Carrying Out Primary Analysis of Transformers Utilizing Monitoring Techniques According to the Dielectric Properties of Transformer Oil

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**Abstract.** This work analysis the implementation of transformer circumstance monitoring according to the dielectric properties of transformer oil as a means of enabling initial diagnosis of potential failures. The important components in energy systems are power transformers, and expensive interruptions and equipment destruction are the result of their failures. To enhance operational dependence and life of power system components, the analysis of dielectric parametres should provide an powerful method for initial fault. The study find out how these parameters alter under aging conditions and how they can be continually monitored using embedded sensors and automatical data acquiring systems. By combining these measurements into a real-time monitoring framework, preservation teams can make informed decisions, schedule timely interventions, and avoid unexpected breakouts. Moreover, the paper emphasizes the technical viabilty and practical relevance of incorporating dielectric diagnostics into existing transformer maintenance strategies. The accuracy of analysis will be improved along with predictive linked practices which contributes online dielectric monitoring. This approach describes a reliable solution to transformer health management in modern power grids where reliability and efficiency are paramount.

**Keywords:** transformer, dielectric oil, monitoring, diagnostics, electrical equipment, dielectric analysis

**INTRODUCTION**

Main components of electrical energy system are power transformers. Disfunctions in their operation can have a serious influence on the whole system, posing risks to energy dependence and persistence. For that reason, primary analysis of transformers plays a crucial role in ensuring their reliable operation and in identifying potential failures before they lead to major situation. In decades, the demand for analyzing faults of physical and chemical properties of transformer oil has been increased. Moreover, monitoring the dielectric properties of transformer oil provides wider insights into the current state of the insulation system, its aging level, and potential internal defects. An important factor for detecting dielectric losses in the insulation is the potential internal defects. An increase in this parameter typically signals insulation aging or moisture ingress. Additionally, gas chromatography can be used to analyze the composition and concentration of dissolved gases in the transformer oil-such as hydrogen, methane, acetylene, ethylene. When these diagnostic methods are used in combination, they enable a deep and reliable assessment of the internal condition of the transformer, which is essential for establishing early warning systems and improving predictive maintenance practices. The conversion of the magnetic field inside power transformer creates certain heat that increases the temperature and insulating oil can cool this heat sufficiently. That is to say, the insulating oil is employed to insulate between the conductor and the shell, and through the working of the cooling system of discharging the heat produced in operating by the internal wires, to lower the temperature and increase the power supplying capacity and efficiency. Besides the cool down which it gives by virtue of the cooling power system, a certain electrical insulation is also given by the insulating oil between the internal live parts to ensure long-run stability under the high temperature. Besides, the quality of the oil should be sampled and analyzed on a regular basis in order to ascertain whether the oil presents latent defects so as to be treated effectively. Hence, in the event of negligence/inappropriate analysis of sampled and analyzed data on oil quality data, power outage may occur leading to loss of the power transformer. Consequently, diagnosis of insulating oil in power transformers is an extremely significant one, in electric power [1, 2].

**MATERIALS AND METHODS**

Measuring the tangent delta (δ) of transformer oil (also known as the dielectric loss tangent, tan δ, or loss tangent) is one of the key methods used to assess the dielectric condition of transformer insulation. This measurement helps determine how clean and aged the oil is, as well as detect moisture levels and other contaminants.Below are the main formulas and the step-by-step methodology used to measure the tangent delta of transformer oil. It is based on the ratio between the active (real) power and the reactive (capacitive) power in the dielectric material [3]:

= (1)

here: P – dielectric loss power (Watt); ω=2πf – angular frequency (in radians per second); C – dielectric capacitance of the transformer oil (Farads); U – voltage (Volts).

If we express the formula in terms of the capacitive and loss components of the current, it canbe written as follows:

= (2)

here: – loss current; – pure capacitive current.

