural, the assessing of condition and remaining life of paper of insulation are obtained.	1. Condition of Solid Insulation. 2. Residual life assessment.	1. Easy and Simple 2. Off line 3. Indecisive for fault location but only assess the condition of the insulation. 4. Routine.

Growing fast. So condition monitoring of the transformer and diagnosis of the monitoring data are becoming the essential need for the equipment. Some of the recently used conditions monitoring techniques and new emerging techniques have been explained below.

### Special Method of Condition – Monitoring<sup>3, 6</sup>

#### Sensor Signal conditioning (SSC)

For this conditioning method following type of sensors are used inside the transformer

- Acoustic sensors/ Piezo-electric transducers.
- Infrared Receivers
- Special sensitive microphones
- Radio wave Receivers

The signals produced by the source (Faulty area) are very weak and required amplifications. So these signals being received by the sensors are amplified and processed in the conditioning unit. Then the processed signals are applied to the measuring device.

Measuring device is a microprocessor unit, which contains Data Acquisition Module (DAM), Data Processor Unit (DPU) and other units (communication system, interface system, input/output module etc). Now the signals from the conditioning units are accepted and converted to suitable Database by the Data Acquisition module. The data are then sampled and processed by processor Unit of detection/analysis of the fault by a PC. This device has also the facility for storing; transfer or display of the data for further comparison analysis.

Here in Fig 1.

- 1, 2, 3, 4: Different sensors for receiving the signals
- 5: Signal Conditioner
- 6: DMA (Data Acquisition Module)
- 7: DPU (Data Processor Unit)
- 8: Display Unit
- 9: Communication Module
- 10: Input/Output Device and Interface Unit.

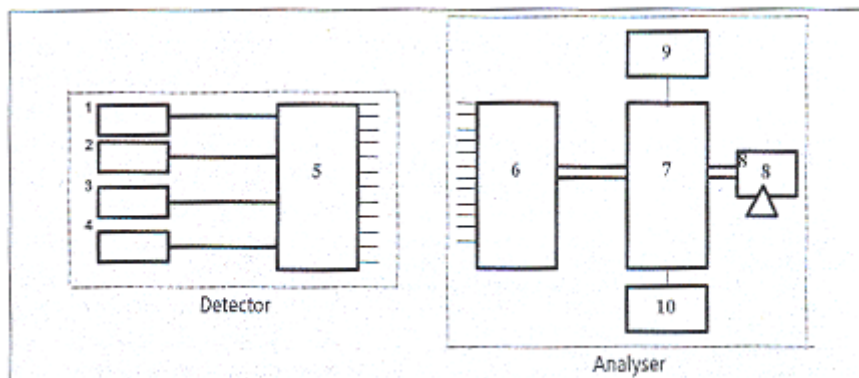


Fig 1

#### - Detector

This unit is placed inside the transformer, which contains the sensor and conditioning unit. Number of detectors is usually spread at different places inside the equipment to collect the signals from the faults generated portion.

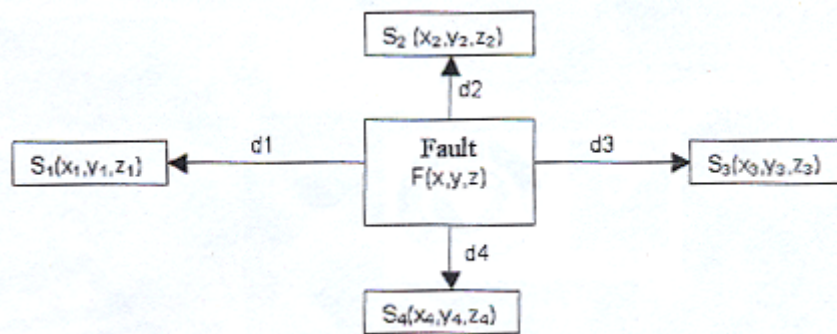
#### Analyzer

This unit is placed outside the transformer, which contains DAM, DPU and other accessories as described earlier, for correct analysis of the data.

