# INSULATION INSIGHTS : MASTERING DIELECTRIC DISSIPATION FACTOR TESTING FOR POWER TRANSFORMER

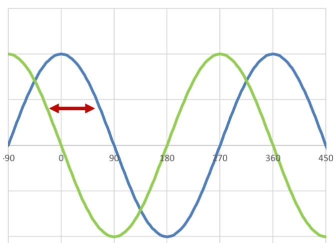
Dielectric dissipation factor testing is one of the critical diagnostic method used to assess the insulation condition of power transformers. This test is typically performed during factory acceptance testing, commissioning, and routine maintenance to ensure the long-term reliability and safety of in-service transformers. By identifying insulation issues early, utilities and maintenance teams can take corrective actions to prevent costly outages and equipment damage.

## INTRODUCTION

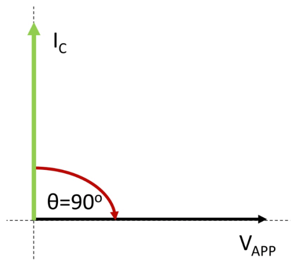

On-site transformer DDF testing

Insulation plays a vital role in the reliable operation of power transformers. The insulation system, typically composed of solid materials like paper and liquid dielectrics such as mineral oil, must maintain high dielectric strength and low conductivity throughout the transformer's service life. However, over time, transformer insulation is subject to various forms of degradation, such as thermal aging, electrical stress, moisture ingress, oxidation, and contamination. As insulation deteriorates, its dielectric properties decline, increasing the risk of partial discharges, dielectric breakdown, and ultimately, transformer failure. To ensure the continued health and performance of a transformer, it is essential to regularly assess the condition of its insulation system. One of the most effective diagnostic tools for this purpose is Dielectric Dissipation Factor (DDF) testing, also known as Power Factor testing.

## THEORY OF DIELECTRIC DISSIPATION FACTOR TESTING

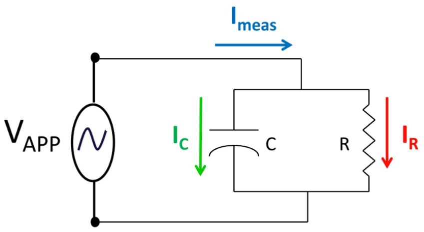



Current leads applied voltage by 90 degrees

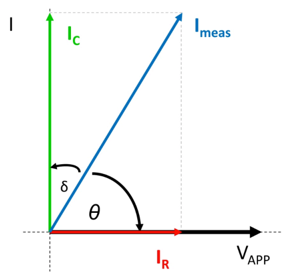



Phasor diagram of capacitive current and applied voltage

To fully grasp the theory behind dielectric dissipation factor testing, it is essential to first develop a solid understanding of dielectric materials and their behavior under electrical stress. A dielectric material is an electrical insulator that resists current flow, making it essential for insulation in transformers and other electrical equipment. An ideal insulator, when subjected to an AC voltage, would only exhibit capacitive behavior, meaning the current would lead the voltage by 90 degrees, with no energy loss. However, real-world insulation materials are not perfect and have some inherent resistance, leading to energy dissipation as heat.




Insulation model when applied with AC voltage



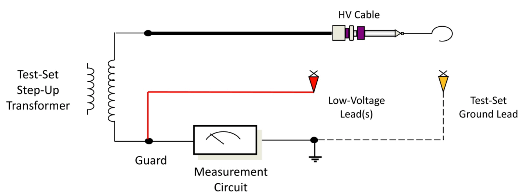

Phasor diagram combination of capacitive and resistive current

The dissipation factor (also known as tan delta or power factor) quantifies this energy loss. It's the ratio of the resistive current component (representing energy loss) to the capacitive current component (representing the ideal charging current). A lower DDF indicates lower losses and better insulation quality.