In some cases, the tangent value of the phase angle between the currents can also be determined through the capacitive reactance and the active resistance of the transformer oil:

= (3)

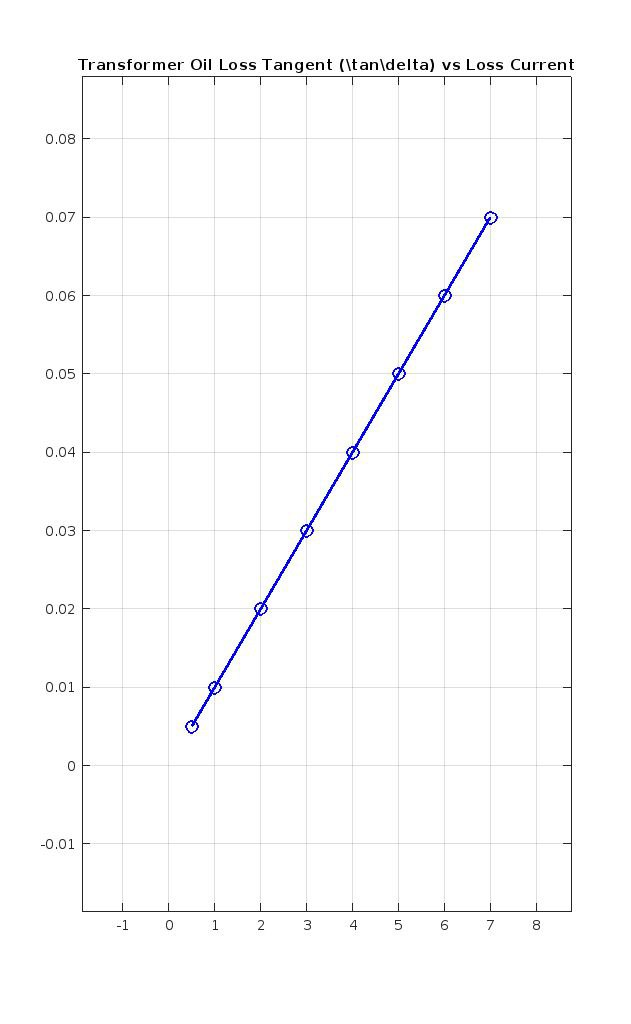
here: R3, R4, C1, C4 – instantaneous values of the resistive and capacitive components in the transformer’s measurement circuit [4].

**TABLE 1.** Experimental results obtained during the measurement of the tangent delta of transformer oil

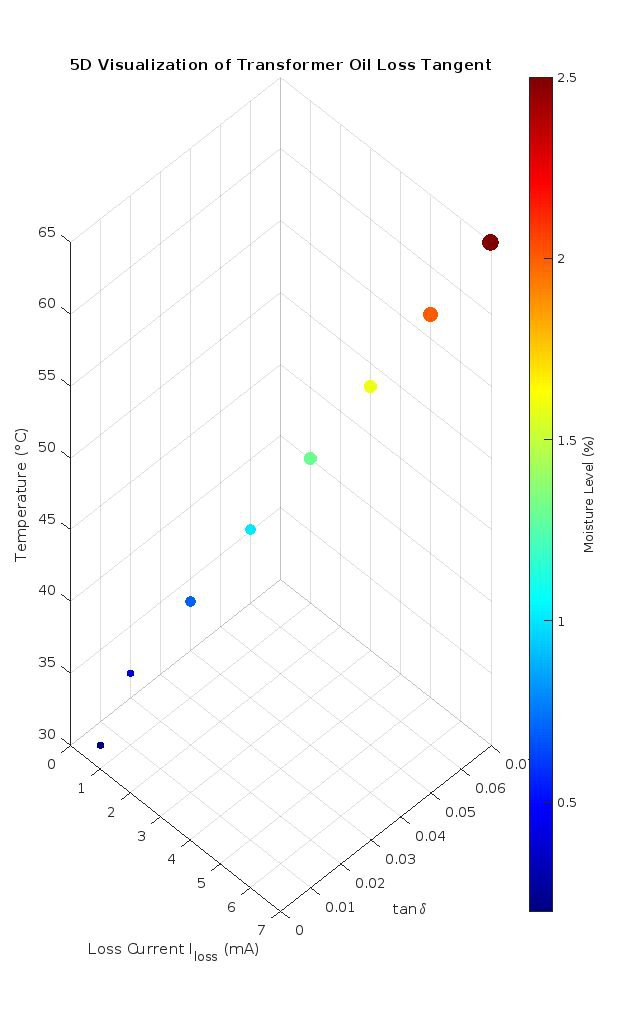
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Experiment № | The amount of loss current in the transformer | Tangent (tan | Temperature () | Moisture content (%) | Degree of oil wear (%) |
| 1 | 0.5 | 0.0 | 30 | 0.2 | 1 |
| 2 | 1.0 | 0.01 | 35 | 0.4 | 1 |
| 3 | 2.0 | 0.02 | 40 | 0.7 | 2 |
| 4 | 3.0 | 0.03 | 45 | 1.0 | 2 |
| 5 | 4.0 | 0.04 | 50 | 1.3 | 3 |
| 6 | 5.0 | 0.05 | 55 | 1.6 | 3 |
| 7 | 6.0 | 0.06 | 60 | 2.0 | 4 |
| 8 | 7.0 | 0.07 | 65 | 2.5 | 5 |

