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PARTIAL DISCHARGE AND MOISTURE IN TRANSFORMER INSULATION

Understanding How Moisture Increases Partial Discharge Risk

EXECUTIVE SUMMARY

Partial Discharge (PD) is one of the most significant indicators of insulation deterioration in power transformers.

Although PD may originate from manufacturing defects, contamination, electrical stress concentrations, or aging insulation, moisture is often one of the underlying conditions that increases PD susceptibility.

More than 95% of transformer moisture is normally contained within the cellulose insulation system rather than the oil.

As moisture content increases:

- Dielectric strength decreases
- Electrical conductivity increases
- Surface leakage currents increase
- Bubble formation risk increases
- PD inception voltage decreases

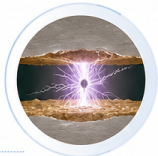
The result is an insulation system that becomes progressively more vulnerable to partial discharge activity and eventual failure.

WHAT IS PARTIAL DISCHARGE?

Partial Discharge is a localized electrical discharge that partially bridges insulation between conductors without causing complete breakdown.

PD may occur:

- Inside paper insulation voids
- At oil–paper interfaces
- Between insulation barriers
- Around sharp conductive points
- Within gas bubbles
- Along contaminated surfaces



Although each discharge contains little energy, repeated activity gradually destroys insulation.

WHY MOISTURE MATTERS

Moisture affects both the electrical and physical properties of cellulose insulation.

ELECTRICAL EFFECTS

- Lower dielectric strength
- Lower PD inception voltage
- Increased dielectric losses
- Increased conductivity

PHYSICAL EFFECTS

- Accelerated hydrolysis
- Reduced mechanical strength
- Formation of microscopic voids
- Increased bubble formation susceptibility

These effects create favorable conditions for partial discharge initiation.

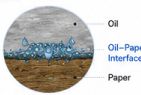
MOISTURE DOES NOT STAY UNIFORMLY DISTRIBUTED

Transformer moisture continuously migrates between paper and oil. Temperature changes cause moisture movement throughout the insulation system.

Research published by CIGRÉ and field investigations presented at the International Symposium on High Voltage Engineering (ISH 2011) show that moisture can become concentrated at oil–paper interfaces.

These localized wet regions may experience:

- Reduced dielectric strength
- Increased electric field stress
- Increased PD susceptibility



This explains why partial discharge activity can occur even when average oil moisture measurements appear acceptable.

MOISTURE-INDUCED PARTIAL DISCHARGE MECHANISMS

1 REDUCED DIELECTRIC STRENGTH

Wet cellulose requires less electrical stress to initiate discharge.

2 FORMATION OF MICROVOIDS

Hydrolysis weakens paper structure and creates microscopic voids where PD can develop.

3 INCREASED SURFACE CONDUCTIVITY

Moisture increases leakage currents and surface tracking.

4 BUBBLE FORMATION

Rapid temperature increases can vaporize moisture trapped within paper insulation. The resulting vapor bubbles have dramatically lower dielectric strength than oil and can become sites for PD initiation.

KEY MESSAGE

Moisture does not directly create partial discharge.

However, moisture significantly increases the probability of partial discharge initiation by reducing dielectric strength and creating localized insulation weaknesses.

vishal@drytrans.com
+971506790417
www.drytrans.com

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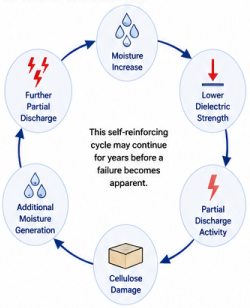
MOISTURE, PARTIAL DISCHARGE AND INSULATION FAILURE

Controlling insulation moisture is one of the most effective ways to reduce partial discharge risk and extend transformer life.

THE MOISTURE–PD AGING CYCLE

Moisture and partial discharge often reinforce one another, creating a self-sustaining deterioration cycle.



WHY OIL MOISTURE ALONE CAN BE MISLEADING

A transformer may contain:

- Wet paper insulation
- Free water
- High PD risk

while oil moisture measurements appear acceptable.

Unless thermal and moisture equilibrium exists, oil test results may not represent the actual moisture condition of the insulation system.

This is one reason why moisture trend analysis is often more valuable than a single oil sample.

FIELD EVIDENCE FROM TRANSFORMER FAILURE INVESTIGATIONS

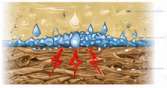
A study presented at the XVII International Symposium on High Voltage Engineering (ISH 2011) investigated multiple transformer failures associated with partial discharge damage.

250 MVA TRANSMISSION TRANSFORMER

Moisture in oil	≈ 24 ppm at 8°C
Relative Saturation	≈ 65%
PD damage observed	Extensive along oil–solid insulation interfaces
Failure mode	Flashover within HV winding insulation
Outcome	Transformer failure

Investigators concluded that high moisture levels were a likely contributor to widespread insulation deterioration and PD activity.

MOISTURE MIGRATION CREATES LOCALIZED ELECTRICAL WEAKNESS



As temperature changes, moisture can concentrate at oil–paper interfaces. These localized wet regions experience lower dielectric strength and higher electric field stress, increasing the chance of partial discharge initiation.

