Understanding the Value of Electrical Testing for Power Transformers

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Abstract

The electric power industry is always looking for the best approach to better determine and continually track the condition of power transformers. It is important to understand the need for and value of comprehensive testing of power transformers.

Through careful selection, hierarchal value, and appropriate times of use, today transformer diagnostics generally consists of a comprehensive suite of basic or standard electrical field tests including:

- Power Factor
- Exciting Current
- Turns/Voltage Ratio
- Leakage Reactance
- DC Winding Resistance
- Sweep Frequency Response Analysis (SFRA)

These specific diagnostic tests have been selected as the primary focus for this presentation and discussion.

This paper focuses on how diagnostic techniques can be applied to power transformers as part of the standard condition assessment protocol. The audience will be provided with an understanding, application, and analysis of these tests, supported by specially selected case studies validating the value that these diagnostic tests bring to testing, and finally assessing, power transformers.

Introduction

The primary goal when performing diagnostic tests on power transformers is to ensure safe operation and accomplish life extension. Understanding the condition of the power transformer is essential. Maintenance personnel must manage moisture, heat, and oxygen, while attempting to protect the power transformer from dielectric, thermal, and mechanical failure modes. This paper is going to focus on a subset of electrical diagnostic tests. We will investigate test procedure, test preparation, and expected results. For the purpose of this paper, we will focus on a delta-wye power transformer (Dyn1); this will simplify our discussion.

We introduce and focus on the following tests:

1.) Overall Power Factor and Capacitance
2.) Bushing Power Factor and Capacitance
3.) Exciting Current Test
4.) TTR – Transformer Turns Ratio
5.) Leakage Reactance (3-Phase Equivalent and Per Phase)
6.) DC Winding Resistance
7.) Sweep Frequency Response Analysis (SFRA)

The test plan, procedure, and analysis recommendations found in this paper are based on the contents of:

- IEEE C57.152-2013, "IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors".
- ANSI/NETA MTS-2015, "Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems".
- IEEE C57.149-2012, "IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformers".

Transformer Testing

1.) Overall Power Factor and Capacitance

The overall power factor measurement is used to assess the integrity of the insulation system within a transformer. The unit-less value of power factor represents efficiency. With respect to insulation, we expected the insulation system to be efficient with respect to power loss. Several contributing factors may affect the efficiency of the insulation. The insulation system may become compromised due to one or more of the following contributing factors:

- Natural aging and deterioration
- Overheating
- Moisture ingress
- Localized defects (such as partial discharge, voids, cracks, and partial or full short-circuits)

When the insulation system of a transformer becomes compromised, the insulation becomes mechanically and/or dielectrically weaker, which may lead to an undesired failure mode.

For discussion purposes, we will consider a two-winding transformer; delta-wye (Dyn1). When studying the two-winding transformer, there are three insulation components that can be isolated and tested when the overall power factor is performed, which includes,

1.) CH: High-voltage winding-to-ground insulation, including the high-voltage bushing insulation
2.) CL: Low-voltage winding-to-ground insulation, including the low-voltage bushing insulation
3.) CHL: High-voltage to low-voltage (inter-winding) insulation, which does not include the bushing insulation

Special attention is given to analyzing the CHL insulation. This inter-winding insulation component consists of major insulation between windings. This measurement performed in the UST mode is exempt from external influences, such as the bushing insulation and external surfaces.

Test Preparations:

When performing overall power factor and capacitance measurements, the following test preparations are recommended:

1.) Ensure that the transformer tank and core are solidly grounded, also connect both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Ensure that all bushing surfaces are clean and dry.
3.) Completely isolate the transformer terminals; remove external connections and buswork from H1, H2, H3, X1, X2, X3 and X0.
4.) Bond/short the H1, H2, and H3, making sure that they are isolated. We will refer to this point as the "HV" node.
5.) Bond/short the X1, X2, X3, and X0 making sure that they are isolated. We will refer to this point as the "LV" node.
6.) Document tap-positions, temperatures, humidity, fluid levels, and pressures.

