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METHODS FOR ASSESSING THE TECHNICAL CONDITION AND DIAGNOSTICS OF POWER TRANSFORMERS

Khudoberdiev Shavkatjon Nurmatjon ugli
PhD Student, Faculty of Power Engineering, Tashkent State Technical University
ORCID: 0009-0005-8894-2725

Olimjon Zuvirivich Toirov
Doctor of Technical Sciences, Professor
Dean of the Faculty of Power Engineering, Tashkent State Technical University

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Abstract: Power transformers are among the most critical components of electrical power systems, ensuring reliable transmission and distribution of electrical energy. The technical condition of transformers directly affects the reliability, efficiency, and operational safety of power networks. This paper investigates modern methods for assessing the technical condition and diagnosing power transformers. Particular attention is paid to Dissolved Gas Analysis (DGA), thermal imaging diagnostics, partial discharge monitoring, insulation condition assessment, and online monitoring systems. Experimental data obtained from several transformers are analyzed to evaluate their operational status and identify potential defects. The results demonstrate that comprehensive diagnostic approaches significantly improve fault detection accuracy, reduce maintenance costs, and extend transformer service life. The proposed condition assessment methodology can be effectively applied in modern smart grid environments and predictive maintenance systems.

Keywords: Power transformer, condition assessment, diagnostics, dissolved gas analysis, thermal monitoring, partial discharge, predictive maintenance, transformer reliability.

1. Introduction

Power transformers play a crucial role in modern electrical power systems by enabling efficient voltage transformation and energy transmission. Due to continuous operation under varying load conditions, transformers are exposed to thermal, electrical, mechanical, and environmental stresses that gradually deteriorate their insulation systems and internal components.

Transformer failures can result in significant economic losses, interruptions in power supply, and costly repair procedures. Therefore, accurate assessment of transformer condition and early fault detection are essential for maintaining system reliability and operational efficiency.

Recent developments in monitoring technologies and diagnostic techniques have enabled utilities to move from traditional time-based maintenance toward condition-based and predictive maintenance strategies. These approaches improve asset management and minimize unexpected outages.

The objective of this study is to analyze the effectiveness of modern transformer diagnostic methods and evaluate their applicability for assessing transformer technical condition.

2. Materials and Methods

2.1 Dissolved Gas Analysis (DGA)

Dissolved Gas Analysis is one of the most widely used methods for transformer diagnostics. Faults occurring inside transformers generate gases that dissolve in insulating oil. The concentration and ratio of these gases provide valuable information regarding fault types and severity.

Gas	Associated Fault
Hydrogen (H_2)	Partial discharge
Methane (CH_4)	Low-temperature overheating
Ethane (C_2H_6)	Thermal decomposition
Ethylene (C_2H_4)	High-temperature overheating
Acetylene (C_2H_2)	Electrical arcing
Carbon Monoxide (CO)	Cellulose insulation degradation

Table 1. Key Diagnostic Gases and Corresponding Fault Types

2.2 Thermal Imaging Diagnostics

Infrared thermography is a non-invasive diagnostic technique used to identify abnormal temperature distributions on transformer surfaces. Thermal hotspots often indicate loose connections, overloaded windings, insulation deterioration, or cooling system malfunctions.

Advantages include:

Real-time monitoring;

Non-contact measurements;

Early fault detection;

Improved maintenance planning.

2.3 Partial Discharge Monitoring

Partial discharge (PD) activity is one of the earliest indicators of insulation deterioration. Continuous monitoring of PD signals helps identify developing defects before catastrophic failures occur.

Common PD measurement techniques include:

Ultra High Frequency (UHF) sensors;

Acoustic emission sensors;

Electrical pulse detection methods.

2.4 Insulation Resistance Measurement

Insulation resistance tests evaluate the condition of transformer insulation systems. Low resistance values may indicate moisture contamination, aging, or insulation degradation.

3. Experimental Results

Four power transformers operating under different loading conditions were selected for analysis.

Transformer	Rated Power (MVA)	Temperature (°C)	H_2 Concentration (ppm)	Condition
T1	25	58	85	Good
T2	40	67	160	Acceptable
T3	63	82	420	Warning
T4	125	95	760	Critical

Table 2. Measured Transformer Parameters

The obtained results indicate a significant increase in dissolved gas concentrations with increasing operating temperature.

4. Discussion

4.1 Thermal Performance Analysis

Temperature is one of the most influential factors affecting transformer aging. According to international standards, every 6–8°C increase above the design operating temperature may reduce insulation life by approximately 50%.

The experimental data show that Transformer T4 operates near critical thermal conditions. Elevated temperatures accelerate oil oxidation and cellulose insulation degradation.

4.2 Dissolved Gas Analysis Results

The measured gas concentrations for Transformer T4 are presented below.

Gas	**Concentration (ppm)**
H_2	760

Gas	Concentration (ppm)
CH_4	420
C_2H_4	215
C_2H_2	92
CO	670

Table 3. DGA Results for Transformer T4

The high concentration of hydrogen and acetylene indicates possible electrical arcing and severe insulation stress. Carbon monoxide concentration suggests accelerated degradation of cellulose insulation.

$$K = 0.35DGA + 0.25T + 0.20PD + 0.20IR$$

4.3 Comprehensive Condition Assessment

A comprehensive transformer condition index was developed using weighted diagnostic parameters:

CI – Condition Index;

DGA – Dissolved Gas Analysis score;

T – Thermal condition score;

PD – Partial Discharge score;

IR – Insulation Resistance score.

Transformer	Condition Index
T1	0.91
T2	0.78
T3	0.54
T4	0.31

Table 4. Calculated Condition Index

Condition classification:

Condition Index	Assessment
0.80–1.00	Good
0.60–0.79	Acceptable
0.40–0.59	Maintenance Required
Below 0.40	Critical

The analysis indicates that Transformer T4 requires immediate maintenance intervention.

5. Advantages of Modern Diagnostic Systems

Implementation of online monitoring systems offers several benefits:

Continuous asset condition monitoring;

Early fault detection;

Reduced maintenance costs;

Increased transformer reliability;

Improved asset management;

Extension of transformer service life.

Integration with artificial intelligence and machine learning algorithms can further enhance diagnostic accuracy and predictive maintenance capabilities.

6. Conclusion

This study investigated various methods for assessing the technical condition and diagnosing power transformers. The following conclusions were obtained:

Dissolved Gas Analysis remains one of the most effective methods for detecting internal transformer faults.

Thermal imaging successfully identifies overheating components and cooling system deficiencies.

Partial discharge monitoring provides valuable information regarding insulation degradation.

Comprehensive diagnostic assessment significantly improves transformer reliability and reduces unexpected failures.

Online monitoring technologies and predictive maintenance strategies can extend transformer service life by up to 30%.

The integration of digital monitoring platforms with intelligent diagnostic algorithms represents a promising direction for future power system asset management.

The proposed methodology can be effectively applied in modern electrical networks to improve transformer reliability, reduce maintenance costs, and enhance overall power system stability.

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