Assessment of Transformer Fault Diagnosis and Condition Monitoring Methods

Nasir ul Islam Wani, Anupama Prakash, and Pallavi Choudekar

Abstract Power transformer provides an essential element for transmission and distribution of electrical energy. Such static devices are prone to many harsh conditions during their operation and hence has a maximum chance of deterioration. Since transformers are one of the costly equipment's of a transmission system, their failure can lead to huge losses. If transformers are regularly monitored their failure can be prevented. This results in efficient utilizations of resources. This paper incorporates various monitoring techniques which can be used for fault detection of transformers.

Keywords Condition monitoring · Power transformer · Faults

1 Introduction

Power transformers provide an essential element for the generation and distribution of electrical energy [1]. They form an important component of power system. Such static devices are subjected to harsh operating conditions and hence has a maximum chance of decline in their performance. Thus, their better performance implies high power system efficiency.

Transformer faults are classified as Internal and External faults [2]. Internal faults can be active or incipient in nature. Active faults are solid faults that appear on wending of transformer. It may be phase to phase or phase to ground. These faults lead to insulation breakdown. Incipient faults are thermal or electrical. The paper discusses various types of monitoring techniques for fault detection.

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The condition monitoring technique of power transformer has been translated into practice in the space of few years. It caters largely for diagnosis of internal faults in transformers caused due to aging and degradation [1]. The condition monitoring allows early identification of developing faults before any failure. Condition monitoring is aimed for not only the detection of fault at early state but also reduces the maintenance cost for transformer.

2 Condition Monitoring Techniques

2.1 Chemical Techniques

It involves Dissolve Gas Analysis and Partial Discharge Analysis.

2.1.1 Dissolve Gas Analysis

It is used to know the condition of an oil immersed transformer [2]. The concentration and production rate of the generated gases is used for various faults detection.

- Arcing fault can be detected by the analysis of H_2, C_2H_2 gases in the oil.
- Corona effect can be analyzed by monitoring the production of carbon monoxide in the transformer oil.
- Sparking can be detected by monitoring the level of methane in the transformer oil.

The Dissolve Gas Analysis is performed by carrying out the gas chromatography in the oil samples taken from the main oil stream to measure the concentration and production of various gases. The process of Dissolve Gas Analysis is shown in Fig. 1.

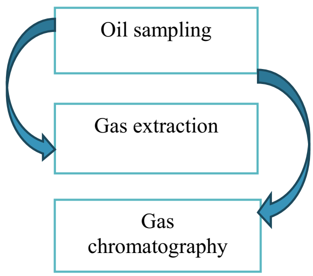


Fig. 1 Process of dissolve gas analysis

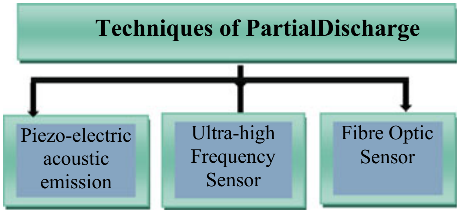


Fig. 2 Different techniques of partial discharge

2.1.2 Partial Discharge Analysis

Partial discharge analysis has evolved as a crucial, unobjectionable, quick and robust diagnostic utility and contains a substantial amount of insulation state statistics of power transformer [3]. All the Ultra-high frequency Partial discharge signals of different frequency band components are recorded and used for making the frequency matrix and then feasible signal region is developed using multidimensional energy parameter and multi dimension sample entropy parameters [4].

The techniques involved in partial discharge are (Fig. 2).

- Piezoelectric Acoustic Emission: In this, the acoustic sensors which converts discharge acoustic emission signal to electrical signal are placed on the experimental transformer tank. These sensors help in identifying source of Partial Discharge within the transformer.
- Ultra-high Frequency Sensor: Detection of any partial discharge activity is an indication of insulation defect. Once detected analysis of data is carried out to identify the type and location of defect.
- Fiber optic sensor: It can detect acoustic pressure and detect partial discharge in small voids and then transmit the information from high voltage equipment to monitoring equipment for analysis.