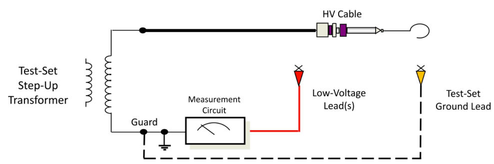
## TERMINOLOGY OF TESTING MODES

When it comes to DDF test, there are three key test modes are commonly used to evaluate insulation condition. Each mode targets different parts of the insulation system and helps isolate specific issues. Those terms are explained as follows:

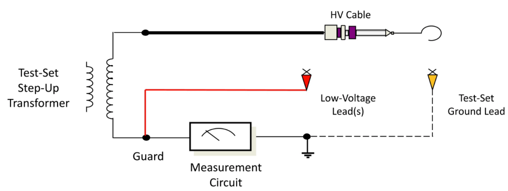
- **Ground Specimen Test (GST) Guard**: In this test mode, it measures the dielectric dissipation factor whereas a guard circuit is employed to isolate and exclude surface leakage or stray currents from adjacent insulation paths that are not part of the intended test area.
- **Unground Specimen Test (UST)**: Used to measure the insulation condition between two ungrounded terminals such as between transformer windings. Unlike GST modes, the UST configuration isolates the test from ground, allowing for the evaluation of insulation between internal components without interference from ground leakage currents.
- **Ground Specimen Test (GST)**: GST mode is used to measure the dielectric dissipation factor between a high-voltage terminal and ground. In this configuration, the measurement captures the total insulation losses including any leakage currents.




GST-Guard test mode



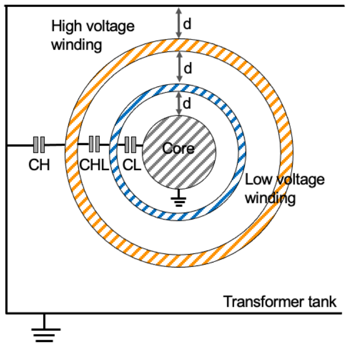

UST test mode




GST test mode

## TESTING PROCEDURE

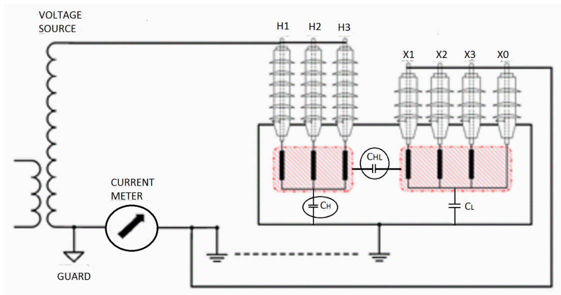
Dielectric Dissipation Factor (DDF) testing is typically performed using a specialized test set, with the transformer de-energized and properly isolated. Initially, the individual windings of the transformer are shorted together, forming a single insulation system for testing purposes. This approach allows for a comprehensive assessment of the transformer's insulation condition across all critical interfaces. In the case of a three-winding transformer, this configuration results in three distinct insulation systems:




Typical insulation of three winding transformer

- CH - insulation between the high voltage winding and ground
- CHL - insulation between the high voltage and low voltage winding
- CL - insulation between the high voltage winding and ground

A high voltage typically up to 10kV will be injected at one winding terminal while the measuring lead of the test set will be connected to other winding terminal. Measurement are taken in various configuration to assess insulation condition to ground and between internal components. The IEEE C57.152 standard outlines the recommended test configurations for dielectric dissipation factor (DDF) testing across different transformer designs, ensuring consistency and reliability in insulation diagnostics.




Typical set-up of DDF test

| Test | Energize | Ground | Guard | UST | Measured | Notes |
|---|---|---|---|---|---|---|
| 1 | HV | LV | — | — | CH + CHL | Validation check |
| 2 | HV | — | LV | — | CH | HV winding |
| 3 | HV | — | — | LV | CHL | Inter-winding |
| 4 | LV | HV | — | — | CL+CHL | Validation check |
| 5 | LV | — | HV | — | CL | LV winding |
| 6 | LV | — | – | HV | CHL | Inter-winding |

| Validation check | Calculation | Results |
|---|---|---|
| 1 | Test 1 – Test 2 | CHL (calculated) |
| 2 | Test 4 – Test 5 | CHL (calculated) |