Test Procedure:

When performing overall power factor capacitance measurements, the following test procedures are recommended:

The test voltages will be limited and should not exceed the line-to-ground rating of the insulation system. Often, a 10 kV maximum is applied; due to the limits of portable test equipment. When convenient, Variable Frequency Power Factor Tests will be performed on CH, CL, and CHL insulation components, along with Power Factor Tip-Up measurements.

Before each measurement, ensure that the cable is in the clear.

Shown below, in **Table 1**, is a typical test plan for overall power factor in capacitance measurements:

Table 1 - Overall Power Factor and Capacitance Measurements

Test	Insulation	Test Voltage *	Test Mode	Energize	Red LV Lead
1	CH + CHL	10 kV	GST	HV	LV
2a	CH	10 kV	GST-gA	HV	LV
2b	CH(f)	2 kV (15-400 Hz)	GST-gA	HV	LV
3a	CHL	10 kV	UST-A	HV	LV
3b	CHL(f)	2 kV (15-400 Hz)	UST-A	HV	LV
4	CL + CLH	7 kV	GST	LV	HV
5a	CL	7 kV	GST-gA	LV	HV
5b	CL(f)	2 kV (15-400 Hz)	GST-gA	LV	HV
6a	CLH	7 kV	UST-A	LV	HV
6b	CLH(f)	2 kV (15-400Hz)	UST-A	LV	HV

Expected Results:

The following shall be expected regarding power factor measurements transformers:

IEEE C57.152 [1]

- PF < 0.5% at 20 °C for "new" liquid filled power transformers rated under 230kV
- PF < 0.4% at 20 °C for "new" liquid filled power transformers rated over 230kV
- PF < 1.0% at 20 °C for "service aged" liquid filled power transformers
- PFs between 0.5% and 1.0% at 20 °C warrant additional testing and investigation

NETA MTS [2]

- PF < 1.0% for liquid filled power transformers
- PF < 2.0% for liquid field distribution transformers
- PF < 2.0% for dry-type power transformers (CHL insulation)
- PF < 5.0% for dry-type distribution transformers (CHL insulation)
- PF Tip-Up for dry-type insulation should be < 1.0%

Note: Measured values should also be compared to the manufacturer's published data.

2.) Bushing Power Factor and Capacitance

A bushing power factor measurement is used to assess the integrity of the insulation system within a bushing. Availability of a test tap or a potential tap will allow testing of the main insulation, C1, and the tap insulation, C2. If neither are available, a hot collar test will be performed. The nameplate ratings of the bushings will determine applicable test voltages.

Note: Only remove one bushing tap adapter cap at a time. Immediately return each bushing tap cap after every test.

Test Preparations:

When performing bushing power factor measurements, the following test preparations are recommended:

1.) Ensure that the transformer tank, bushing flanges, and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Identify the bushing type and characteristics, such as tap type (potential tap or test tap). It is also important to identify whether the bushing insulation system is oil impregnated paper or resin impregnated paper.
3.) Identify the bushing's line to ground rating. This will help in selecting the appropriate test voltage.
4.) Ensure that all bushing surfaces and tap areas are clean and dry.
5.) Completely isolate the transformer terminals; remove external connections and buswork from H1, H2, H3, X1, X2, X3 and X0.
6.) Bond/short the H1, H2, H3, and H0, making sure that they are isolated. We will refer to this point as the "HV" node.
7.) Bond/short the X1, X2, X3, and X0 making sure that they are isolated. We will refer to this point as the "LV" node.
8.) Prepare and obtain any necessary bushing tap adapters and hot collar straps.
9.) Document tap-positions, temperatures, humidity, fluid levels, and pressures.

Test Procedure:

When performing bushing power factor and capacitance and hot collar measurements, the following test procedures are recommended:

The test voltages will be limited and not exceed the line-to-ground rating of the insulation system. Often, a 10 kV maximum is applied; due to the limits of portable test equipment. When convenient, Variable Frequency Power Factor Tests can be performed on C1 insulation components, along with Power Factor Tip-Up measurements.