As the leakage current increases, tan δ also increases. This can be explained by the formula tan δ = resistive component / reactive component-as dielectric losses rise, the current increases accordingly.As the water content increases, the value of tan δ grows proportionally, because moisture breaks down insulation resistance and raises dielectric losses.The oxidation products in the oil (polar contaminants) elevate tan δ. Thus, increasingly degraded oil can be identified by its higher tan δ value.Both moisture and oil degradation tend to increase simultaneously as the transformer operates longer, temperatures rise, and chemical aging occurs. Their relationship is not causal, but they increase together over time. The tangent of the transformer oil is determined based on the above parameters, and if the tangent values are greater than 0.005 but less than 0.01(0.005), it can be concluded that the oil is in normal condition and there is no serious risk associated with the transformer. This method is the most effective way to determine the dielectric properties of transformer oil. Below, let’s examine the correlation graphs and the simulation results in MATLAB [5 ,6].

Figure 1 This graph shows the relationship between the transformer oil loss tangent (tanδ) and the loss current. The vertical axis represents tanδ (dielectric loss tangent), while the horizontal axis shows the values of the loss current.X-axis (horizontal)- loss current in the transformer (expressed in mA or possibly other units).Y-axis (vertical)- loss tangent of the oil (tan δ), which indicates the level of dielectric loss.Each point represents a measurement result, and the line connecting them shows their linear relationship.The values indicate that as the loss current increases, the dielectric properties deteriorate, which is reflected in the increase of tan δ. From the graph, it is evident that as the loss current increases, the value of tan δ also increases in an almost linear manner. This indicates that the dielectric properties of transformer oil are highly sensitive to the loss current, showing a strong positive correlation between them.This suggests that tan δ can be used as a reliable diagnostic indicator for assessing the quality of the transformer oil. This relationship can be useful in developing early warning systems for transformer diagnostics. If the value of tan δ suddenly increases, it may signal that the oil has aged, absorbed moisture, or become contaminated [7].