#### - Principle of fault location

From a reference point, the fault location is calculated by considering the fundamental theories of coordinate geometry. In this proposed method, the detectors are placed at different points, whose coordinates are known. Say points are  $S_1 (X_1, Y_1, Z_1)$ ,  $S_2 (X_2, Y_2, Z_2)$ ,  $S_3 (X_3, Y_3, Z_3)$ ,  $S_4 (X_4, Y_4, Z_4)$ .

Whenever any fault occurs, the radiated waves are propagated and received by the sensors. The quantum of signals and the time required for reaching of the signals from faulty portion to the sensors, depend upon the distance of placement of the sensors from the fault.



The assessment of the fault is determined by the magnitude/quantum of signals received by the sensors. But the location of fault is determined by taking the time intervals of reaching the waves among the sensors.

Example: Consider the figure shown below:

According to the co-ordinate geometry:

Similarly

$D_{23} =$

$$\sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} - \sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2}$$

Similarly

$d_{23} =$

$$\sqrt{(x-x_2)^2 + (y-y_2)^2 + (z-z_2)^2} - \sqrt{(x-x_3)^2 + (y-y_3)^2 + (z-z_3)^2}$$

$d_{34}$ ,  $d_{41}$  etc.... can accordingly be computed.

Where

$d_{12}$  = Difference in distance between sensor No.1 and No. 2 =  $(d_1 \sim d_2)$ .

$d_{23}$  = Difference in distance between sensor No.2 and No. 3 =  $(d_2 \sim d_3)$ .

$d_{34}$  = Difference in distance between sensor No.3 and No. 4 =  $(d_3 \sim d_4)$ .

$d_{41}$  = Difference in distance between sensor No.4 and No. 1 =  $(d_4 \sim d_1)$ .

Now the difference in the time interval of reaching of the waves can also be measured as follows:

$T_{12} = (t_1 \sim t_2)$  = Difference in the time interval between sensor No. 1 and No. 2.

$T_{23} = (t_2 \sim t_3)$  = Difference in the time interval between sensor No. 2 and No. 3.

$T_{34} = (t_3 \sim t_4)$  = Difference in the time interval between sensor No. 3 and No. 4. etc.

Where,

$t_1$  = Time of reaching the signal from the fault to sensor No.1 (One).

$t_2$  = Time of reaching the signal from the fault to sensor No. 2 (Two).

$t_3$  = Time of reaching the signal from the fault to sensor No.3 (Three).

$t_4$  = Time of reaching the signal from the fault to sensor No.4 (Four).

Then  $d_{12} = v \times T_{12}$  .....Eq<sup>n</sup> (1).

$d_{23} = v \times T_{23}$  .....Eq<sup>n</sup> (2).

$d_{34} = v \times T_{34}$  .....Eq<sup>n</sup> (3).

Similarly for n Nos. of sensors the equation can be developed as follows:

$$d_{n1} = v \times T_{n1} \dots \dots \dots \text{Eq}^n$$

Note: v = Velocity of wave propagations.

For the solution of the above equations and sampling of the possible available data, necessary software can be used to obtain the location and other information about the fault.

### **\*Radiated Waves**

Every heating source is always accompanied with radiation of different waves. These waves are described in the form of light, sound and other electromagnetic waves. Basically acoustic emission, infrared and radio waves are generated whenever any electric arc results, the radiated energy in the form of light and sound becomes prominent along with other waves. The acoustic sensors, infrared receivers, radio wave receivers and special sensitive microphones are used for correct fault determination and location.

### **Conclusion**

The sensor signals conditioning method becomes helpful for the exact location of fault in the equipment. The faults associated with heat, are always dangerous as compared to any other faults. This method is the only successful one, which detects the fault quickly to avoid the failure of transformer.

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