Before each measurement, ensure that the cable is in the clear, especially for the C2 measurement.

Shown below, in **Table 2**, is a typical test plan for overall power factor and capacitance measurements:

<p align="center">**Table 2** - Bushing Measurements (C1, C2, and Hot Collar)</p>

Test	Insulation	Test Voltage *	Test Mode	Energize	Red LV Lead
H1	C1	10 kV or L-G	UST-A	Center Conductor	Test/Potential Tap
H1(f)	C1	2 kV (15-400 Hz)	UST-A	Center Conductor	Test/Potential Tap
H1	C2	0.5kV/2 kV	GSTg-A	Test/Potential Tap	Center Conductor
H1	Hot Collar	10 kV	UST	Hot Collar	Center Conductor

Notes:

- Bushings shall remain shorted, similar to the overall power factor test. Failure to short the bushing terminals, may result in compromised measurements.

- Hot Collar tests are optional; they will not be performed if test taps or potential taps are available.

- Test taps and potential taps can be identified, based on the bushing rating, as follows:

    - Test Taps <= 350 kV BIL
    - Potential Taps > 350 kV BIL

- C2 tests must be performed carefully, ensuring that the "hook" is in the clear, completely.

Expected Results:

The following shall be expected regarding power factor measurements:

- The C1 results should compare well with the nameplate data. C1 Power Factor values should not exceed 1.5X to 2.0X nameplate data. C1 capacitance should not exceed +/- 5% of nameplate data.

- C2 values should compare well with the nameplate or amongst similar bushings.

- The hot collar results are analyzed from watts loss. We expect less than 100 mW loss.

3.) Exciting Current

The exciting current measurement is performed by applying an AC (60Hz) Voltage (typically at 10kV) across a primary winding of the transformer, while the secondary and other windings are open circuited. Both current and watts loss are measured and recorded. The exciting current test is a single-phase test, and therefore, a series of three measurements are required to measure the exciting current of each phase. They should be repeated on each tap position. These patterns can then be compared and analyzed.

The exciting current test is used to detect the following transformer failure modes,

- Compromised/shorted Insulation (turn-to-turn, inter-winding, and/or winding-to-ground insulation)
- Core and core ground defects, including magnetization
- Poor Connections and/or open circuits

The analysis of the exciting current measurement is unique, because it does not typically involve applying industry limits or even a comparison to a factory or baseline value. Instead, the analysis of the exciting current measurement involves phase-to-phase or LTC pattern validation and recognition.

Test Preparation:

1.) Ensure that the transformer tank and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Completely isolate the transformer terminals; remove external connections and buswork from H1, H2, H3, X1, X2, X3, and X0.
3.) Isolate X1, X2, X3, and X0 making sure that they are not connected together. All three of these points must remain in the clear. If present, X0 should be grounded.
4.) Document temperatures, humidity, and DETC/OLTC tap positions.

Test Procedure:

Three single-phase tests will be performed. Depending on the rating and burden of the open circuit losses, up to 10 kV will be applied. It is recommended to perform the test in the as found DETC position, while testing each position on the OLTC.

Shown below, in **Table 3**, is a typical test plan for exciting currents on one OLTC tap position.

Table 3 - Exciting Currents

Phase	Test Voltage	Test Mode	Energize	Red LV Lead	Ground	Measure
A	Up to 10 kV	UST	H1	H3	H2	Ima and Watts Loss
B	Up to 10 kV	UST	H2	H1	H3	Ima and Watts Loss
C	Up to 10 kV	UST	H3	H2	H1	Ima and Watts Loss

If the required test current exceeds 200 mA, the test voltage may have to be reduced. The test instrument will automatically stop the test if the current limit has been exceeded.

Expected Results:

The analysis of the exciting current measurement is unique, because it does not typically involve applying industry limits or even a comparison to a factory or baseline value. Instead, the analysis of the exciting current measurement involves phase-to-phase or LTC pattern validation and recognition.

The typical excitation current test data pattern for a transformer is two similar current readings (on the windings of the outer phases of the core) and one lower current reading (on winding on the center phase of the core).

