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UNDERSTANDING MOISTURE SOURCES IN POWER TRANSFORMERS

HOW WATER ENTERS, FORMS, AND ACCUMULATES WITHIN THE INSULATION SYSTEM

INTRODUCTION

Moisture is one of the most significant factors affecting the reliability, performance, and service life of power transformers.

A transformer's insulation system is designed to operate in a dry condition. However, throughout its operational life, moisture continuously enters or forms within the transformer.

Once present, moisture migrates throughout the oil-paper insulation system and influences dielectric performance, insulation aging, thermal behavior, and long-term reliability.

Transformer moisture generally comes from two sources:

TWO PRIMARY SOURCES OF MOISTURE

1. EXTERNAL MOISTURE INGRESS

Moisture entering from the surrounding environment.

2. INTERNAL MOISTURE GENERATION

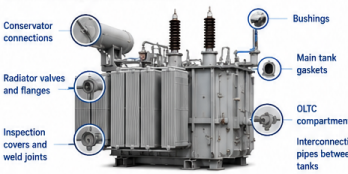
Moisture produced by the aging and degradation of insulation materials.

EXTERNAL MOISTURE INGRESS

External moisture ingress occurs whenever atmospheric moisture finds a pathway into the transformer.

1. OIL LEAKAGE – THE MOST UNDERESTIMATED SOURCE

Oil leakage creates a direct pathway for moisture ingress. Common leakage locations include:



As transformer temperature changes during daily loading cycles, oil expands and contracts. When oil contracts, local pressure reductions can occur. This allows humid atmospheric air to enter through leakage points.

OIL OUT → AIR IN → MOISTURE IN

Even small leaks can introduce moisture continuously over many years.

2. BREATHER SYSTEM DEFICIENCIES

Moisture ingress can increase significantly when silica gel becomes saturated, breathers are not maintained, oil traps malfunction, or seals deteriorate. Humid air can enter the conservator and affect the insulation system.

3. DAMAGED SEALS AND GASKETS

Gaskets and sealing materials deteriorate with age due to temperature cycling, UV exposure, mechanical stress, and environmental conditions, allowing slow moisture ingress even without visible oil leakage.

4. MAINTENANCE AND OPERATIONAL ACTIVITIES

Moisture may enter during oil filling, oil sampling, internal inspections, repairs, bushing replacement, transportation and storage. Improper handling procedures can introduce significant moisture.

5. CONDENSATION

Condensation may occur when internal surfaces cool below the dew point temperature. Water droplets formed through condensation become a direct source of moisture contamination.

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INTERNAL MOISTURE GENERATION AND MOISTURE MIGRATION

INTERNAL MOISTURE GENERATION

Moisture Does Not Always Come From Outside

As the insulation system ages, cellulose paper undergoes chemical degradation reactions that produce water as a by-product. Therefore, a transformer can experience increasing moisture levels even without any external ingress.

CELLULOSE HYDROLYSIS – A SELF-ACCELERATING PROCESS

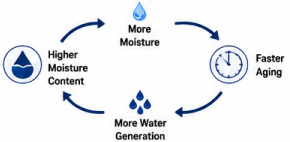
Transformer insulation paper is primarily composed of cellulose. Over time, heat, oxygen, acids, and existing moisture break down cellulose chains through hydrolysis reactions.

Cellulose (Insulation Paper) + **Water** (Moisture) + **Heat** (Energy) → **Degraded Cellulose** + **More Water** (Water is Generated)

As hydrolysis progresses:

- Degree of Polymerization (DP) decreases
- Mechanical strength of insulation reduces
- Additional water is generated
- Aging rate accelerates

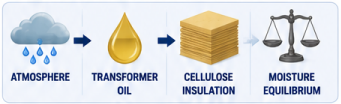
THE SELF-REINFORCING CYCLE



For aging transformers, internally generated moisture can become as significant as external moisture ingress.

HOW MOISTURE MOVES INSIDE A TRANSFORMER

Once moisture enters or forms inside the transformer, it continuously migrates between:

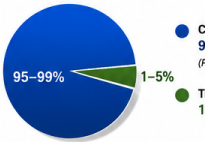


Water entering the transformer first dissolves into the oil. The oil then exchanges moisture with the cellulose insulation until thermodynamic equilibrium is achieved.

Because cellulose has a much greater affinity for water than oil, most moisture eventually accumulates in the paper insulation.

WHERE IS THE MOISTURE LOCATED?

Typical moisture distribution inside a transformer:



This is why oil moisture measurements alone do not tell the complete story. The paper insulation contains the majority of the transformer's moisture inventory.

WHY UNDERSTANDING MOISTURE SOURCES MATTERS

Increasing moisture trends may indicate:

- Active oil leakage
- Breather maintenance deficiencies
- Deteriorated seals and gaskets
- Internal insulation aging
- Multiple moisture mechanisms occurring simultaneously

KEY TAKEAWAYS

- Moisture originates from both external ingress and internal generation.
- Oil leakage is a two-way pathway: Oil Out → Air In → Moisture In.
- Breathers, seals, maintenance activities, and condensation are common ingress sources.
- Cellulose aging continuously generates additional moisture throughout transformer life.
- Moisture migrates between oil and paper until equilibrium is established.
- More than 95% of transformer moisture resides within paper insulation.
- Moisture accumulation is a continuous process throughout transformer operation.

CONCLUSION

Moisture inside a transformer is not simply contamination from the outside environment. It is the combined result of external moisture ingress, internal moisture generation, and continuous moisture migration within the insulation system.

Understanding these mechanisms is fundamental for preserving insulation integrity, extending transformer life, and improving long-term reliability.

REFERENCES

1. T. V. Oommen, "Moisture Equilibrium in Paper-Oil Insulation Systems," *Electrical Insulation Magazine*, IEEE.
2. CIGRÉ Technical Brochure 349, Moisture Equilibrium and Moisture Migration Within Transformer Insulation Systems.
3. IEC 60422, Mineral Insulating Oils in Electrical Equipment – Supervision and Maintenance Guidance.
4. Koch, M. and Tenbohlen, S., Diagnostic Application of Moisture Equilibrium and Moisture Determination in Power Transformers.

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