2.2 Electrical Techniques

It involves following methods.

2.2.1 Vibration Analysis

It is an effective method for detecting internal fault in transformers. There are different types of vibrations associated with transformers.

- Winding vibration: The electric forces that are caused due to interaction between circulating currents in winding and leakage flux associated to the winding. Such forces are generated both in axial and radial direction.
- Core vibration: These vibrations are caused by magneto restriction and magnetic forces. The magnetic force changes the dimension of objects.

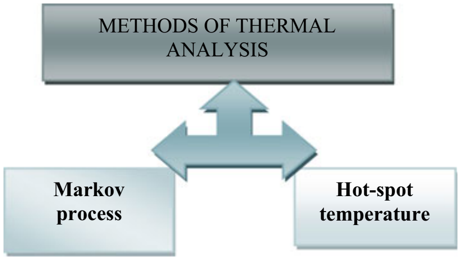


Fig. 3 Different methods of thermal analysis

The accelerometer is placed in the vicinity of transformer to capture these vibrations. The vibrations are converted into electrical signals [3]. The frequency spectrum is plotted and is compared with the reference spectrum for detection of any unusual vibration.

2.2.2 Thermal Analysis

Thermal analysis allows study of heat distribution in the transformer at different operating conditions [5]. It is seen that 80% of failures occur due to coil insulation break down which is as an outcome of hotspots in the winding. It has been established that an increase in the working temperature range of the transformer by 10 K decreases it average lifetime by 2.5% [6]. The thermal analysis is carried by following methods as in Fig. 3 are:

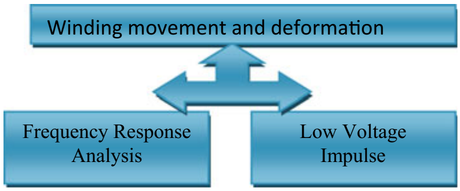
- Markov Process: This process forms a probabilistic approach where the transit plausibility can be determined from existing data base [7]. This method is thus used to optimize periodic inspection so that the cost is minimized, and availability of transformer is maximized.
- Hot-spot Temperature: Hot-spot temperature is one of the most important parameters when defining thermal condition and overloading capacity. The abnormal condition is detected by analyzing Hot-spot temperature [8]. In order to measure the hot-spot temperature, the thermal sensors is placed between the winding and is attached to the optical fiber. The signals are transmitted via optical fiber to the control center.

2.2.3 Winding Movement and Deformation

The transformer winding and deformation are mainly caused due to short circuit event caused in transformers. The high current interacts with leakage flux density and result in extreme force to act on winding ($F = L{*}I{*}B$) [9]. These forces have radial and axial components thus leads to both radial and axial deformation.

$$\text{Axial deformation } (F_y) = [50.8 * S]/[Z * H * f]$$

Fig. 4 Methods for detecting winding movements



$$\text{Radial deformation } (F_x) = [\mu \text{NI}^2/H][*\pi * D]$$

where

F	Force on winding.
L	length of the conductor.
B	Flux Density.
S	Rated power per limb in kVA.
Z	Impedance in per unit.
H	Height of winding in meters.
f	Frequency (Hz).
μ	Absolute permeability.
NI	Ampere turns.
D	Mean diameter.

These deformations not only reduce the short circuit withstand capacity of the transformer but also ruptures the insulation.

Winding movement [10] and deformation analysis is done by different methods as mentioned in Fig. 4:

- Frequency Response Analysis (FRA): This is an effective characteristic technique extensively used for recognition of lateral faults [9]. Frequency Response Analysis is an offline approach where an AC signal with low voltage is introduced to the terminal of winding and reaction is recorded at the other terminal [11]. The transfer function, impedance or admittance of winding is measured over a frequency range and these are used for fault diagnosis. The faults diagnosed by FRA are:

  Mechanical faults.