However, other patterns can surface in addition to H-L-H:

1. High – Low – High (HLH) Pattern (most common)

    - Expected for a 3-legged core type transformer
    - Expected for a 5-legged core (or shell) type transformer with a Delta connected secondary winding

2. Low – High – Low (LHL) Pattern

    - Will be obtained on a 3-legged core type transformer if the traditional test protocols are not followed
    - Neutral on high side Wye-configured transformer is inaccessible
    - Forget to ground 3rd terminal on a Delta-connected transformer

3. All 3 Similar Pattern

    - Expected for a 5-legged core (or shell) type transformer with a non-delta secondary winding

Magnetization can and will affect the results.

4.) TTR – Transformer Turns Ratio

The transformer turns-ratio (TTR) test is a functional check of the transformer, used to assess if it is properly transforming voltage, according to the nameplate value. If the TTR test does not "pass", then the transformer is usually not returned to service until the source of the issue has been identified and resolved.

The TTR measurement is used to detect the following transformer failure modes:

- Compromised Insulation (turn-to-turn, inter-winding, and/or winding-to-ground insulation)

- Core Defects
- Severe Discontinuities, Poor Connections, and/or Open-Circuits
- Severe Mechanical Failures (e.g. winding movement or deformation)

Test Preparation:

1.) Ensure that the transformer tank and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Completely isolate the transformer terminals; remove external connections and buswork from H1, H2, H3, X1, X2, X3, and X0.
3.) Isolate H1, H2, and H3, making sure that they are not connected together.
4.) Solidly ground X0.
5.) Isolate X1, X2, and X3, making sure that they are not connected together.
6.) Document temperatures, humidity, and DETC/OLTC tap positions.

Test Procedure:

We are assuming that the vector group is a "Dyn1". Anything from a few volts to several hundred volts can be applied as long as the L-G rating or test instrument ratings are not exceeded.

It is recommended to perform the test in the as found DETC position, while testing each position on the OLTC.

Shown below, in **Table 4**, is a typical test plan for Turns Ratio on one OLTC tap position.

Table 4 - TTR Measurements

Test	Energize	GROUND	Measure	Measure
A	H1$_{RED}$-H3$_{BLACK}$	H3, X0	H1$_{RED}$-H3$_{BLACK}$	X1$_{RED}$-X0$_{BLACK}$
B	H2$_{RED}$-H1$_{BLACK}$	H1, X0	H2$_{RED}$-H1$_{BLACK}$	X2$_{RED}$-X0$_{BLACK}$
C	H3$_{RED}$-H2$_{BLACK}$	H2, X0	H3$_{RED}$-H2$_{BLACK}$	X3$_{RED}$-X0$_{BLACK}$

Expected Results:

Turns-ratio test results shall not deviate more than one-half of one percent from either the adjacent coils (phases) or from the calculated winding ratio.

5.) Leakage Reactance

The field leakage reactance test is an AC (60Hz) short-circuit impedance test, which is performed to detect mechanical winding movement and/or deformation within a power transformer. There are two methods for performing leakage reactance tests, as follows:

1.) Three Phase (3-Phase) Equivalent Test
2.) Per-Phase Test

Test Preparation:

1.) Ensure that the transformer tank and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Completely isolate the transformer terminals; remove external connections and buswork from H1, H2, H3, X1, X2, X3, and X0.

3.) Isolate H1, H2, and H3, making sure that they are not connected together.
4.) Document temperatures and humidity.
5.) Supply #4 solid bare copper conductor and C Clamps/Vice Grips/Channel Nuts.
6.) Solidly short X1, X2, and X3, do NOT include X0; ground X0.
7.) Identify impedance, base power, and base voltage from nameplate.
8.) Verify that the DETC and OLTC are in the nominal rated tap position. If not, three-phase equivalent measurement will not be comparable to nameplate.

Test Procedure:

Six tests are to be performed; 3 (3 Phase Equivalent) and 3 (Per-Phase). A four-wire Kelvin connection will be applied. An AC test current should be injected to establish a 30 -100 VAC drop across the primary winding. **Table 5** and **Table 6**, shown below, provided the connections for both the 3 Phase Equivalent tests and Per-Phase tests, respectively.