Test configuration of two winding transformer

| Test | Energize | Ground | Guard | UST | Measured | Notes |
|---|---|---|---|---|---|---|
| 1 | HV | LV | TV | — | CH + CHL | Validation check |
| 2 | HV | — | LV, TV | — | CH | HV winding |
| 3 | HV | — | — | LV | CHL | Inter-winding |
| 4 | LV | TV | HV | — | CL + CLT | Validation check |
| 5 | LV | — | HV, TV | — | CL | LV winding |
| 6 | LV | HV | — | TV | CLT | Inter-winding |
| 7 | TV | HV | LV | — | CT + CHT | Validation check |
| 8 | TV | — | HV, LV | — | CT | LV winding |
| 9 | TV | LV | — | HV | CHT | Inter-winding |

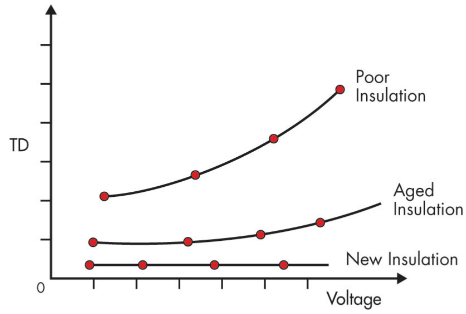
| Validation check | Calculation | Results |
|---|---|---|
| 1 | Test 1 – Test 2 | CHL (calculated) |
| 2 | Test 4 – Test 5 | CLT (calculated) |
| 3 | Test 7 – Test 8 | CHT (calculated) |

Test configuration of three winding transformer

## ANALYSIS OF TEST RESULTS

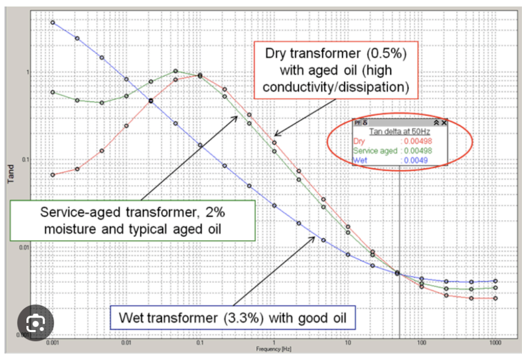
As mentioned earlier, DDF or tan delta value reflects the phase angle difference between the capacitive and resistive components of the current, with higher values indicating greater energy loss which is often a sign of insulation degradation due to aging, moisture, or contamination. There are two common approaches to analyzing DDF test results. The first involves comparing current measurements with historical data to identify trends and assess the progression of insulation deterioration over time. The second approach is to evaluate the insulation condition directly based on the measured DDF value. For reference, a new power transformer typically exhibits a DDF value of less than 0.5% corrected to 20°C, while an in-service unit should generally maintain a DDF value of less than 1.0% at the same temperature. Values exceeding these thresholds may warrant further investigation or maintenance actions.

In addition, further analysis of DDF results can be performed by evaluating measurements taken at different voltage levels and frequency ranges. When the insulation is in good condition, the loss factor values remain relatively consistent across varying test voltages. However, when the insulation quality has deteriorated, the loss factor values tend to increase with higher test voltages. This rise in DDF values indicates the presence of a significant resistive current component within the insulation, suggesting increased dielectric losses and potential degradation.



DDF versus different voltage level

Meanwhile, the DDF value for different frequency range is not constant and varies with frequencies. The specific relationship between DDF and frequency can be affected by the type of insulation, its condition and the presence of defects. Moisture ingress into insulation can cause a significant increase in DDF typically at lower frequencies. Partial discharges which are localized electrical breakdowns in the insulation can cause a rise in DDF values especially at higher frequencies. In summary, DDF measurement especially when combined with varying frequencies, provides a valuable method for assessing insulation condition and detecting degradation due to aging and other factors.



DDF versus frequencies for different ageing condition

## Next Issue : July - Sept 2025

***Built to Withstand:***
***The Engineering Behind***
***Transformer Tank Design***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