(a) Winding deformation
(b) Core displacement

  Electrical Faults.

(a) Short circuit or open circuit
(b) Bad ground connection

- **Low Voltage Impulse:** Low voltage impulse is sensitive technique for detecting winding movement and deformation in transformer caused due to short circuit or short low voltage impulse (300 V) [2]. The impulse is applied, and the coupled currents are recorded. The FFT is carried out on the recorded waveforms and compared with results of the transformer of same type or previously recorded data on same transformer to identify the faults.

2.2.4 On Load Tap Changing(OLTC)

On load tap changers are responsible for voltage regulation in transmission system [12]. They are mainly connected to transformer for maintaining voltage levels under variable loads. The OLTC leads to change in turns ratio and thus level of output voltage. There are primarily two OLTC designs:

- Diverter Design: This is mainly employed for value of high voltage and power. This type of Diverter consists of a separate tap selector to select taps in transformer tank and a separate diverter switch. To switch the load current.
- Non-Diverter Design: This is mainly employed for low values of voltage and combines function of diverter switch and tap selector.

Most of the transformer's failures are associated to tap changing. Thus, we need to carefully review and watch their operating conditions. The methods used for on load tap changing are [2]:

- Winding Resistance: The resistance at various connections are measured and this is compared with the values of factory and any variation from these values are recorded.
- Torque Measurement: This method uses motor parameter for finding any problem due to any mechanical defect due to aging.
- Gas Analysis: In this method the concentration of gas is determined in tap changing compartment. The variation in gas level indicates any abnormal behavior.

2.3 Soft Computing Methods

This methods incorporates approximations to any problem followed by learning and optimization [13] two processes:

2.3.1 Artificial Neural Network

Artificial neural network is an information processing paradigm that is inspired by biological nervous system in human brains. Neural network provides an advantage in following ways:

(a) Adaptive learning: The capability of performing the given piece of work based on information it receives.
(b) Self-organization: They capability to arrange the information it receives during learning time.

(c) Real time operation: Artificial neural network computation are done in a coordinated and special hardware device.

Neural network base algorithm for fault detection in transformers**:** The artificial neural network consists of three operating layers: the input layer, the output layer and the hidden layer [14]. The neural network is used in following procedure:

(a) The neural network is provided with data to train it.
(b) The output is checked and compared with the actual output.
(c) Then the neural network is trained, and the weights and bias are changed.

Some of the neural networks used for fault detection are [15]:

- Multilayer perceptron: In a multilayer perceptron there can be more than one layers. It is a feed forward network consisting of several fully connected layers where the parameters of each unit are independent of rest of units in the layer.
- Back propagation: The back propagation algorithm is the basic method for weight updating. In this gradient-descent method is used to give the error back to the hidden layer.

The different faults techniques in which artificial neural network can be used are:

(a) Dissolved gas analysis
(b) Partial discharge analysis.

2.3.2 Fuzzy logic

The fuzzy logic is a contemporary technique of determining imprecision and unpredictability in information. In fuzzy logic a declaration has certain level of association varying from totally legitimate through partial legitimacy to totally inaccurate which differs from the traditional method [16].

The fuzzy logic analysis consists of three parts:

(a) Fuzzification: It is a method of converting a systematic data set into classes of fuzzy set. This process converts numerical values into linguistic sets and then assigns a membership function value. The Fuzzifier is used to covert systematic data in fuzzy variables.
(b) Fuzzy inference system: The fuzzy inference system is responsible for drawing conclusion from the knowledge-based fuzzy rule set of if–then linguistic.
(c) Defuzzification: It is a process of converting the fuzzy output values back to crisp values. Defuzzification is a process of converting output fuzzy variable into a unique number. Defuzzification methods include

    - Max-membership principle
    - Centroid method
    - Weighted average method
    - Mean-max membership.