Table 5 - Connections for the 3 Phase Equivalent Test

Test	Phase	Terminals	Ground	Short	Measure
1	LL-A	H1$_{RED}$-H3$_{BLACK}$	X0	X1,X2,X3	H1-H3
2	LL-B	H2$_{RED}$-H1$_{BLACK}$	X0	X1,X2,X3	H2-H1
3	LL-C	H3$_{RED}$-H2$_{BLACK}$	X0	X1,X2,X3	H3-H2

Table 6 - Connections for the Per Phase Test

Test	Phase	Terminals	Float	Short	Measure
4	LL-A	H1$_{RED}$-H3$_{BLACK}$	X2,X3	X1 & X0	H1-H3
5	LL-B	H2$_{RED}$-H1$_{BLACK}$	X1,X3	X2 & X0	H2-H1
6	LL-C	H3$_{RED}$-H2$_{BLACK}$	X2,X1	X3 & X0	H3-H2

Expected Results:

The purpose of the 3-Phase equivalent test is to produce a test result to compare to the factory short-circuit impedance percentage value (Z% nameplate), which can be found on the transformer nameplate. A deviation greater than ±3% of the reported value should be investigated.

If one or more of the Per-Phase measurements is dissimilar from the others, a mechanical failure may exist within the transformer, which should then trigger further investigation. We recommend that the measured impedance (Ω) values of the three Per-Phase measurements compare to within ±3% of the average of the three (Ω) values.

6.) DC Winding Resistance

The DC Winding Resistance test is used routinely in the field to validate and assess the continuity of the current carrying path between terminals of a power transformer winding. The DC Winding Resistance test is looking for a change in the continuity or real losses of this circuit, generally indicated by high or unstable resistance measurements. The DC Winding resistance test is used to identify problems such as loose lead connections, broken winding strands, or poor contact integrity in tap changers. Understanding the expected resistance values is important for setting up and performing a DC Winding Resistance measurement. It is recommended to compare phase measurements, review previous results, or consult the factory test report for determining the expected results. Typical transformer winding resistances generally range from a few milli-Ohms (mΩ) to several Ohms (Ω).

It is recommended to compare phase measurements, review previous results, or consult the factory test report for determining the expected results. It is recommended to compare phase measurements, review previous results, or consult the factory test report for determining the expected results.

Performing the DC Winding Resistance test quickly and accurately is often challenging. The challenge is due to the fact that the transformer core must be saturated to remove the reactive component of the test circuit before the resistance can be isolated and measured. Testing low resistance windings is often problematic because in order to achieve an adequate terminal voltage, the injected test current must be relatively large, and saturation may take a long time.

Test Preparation:

1.) Ensure that the transformer tank and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Completely isolate the transformer terminals. Remove external connections and buswork from H1, H2, H3, X1, X2, X3, and X0; verify that all surfaces are clean and dry.
3.) Isolate H1, H2, and H3, making sure that they are not connected together.
4.) Isolate X1, X2, and X3, making sure that they are not connected together.
5.) Solidly ground X0.
6.) Document temperatures, humidity, and bushing fluid levels.

Safety:

- Strictly follow all local safety policies and procedures

- Potential high voltage is present when applying the DC output to test objects with a high inductance

- As long as energy is flowing in the measurement circuit, NEVER connect or disconnect test objects and/or cables.

- Always swap leads at bushing terminals and never at test equipment.

- Use separate clamps for current and voltage connections on both sides of the test object to avoid hazards in case one clamp falls off during the test.

Test Procedure:

Six tests will be performed; 3 on the HV windings and 3 on the LV windings. These tests are shown in **Table 7** and **Table 8**. The optimal current injection level is unknown until the actual test is performed. The tables below recommend current injection ranges. It is recommended that the user start with a default of 1 A DC and 10 A DC, for the HV and LV sides, respectively. The actually injected current will be determined once a preliminary measurement is performed.