**FIGURE 1.** The characteristic of the relationship between loss currents in the transformer and the tangent of the oil



**FIGURE 2**. Simulation view of the correlation between moisture content, temperature, oil tangent, and loss currents in the transformer

As you can see figure 2, This graph is a scientific visualization of the “Transformer Oil Loss Tangent” (tan δ) in a five-dimensional (5D) format, simultaneously displaying key physicochemical parameters used to assess the condition of transformer oil. X-axis (bottom horizontal axis) -Loss Current (Iloss), mA.This parameter indicates the level of losses in the transformer. As the current increases, signs of oil degradation intensify.Y-axis (side horizontal axis) - Tangent δ (tan δ) .The dielectric loss tangent is one of the most important parameters reflecting the insulation properties of the oil. A high tan δ value indicates poor insulation quality or degradation.Z-axis (vertical axis) -Temperature (°C).Represents the heat generated during transformer operation. As the temperature rises, the physicochemical condition of the oil changes.Point color (color coding) -Moisture level (%).The color varies along a spectrum: blue , yellow , red, representing moisture levels from 0% to 2.5%.Low moisture: blue.Medium moisture: green-yellow.High moisture: red.Point size or shape: This factor is not visible in this graph, so in this 5D visualization, only four dimensions are represented through position and color. The fifth dimension is interpreted as the overall spatial relationship based on the three main axes.

**RESULTS AND DISCUSSION**

Stability of Dielectric Condition:A tan δ value within the 0.005 - 0.01 range indicates that the transformer oil still possesses good dielectric properties.This range falls within the safe zone, suggesting that the insulation level remains in a normal, acceptable condition.Low Moisture Level:

In the 5D visualization, data points with tan δ values between 0.005 and 0.01 are shown in blue or bluish tones, indicating a moisture content of approximately 0.2% - 0.7%.This level suggests that the transformer oil is still in a safe phase with no immediate risk of moisture-related degradation.

Low temperature influence:This tan δ range typically corresponds to an operating temperature of 30°C - 40°C.At this stage, the oil has not yet reached a critical temperature, and thermal degradation processes have likely not begun.Satisfactory oil quality under these conditions, the transformer oil is still considered to be in good shape - its chemical structure and dielectric capacity are well-preserved.There is currently no need for filtering or replacement, though ongoing monitoring is recommended.

**CONCLUSION**

The analysis conducted shows that when the loss tangent (tan δ) value of transformer oil is within the range of 0.005 - 0.01, the dielectric properties of the oil are still well preserved, and the insulation condition remains stable. The linear increase of this parameter confirms its strong correlation with other physicochemical indicators such as loss current, temperature, and moisture content.Accordingly, a tan δ value within this range can be considered a safe zone, however, it is recommended to implement careful monitoring at this stage and adopt a diagnostic approach that enables early detection of gradual deterioration in oil properties.This approach plays a significant role in improving transformer reliability and extending service life, as well as in preventing unexpected failures. Continuous and systematic monitoring based on the dielectric loss tangent (tan δ) is proposed as an effective method for online condition assessment and optimization of maintenance strategies for power transformers.

**FUTURE SCOPE**

By monitoring the dielectric characteristics of the transformer oil, early detection of the internal faults can be displayed very much in advance. This is important in the enhancement of smooth work of power supply system.

Any potential internal malfunctions (presence of moisture or insulation wear) can be identified before they turn into severe failures with help of early warning systems.

It is possible to perform condition-based maintenance as opposed to scheduled ones. The given practice eliminates unfriendly interventions and allows optimizing operational costs.

Continuous tracking of internal conditions through dielectric parameters makes it possible to keep the transformer in good state in order to get extended its service life.

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The inefficient transformers can be diagnosed, fixed or replaced as soon as possible resulting to enhanced overall energy efficiency and reduced energy losses.

The modern systems are able to auto synthesize dielectric parameters (tan 233, breakdown voltage and moisture content) and provide accurate diagnostic output with no manual interpretation.

Transformer failures are commonly known as the cause of major power outages. These risks can be addressed with the assistance of early diagnostic technologies that reduces risks as well as increases the security and dependability of power delivery systems overall.

Transformer oil monitoring systems are accessible and controllable through the internet or mobile apps, and these systems offer convenience to the maintenance team because they do not require an on-site visit.

The early diagnosis is being coupled with new futuristic technologies like artificial intelligence, digital signal processing, Internet of Things (IoT) that generates newer and more predictive and transformer monitoring systems.

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