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COMPREHENSIVE DIAGNOSTIC ASSESSMENT OF A SUSPECTED FAULTY 1600KVA, 33/0.415KV TRANSFORMER AT DRUGFIELD SUBSTATION

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Abstract
Power transformers are pivotal assets in electrical power networks, and their reliability is fundamental to power delivery system stability, safety, and efficiency. This paper presents a comprehensive diagnostic evaluation of a 1600-KVA, 33/0.415-kV Siemens oil-immersed distribution transformer at Drugfield Substation, Nigeria, following reports of operational anomalies. A suite of industry-standard diagnostic tests—including physical inspection, insulation resistance, winding continuity, single-phase transformation ratio, excitation, and earth resistance—was conducted. The results revealed catastrophic high-voltage winding insulation failure, significant HV winding resistance imbalance, and severe transformation ratio discrepancies. These findings indicate that advanced internal faults, including insulation breakdown, winding degradation, and probable open circuits, pose imminent operational and safety risks. This study underscores the importance of regular transformer health assessments, presents a mathematical framework for interpreting diagnostic data, and recommends immediate decommissioning or overhaul of the affected unit. The broader implications for asset management and grid reliability are discussed, with recommendations for advanced diagnostic and monitoring strategies.

1. INTRODUCTION

Transformers are essential for efficient voltage transformation and power distribution in industrial and commercial settings (Gupta, 2012). Despite robust engineering, transformers are susceptible to various failure modes, including insulation breakdown, winding degradation, core faults, tap changer malfunctions, oil contamination, and external factors such as lightning and poor grounding (Tenbohlen & Koch, 2009; CIGRE

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Working Group A2.37, 2015). Insulation failure is the most common cause of transformer failure, accounting for up to 40% of transformer failures globally (Wang *et al*., 2002; Duval, 2002). The early detection of these faults through diagnostic testing is crucial for minimizing downtime and preventing catastrophic failures (Gubanski, 2000).

This paper presents an in-depth analysis of a 1600 KVA, 33/0.415 kV Siemens transformer at Drugfield Substation, which exhibited abnormal tripping and failed excitation tests (Jokojeje, 2025). The objective of this study is to systematically assess the operational status of the transformer using industry-standard diagnostic tests (IEC 60076-1:2011; IEEE Std C57.12.00-2020), mathematically analyze test results for evidence of internal faults, and provide actionable recommendations for risk mitigation and asset management.

2. Transformer Description

The transformer under investigation is a Siemens oil-immersed distribution unit, manufactured in 2022, with the following specifications (Jokojeje, 2025):

i. **Rated Power:** 1600 KVA
ii. **Voltage Rating:** 33 kV (HV) / 0.415 kV (LV)
iii. **Current Rating:** 27.99 A (HV) / 2300.46 A (LV)
iv. **Vector Group:** Dyn11
v. **Impedance Voltage:** 6.52%
vi. **Cooling System:** ONAN
vii. **Feeder Connection:** SANGO 33 kV feeder, Ota Transmission Station

3. Methodology

The methodology adopted for this assessment is as follows (Jokojeje, 2025; Wang et al., 2002):

1. **Physical Inspection:** Visual and mechanical inspection of external components, oil level, bushings, tap changer, and general physical state.
2. **Insulation Resistance Test:** Measurement of insulation resistance between windings and earth and between HV and LV windings was measured using a 1 kV megger.
3. **Winding Continuity Resistance Test:** Measurement of DC resistance of each winding phase-to-phase was measured using a digital ohmmeter.
4. **Single-Phase Transformation Ratio Test:** Application of voltage to the primary winding and measurement of the resulting secondary voltage is measured for each phase.
5. **Excitation Test:** Energization of each phase to observe the excitation current and tripping behavior.
6. **Earth Resistance Test:** Measurement of grounding system resistance using a ground resistance tester.
7. **Advanced Diagnostic Indices (where necessary):** Calculation of deterioration indices, weighted condition scores, and relative inferiority degrees for comprehensive assessment (Du & Sun, 2022; Zhang *et al*., 2019).