Table 7 - DC Winding Resistance - HV Winding

Test	Phase	Current Injection	Terminals	Ground	Float	Measure
1	HV-A	1 - 5 A DC	$H1_{RED}$-$H3_{BLACK}$	H3, X0	X1,X2,X3	$H1_{RED}$-$H3_{BLACK}$
2	HV-B	1 - 5 A DC	$H2_{RED}$-$H1_{BLACK}$	H1, X0	X1,X2,X3	$H2_{RED}$-$H1_{BLACK}$
3	HV-C	1 - 5 A DC	$H3_{RED}$-$H2_{BLACK}$	H2, X0	X1,X2,X3	$H3_{RED}$-$H2_{BLACK}$

Table 8 - DC Winding Resistance - LV Winding

Test	Phase	Current Injection	Terminals	Ground	Float	Measure
4	LV-A	10 - 25 A DC	$X1_{RED}$-$X0_{BLACK}$	X1	H1,H2,H3	$X1_{RED}$-$X0_{BLACK}$
5	LV-B	10 - 25 A DC	$X2_{RED}$-$X0_{BLACK}$	X2	H1,H2,H3	$X2_{RED}$-$X0_{BLACK}$
6	LV-C	10 - 25 A DC	$X3_{RED}$-$X0_{BLACK}$	X3	H1,H2,H3	$X3_{RED}$-$X0_{BLACK}$

Expected Results:

Note: Temperature correction is not required, however it is recommended.
The test results will be compared one phase to another. In the phase-comparison it is expected that the resistance measurements compare to within ±2%, however, ±5% is allowable. Special consideration will be given to measurements below 10 mΩ; small variation can cause large "%" differences.

7.) Sweep Frequency Response Analysis

Sweep Frequency Response Analysis (SFRA) is a diagnostic tool used to assess the mechanical and electrical integrity of power transformers. The SFRA test consists of measuring the transfer function (Vout/Vin) of a power transformer winding over a wide sweep of frequencies from 20 Hz to 2 MHZ. The equivalent circuit of a transformer winding includes the coil resistance and inductance as well as capacitances between the turns and the other windings, and between the winding, the tank wall, and the core. Winding movement and/or deformation will cause changes in these passive RLC elements, thus changing the frequency response of the transformer winding. Deviations in the SFRA Measurements can be used to identify the following mechanical failure modes:

- Radial Deformation (faults)
- Axial Deformation (faults)
- Bulk Winding Movement (transportation)

It can also identify electrical problems such as:

- Broken or Loose Connections
- Shorted Turns (Compromised Insulation)

Test Preparation:

1.) Ensure that the transformer tank and core are solidly grounded, also include both the test instrument and power source ground to this point. We will refer to this point as the "GROUND" node.
2.) Completely isolate the transformer terminals; remove external connections, such as cables, from H1, H2, H3, X1, X2, X3, and X0.

Test Procedure:

Based on the IEEE C57.149 guide, 9 tests are recommended for the Dyn1 configuration. The 9 tests are shown in Table 9:

Table 9 - SFRA Test Plan

Test	Name	Reference	Response	Shorted	Grounded	Test Type
1	HV-A OC	H1	H3	None	None	HV Open Circuit (OC) All Other Terminals Floating
2	HV-B OC	H2	H1	None	None	
3	HV-C OC	H3	H2	None	None	
4	LV-A OC	X1	X0	None	None	LV Open Circuit (OC) All Other Terminals Floating
5	LV-B OC	X2	X0	None	None	
6	LV-C OC	X3	X0	None	None	
7	HV-A SC	H1	H3	X1,X2,X3	None	Short Circuit (SC) Short [X1,X2,X3]
8	HV-B SC	H2	H1	X1,X2,X3	None	
9	HV-C SC	H3	H2	X1,X2,X3	None	

Expected Results:

The test results are to be analyzed in accordance with IEEE C57.149. [3]

Case Studies

Leakage Reactance and SFRA:

This case study is an example of winding deformation identified by both the Leakage Reactance and SFRA tests. The transformer experienced a fault and acetylene gas was produced. After confirming the gas, Leakage Reactance and SFRA tests were performed. **Figure 1** and **Figure 2** present the Leakage Reactance and SFRA tests, respectively.