The different fault analysis techniques developed on fuzzy logic are [13]:

- Fuzzy Roger's ratio: This includes calculation of different gas ratio codes which are given as input and classified as low, high, medium, very high. The membership boundaries are introduced for gas ratio and if–then rule system is applied.
- Fuzzy IEC ratio: The gas ratios are classified as low, medium and high. The membership function is introduced, and fuzzy rules are defined on type of fault.
- Fuzzy dual triangle: The three gases are converted into fuzzy logic controller with three input and each output with some membership function.
- The fuzzy based monitoring of transformer [17] is a developing field and many works are being carried out to find the techniques controlled by fuzzy systems for transformer condition supervision.

3 Results

The overall transformer management consists of the techniques of condition monitoring, maintenance plans and aging. The overall condition monitoring technique as shown in Fig. 5 are used detection of faults at early stages and hence reduce the overall maintenance cost of the transformers.

For monitoring the transformer the position of PD wrt to phase angle is important. It is noticed that PD pulse has 90° phase angle in positive half cycle and nearly 270° phase angle in negative half cycle of the 5 kV applied voltage which is shown in Fig. 6. The nether voltage rate between the test object is not enough to cause field intensity within the void in excess of PD inception strength. Therefore, PDs are mostly appearing at 90° phase angle and 270° phase angle of the applied voltage where the maximum amplitude of the applied voltage is reached.

Table 1 depicts the level p of the different gases. Level 1 corresponds to the range of normal operation of the transformers and Level 2 corresponds to the abnormal conditions where the excessive decomposition of insulator and oil has occurred in gas analysis. The Level 2 depicts that if operation of transformer will be continued their may be the failure of transformer.

Table 2 shows that any variation of frequency exceeding in range of +3 to −3db the fault has occurred and the range of frequency also shows the type of fault. The traces are to compare with the baseline for diagnosis and if the deviations occur it shows the fault has occurred and transformer requires attention.

4 Conclusion

The survey provides an insight to various fault detection and monitoring techniques for the transformer faults. The paper discusses the major techniques such as Electrical techniques, Chemical techniques, Soft computing techniques for monitoring of the transformer faults. These techniques help in life estimation, reducing maintenance