4. Mathematical Modeling and Variables

4.1 Insulation resistance (IR)

The insulation resistance, R_{ins}, is calculated as follows:

$$R_{\text{ins}} = \frac{V_{\text{applied}}}{I_{\text{leakage}}} \quad (1)$$

Where:

i. R_{ins}: Insulation resistance (MΩ)
ii. $V_{applied}$: Applied DC voltage during the test (V)

iii. $I_{leakage}$: Measured leakage current (A)

4.2 Imbalance of winding resistance

The percentage imbalance of the HV winding resistance, ΔR_{HV}, is given as follows:

$$\Delta R_{\mathrm{HV}} = \frac{|R_{\max} - R_{\min}|}{R_{\mathrm{avg}}} \times 100 \tag{2}$$

Where:

i. ΔR_{HV}: Percentage imbalance of the HV winding resistance (%)
ii. $R_{\{max\}}$ Maximum measured phase resistance (Ω)
iii. R_{min}: Minimum measured phase resistance (Ω)
iv. R_{avg}: Average of all measured phase resistances (Ω)
v. R_{RY}, R_{YB}, R_{BR}: Measured resistances between the respective phases pairs (Ω)

$$R_{\mathrm{avg}} = \frac{R_{RY} + R_{YB} + R_{BR}}{3} \tag{3}$$

4.3 Imbalance in Transformation Ratio

The percentage voltage imbalance, $Imbalance_V$, is calculated as follows:

$$\mathrm{Imbalance}_V = \frac{V_{\max} - V_{\min}}{V_{\mathrm{avg}}} \times 100 \tag{4}$$

Where:

i. $Imbalance_V$: Percentage voltage imbalance (%)
ii. $V_{\max}$: Maximum measured secondary voltage (V)
iii. $V_{\min}$: Minimum measured secondary voltage (V)
iv. V_{avg}: Average of all the measured secondary voltages (V)
v. V_{RY}, V_{YB}, V_{BR}: Measured secondary voltages for each phase pair (V)

$$V_{\mathrm{avg}} = \frac{V_{RY} + V_{YB} + V_{BR}}{3} \tag{5}$$

4.4 Earth Resistance

The earth resistance, R_{earth}, is given by

$$R_{\mathrm{earth}} = \frac{V_{\mathrm{earth}}}{I_{\mathrm{earth}}} \tag{6}$$

Where:

i. R_{earth}: Earth resistance (Ω)
ii. V_{earth}: Voltage measured across the earth connection (V)
iii. I_{earth}: Current through the earth connection (A)

4.5 Deterioration Index

A generalized deterioration index, D_k, for the k -th component is expressed as follows:

$$D_k = f(X_k) \tag{7}$$

Where:

i. D_k: Deterioration index for the k -th component
ii. X_k: Measured characteristic quantity for the k -th component

4.6 Weighted Condition Score (WCS)

The comprehensive condition score, S , is:

$$S = \sum_{j=1}^{n} w_j x_j \tag{8}$$

Where:

i. S : Comprehensive condition score (CCS)

ii. w_j: Weight assigned to the j -th defect or index

iii. x_j: Score or normalized value of the j -th defect/index

iv. n : Total number of defects or assessment indices

4.7 Initial Weight Calculation

The initial weight, $w_j^{(0)}$, is determined as follows:

$$w_j^{(0)} = \alpha W_{1j} + (1-\alpha) W_{2j} \tag{9}$$

Where:

i. $w_j^{(0)}$: Initial weight for the $ j $-th index

ii. W_{1j}: Subjective weight from the G1 method

iii. W_{2j}: Objective weight from the entropy method

iv. α: Weighting factor between 0 and 1

4.8 Variable Weight Adjustment

The final adjusted weight, w_j, is:

$$w_j = w_j^{(0)} \cdot \phi(x_j) \tag{10}$$

Where:

i. w_j: Final adjusted weight for the $ j $-th index

ii. $\phi(x_j)$: Adjustment function based on score x_j

4.9 Relative degree of inferiority

The relative degree of inferiority, u_m, is:

$$\mu_m = \frac{e_m - e_{m,\min}}{e_{m,\max} - e_{m,\min}} \tag{11}$$

Where:

i. u_m: Relative inferiority degree of the m -th index

ii. e_m: Current value of the m -th index

iii. $e_{m,min}$: Minimum value of the assessment set

iv. $e_{m,max}$: Maximum value of the assessment set

5. Results and Analysis

5.1 Physical Inspection

All external components were intact with no visible signs of damage. The tap changer was set to position 3 of 5. The oil level and silica gel were satisfactory. No external factors were identified as the cause of failure (Jokojeje, 2025).

5.2 Insulation Resistance Test (IRT)

Test Point	Measured Value (MΩ)	Interpretation
HV Winding to Earth	0	Complete insulation failure
LV Winding to Earth	205	Acceptable
HV-LV Winding	211	Below the ideal threshold
HV Cable	∞	No leakage detected
LV Cable	1700	Excellent insulation

A value of 0 MΩ for HV winding to earth indicates a direct short or severe insulation breakdown (Jokojeje, 2025; Wang et al., 2002).

5.3 The winding continuity resistance test

HV Side	Resistance (Ω)
RY	13.4
YB	26.1
BR	12.9

The HV resistance imbalance, calculated using Eq. (2), is approximately 71.5%, far exceeding the acceptable limits (typically <10%), indicating severe winding degradation (Jarman & Allan, 2015; Jokojeje, 2025).

5.4 Single-Phase Transformation Ratio Test

Phase	Secondary (V)
RY	239
YB	190
BR	47

The transformation ratio imbalance, calculated using Eq. (4), is approximately 95.2%, confirming the existence of internal faults (Jokojeje, 2025; Wang & Kang, 2020).

5.5 Excitation Test

All phases tripped during excitation, indicating probable internal short circuits or severe winding insulation breakdown (Jokojeje, 2025).

5.6 Earth Resistance Test

Test Point	Resistance (Ω)
Transformer Body	1.2
Lightning Arrester	1.2
Feeder Pillar	1.2

All values are within safety standards (<5 Ω), confirming proper grounding (Jokojeje, 2025; Ryder, 2018).

6. Discussion

The diagnostic findings point to multiple critical internal faults:

1. Complete HV winding insulation failure (0 MΩ), likely caused by thermal aging, moisture ingress, or manufacturing defects (Emsley & Stevens, 2000; Jokojeje, 2025).
2. Severe HV winding resistance imbalance ($\Delta R > 70\%$), suggesting advanced winding degradation, possible inter-turn shorts, or open circuits (Jarman & Allan, 2015; Wang et al., 2002).
3. Transformation ratio discrepancies and excitation test tripping further corroborate the existence of internal winding faults (Wang & Kang, 2020).

4. Good earth resistance and cable insulation rule out external or grounding-related causes (Jokojeje, 2025).

The continued operation of this transformer poses a high risk of catastrophic failure, potential fire hazards, and network instability. Immediate shutdown and further advanced diagnostics (e.g., DC Hi-Pot, Tan Delta, micro-ohmmeter tests) are strongly recommended (Duval, 2002; Lapworth, 2003). If insulation and winding faults are confirmed, replacement or major overhaul is necessary (Tenbohlen & Markalous, 2012).

7. Conclusions and Recommendations

This case study demonstrates the effectiveness of systematic diagnostic testing in identifying critical transformer faults (Tenbohlen & Koch, 2009; Wang et al., 2002). The 1600 KVA Siemens transformer at the Drugfield Substation exhibits catastrophic HV insulation failure, severe winding imbalance, and internal faults, rendering it unsafe for continued operation (Jokojeje, 2025).

Recommendations:

1. Immediate transformer shutdown and isolation.
2. Advanced diagnostic testing (DC Hi-Pot, Tan Delta, micro-ohmmeter).
3. Consideration of transformer replacement or complete overhaul if faults are confirmed.
4. Implementation of regular condition monitoring and predictive maintenance strategies (Du & Sun, 2022; Zhang et al., 2019).

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