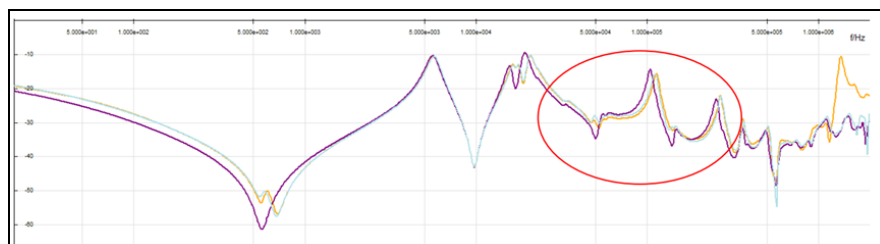**Figure 1** - Leakage Reactance Results

Figure 2 – SFRA Results LV Open Circuit Tests

Both results exhibit an anomaly on Phase B. Winding deformation is expected. Upon internally inspecting the unit, it was clear that there was obvious winding deformation on the Phase B LV winding. This is shown in **Figure 3**.

Figure 3 – Observed Winding Movement LV Winding Phase B

DC Winding Resistance:

In this case study, the winding resistance measurements produced significantly higher readings on OLTC positions 14R and 4L for Phase B, see **Figure 4**. Normal measurements were expected to be in the 25-30 mΩ range. The 14R and 4L measurements clearly exceeded the recommended limit of 2%. At first glance, it appears unusual that separate OLTC positions produce questionable results, however, due to the operation of the reversing switch, these tap positions utilize the same tap lead connection.
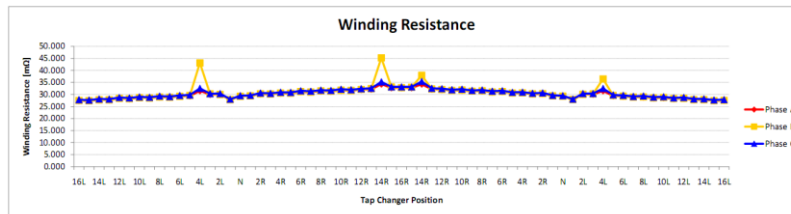

Figure 4 - Winding Resistance Measurements on LTC

Upon further investigation, clear over-heating of connection #7 was observed. This overheating is shown below in **Figure 5**.

Figure 5 - Overheating of Connection #7

Conclusion

- When performed properly, electrical diagnostic testing can provide useful and in depth information regarding the condition of the power transformer. Dielectric, thermal, and mechanical incipient failure modes can be identified.

- Care should be taken to ensure useful results. The test data is only as good as the technician performing the tests. The technician should always know what to expect; utilizing invalid test data can lead to an undesired result in the decision-making process.

- NETA and IEEE standards and guides provide comprehensive information regarding test plans test procedures test preparations, and analysis of the results.

References

[1] IEEE C57.152-2013, "IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers, Regulators, and Reactors".

[2] ANSI/NETA MTS-2015, "Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems".

[3] IEEE C57.149-2012, "IEEE Guide for the Application and Interpretation of Frequency Response Analysis for Oil-Immersed Transformers".

Charles Sweetser received a B.S. Electrical Engineering in 1992 and a M.S. Electrical Engineering in 1996 from the University of Maine. He joined OMICRON electronics Corp USA, in 2009, where he presently holds the position of PRIM Engineering Services Manager for North America. Prior to joining OMICRON, he worked 13 years in the electrical apparatus diagnostic and consulting business. He has published several technical papers for IEEE and other industry forums. As a member of IEEE Power & Energy Society (PES) for 16 years, he actively participates in the IEEE Transformers Committee, where he held the position of Chair of the FRA Working Group PC57.149 until publication in March 2013. He is also a member of several other working groups and subcommittees. Additional interests include condition assessment of power apparatus and partial discharge.