DIAGNOSTICS RECOMMENDED FOR PD AND MOISTURE ASSESSMENT

MOISTURE ASSESSMENT

- IEC 60814 – Karl Fischer Moisture
- Relative Saturation (%RS)
- Water Activity (aw)
- FDS (Frequency Domain Spectroscopy)
- PDC (Polarization Depolarization Current)
- RVM (Recovery Voltage Measurement)

PARTIAL DISCHARGE ASSESSMENT

- IEC 60270 PD Measurement
- UHF PD Monitoring
- Acoustic PD Monitoring
- Offline Electrical Testing

SUPPORTING DIAGNOSTICS (DGA)

- Hydrogen (H_2)
- Methane (CH_4)
- Acetylene (C_2H_2)
- CO / CO_2
- Furans (2-FAL)
- Methanol, Acidity (TAN)

MOISTURE AND DGA TOGETHER

When the following occur simultaneously:

- High or variable moisture
- Increasing hydrogen (H_2)
- Evidence of insulation aging

Utilities should consider detailed PD assessment, dielectric response testing, and offline electrical condition assessment.

WHY CONTINUOUS MOISTURE MANAGEMENT HELPS

Moisture continuously migrates between paper and oil. Periodic oil processing may temporarily dry the oil but often leaves significant moisture inside cellulose insulation.

DryTrans systems continuously remove moisture from the oil phase while the transformer remains energized. This shifts moisture equilibrium and promotes long-term moisture migration from paper insulation.

POTENTIAL BENEFITS

- Higher dielectric strength
- Reduced partial discharge susceptibility
- Reduced bubble formation risk
- Reduced insulation aging rate
- Improved transformer reliability
- Extended asset life and uptime

KEY TAKEAWAYS

- Moisture lowers PD inception voltage.
- Moisture promotes PD activity at oil–paper interfaces.
- Moisture accelerates insulation aging.
- Partial discharge further accelerates insulation degradation.
- Moisture and PD create a self-reinforcing deterioration cycle.
- Managing insulation moisture helps reduce one of the major contributors to PD susceptibility.

vishal@drytrans.com | +971506790417 | www.drytrans.com

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REFERENCES

Key Standards, Technical Papers and Industry Publications

INTERNATIONAL STANDARDS

1	IEC 60270	High Voltage Test Techniques – Partial Discharge Measurements.
2	IEC 60599	Mineral Oil-Filled Electrical Equipment in Service – Interpretation of Dissolved and Free Gas Analysis.
3	IEC 60814	Insulating Liquids – Determination of Water by Karl Fischer Titration.
4	IEC 60422	Mineral Insulating Oils in Electrical Equipment – Supervision and Maintenance Guide.
5	IEEE C57.91	Guide for Loading Mineral-Oil-Immersed Transformers.
6	IEEE C57.104	Guide for Interpretation of Gases Generated in Oil-Immersed Transformers.

CIGRÉ PUBLICATIONS

7	CIGRÉ TB 349	Moisture Equilibrium and Migration in Transformer Insulation Systems.
8	CIGRÉ WG A2/D1	Partial Discharges in Transformer Insulation.
9	CIGRÉ Technical Brochures	Publications on Moisture, Bubble Formation, Insulation Aging and Dielectric Strength.

TECHNICAL PAPERS & RESEARCH

10	Oommen, T.V.	Moisture Equilibrium in Paper-Oil Insulation Systems.
11	Koch, M. & Tenbohlen, S.	Moisture Assessment Using Dielectric Response Measurements.
12	Bolton, C., Lapworth, J. & Ryder, M.	Partial Discharge Problems with Transformers in Service Due to Moisture, XVII International Symposium on High Voltage Engineering (ISH), Hannover, Germany, 22–26 August 2011.

This paper presents multiple transformer failure case studies showing the role of moisture, oil–paper interface deterioration, hydrogen generation and partial discharge activity in service transformers.

13	EPRI Research Publications	Transformer Insulation Aging, Moisture Management and Reliability.
14	IEEE & CIGRÉ Publications	Moisture-induced dielectric degradation, bubble formation and insulation aging in transformer insulation systems.

"Understanding the interaction between moisture, partial discharge and insulation degradation is essential for improving transformer reliability and extending asset life."

REFERENCE NOTE

The technical concepts presented in this flyer are based on internationally recognized IEC, IEEE, CIGRÉ and EPRI publications together with documented transformer failure investigations and moisture-related insulation research.

These references provide the technical foundation for understanding how moisture affects dielectric performance, increases partial discharge susceptibility and accelerates insulation aging.

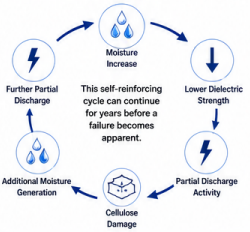
REAL WORLD EVIDENCE MATTERS

ISH 2011 case study (250 MVA transformer):

- Moisture ≈ 24 ppm at 8°C
- Relative Saturation ≈ 65%
- Extensive PD damage along oil–solid insulation interfaces
- Flashover within HV winding insulation
- Transformer failure

This and other investigations confirm that moisture is a major contributor to partial discharge and insulation failure.

THE MOISTURE–PD AGING CYCLE



Breaking this cycle through effective moisture management significantly reduces PD risk and extends transformer life.

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