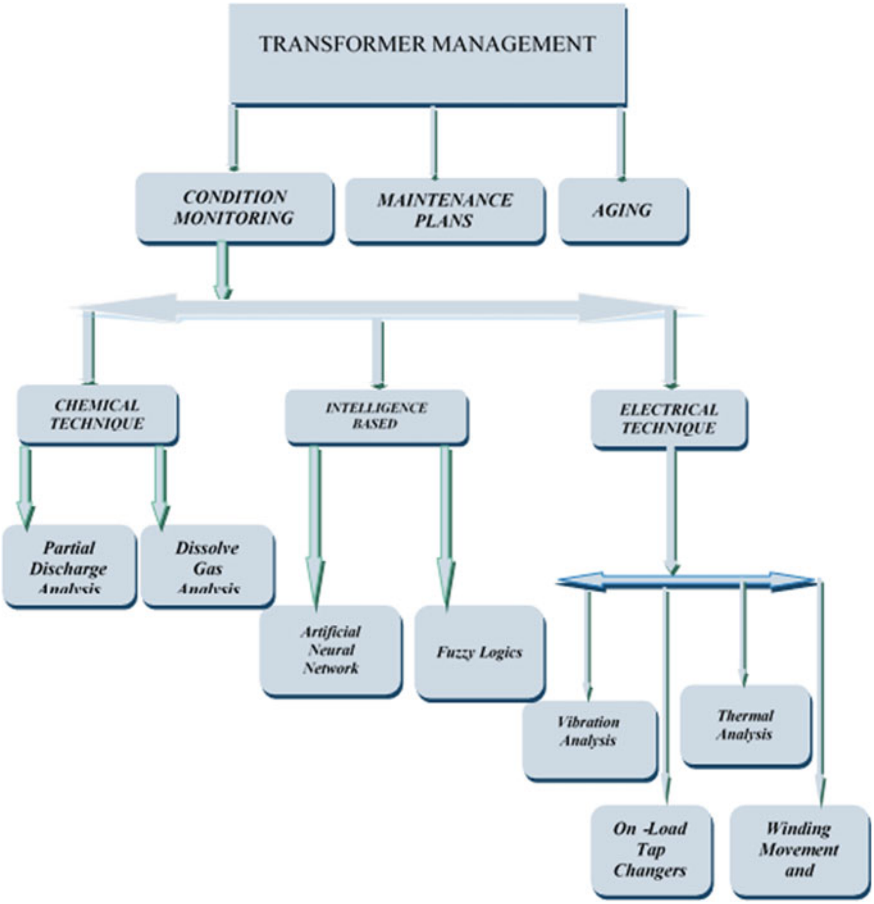


Fig. 5 Overall condition monitoring techniques

cost, enhancing life span and the services of device. Table 3 shows the various methods and the faults diagnosed by them.

There are many researches undergoing on these condition monitoring techniques. Major focus in on development of techniques which can predict any abnormality in transformer before it occurs so that preventive measures can be taken.

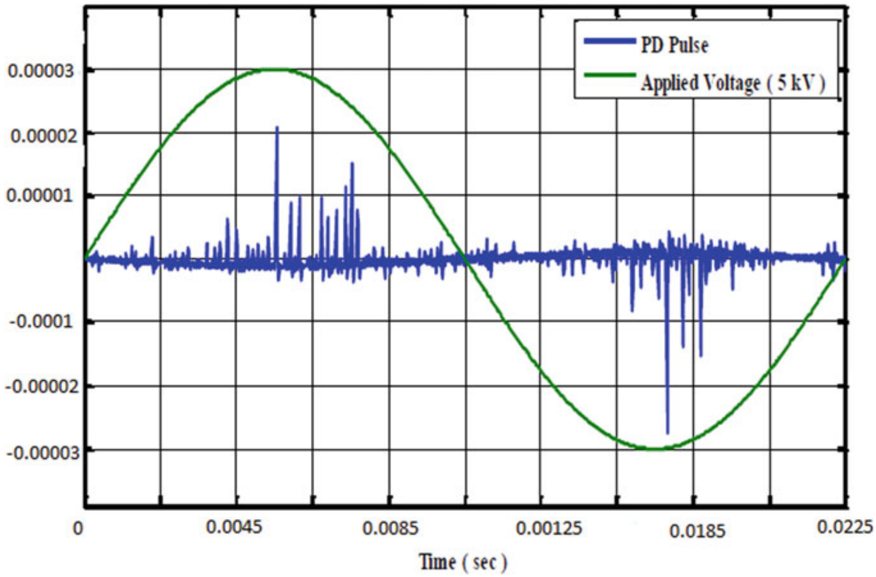


Fig. 6 PD pulse observed at 5 kV voltage

Table 1 Concentration of gases normal and fault operation

Gas	Level 1(ppm)	Level 2(ppm)
Hydrogen	100	> 1700
Ethylene	45	> 195
Carbon monoxide	320	> 1375
Methane	110	> 985

Table 2 Detection of fault in terms of their frequency variations in FRA

Frequency range	Change in frequency (db)	Fault observed
5 Hz–2 kHz	> 6	Open circuit
50 Hz–20 kHz	> 6	Bulk winding movement
500 Hz–2 MHz	> 6	Deformation in winding
25 Hz–10 MHz	> 6	Winding leads problem

Table 3 Various methods and fault diagnosed by the method

S. No	Method	Diagnosis
1	Dissolve gas analysis	Arcing faults, sparking, corona effect
2	Partial discharge gas analysis	Short circuit, insulation failure due to overvoltage
3	Vibration analysis	Partial looseness of windings, Winding deformation
4	Thermal analysis	Insulation breakdown due to excess heating
5	OLTC	Tap changing fault troubleshooting

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