Transformer Reliability by Design

Even if you buy the best vehicle on the market, you can be sure to have problems without the correct application and maintenance.

Corné Dames is the Managing Director of Independent Transformer Consultants, always striving to keep on top of new developments and research. She has expertise as Laboratory Manager in the analysis of transformer oils and as diagnostician identifying problem areas in transformers, as well as profiling of transformers according to available results thus empowering the customer to take preventative steps in maintenance. Corné has vast practical and theoretical knowledge on reliability maintenance programs. Coming from a strong chemical background she has insight in all the chemical processes that are part of the transformer system. Coupled with technical insight, her knowledge and experience help customers optimize their reliability maintenance and electrical asset lifetime.

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Introduction

Power transformer is the highest cost item in a substation, and a critical piece of equipment at every stage of electricity transmission from a power plant to the end-user. While transformers are significant to electric grids, transformer failures are common and costly. There are many causes of failure: insulation failures, design/manufacture errors, oil contamination, overloading, power line surge, loose connections, moisture, and other artificial or natural causes.

Since transformers are the key components in electric grids in terms of reliability and investment, the reliability of transformers is a primary concern to grid operators. Transformer reliability models are crucial for electric grid design, assessment and operation.

Much research has been done on the reliability of transformers. A condition-based evaluation method was presented to assess the lifetime status of power equipment [1]. This method, developed by ABB Group, is a unit-oriented approach that identifies the most vulnerable units in a population by ranking them according to specific rules. Decision-making on appropriate actions is based on this ranking. Two critical factors that are part of the model to perform a life assessment of transformer insulation in power plants are ambient temperature and load on the unit [2].

Van Schijndel, Wouters, and Wetzer [3] proposed a policy to determine the reliability of a whole transformer population from individual transformer reliabilities by estimating the life expectancies of individual components.

Lower cost choices may lead to more expensive maintenance or loss of equipment at the end of the day. Ensuring equipment suitable for the application and environment is vital for prolonged service and reliability.

Transformer design consists of essential components used to compile the end-product. But a variation in each of these components will deliver a unique transformer with a set application at the end of the design and manufacturing process. Each of these components will chemically and electrically interact within the transformer system. In collaboration with environmental factors, these interactive processes will determine the transformer's end of life and maintenance.

Reliability and lifetime optimization are the main goals for the plant manager. The cost of a short outage is phenomenal. Therefore, failure would be a tremendous cost to the owner when the total cost of ownership is calculated.

Reliable transformers are the result of a proven design, qualified manufacturing process and the right choice of materials for the desired application.

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What is failure?

Any unscheduled situation which requires the equipment to be removed from service for investigation, remedial work, or replacement is a failure. This can be divided into minor and major failures, both with forced and scheduled outages.

Major failure

Any situation which requires the equipment to be removed from service for a period longer than seven days for investigation and remedial work usually requires the transformer to be removed from its plinth and returned to the factory. Also, a reliable indication that the condition of the transformer prevents a safe operation should be counted as a major failure if work of more than seven days is required to restore the original service capability.

Minor failure

This type of failure requires remedial work that lasts less than seven days.

Component choices

Some key components in the manufacture of transformers are bushings, tap changers, insulation materials, and active parts.

A power transformer must withstand tremendous loads during its lifetime. This requires quality down to the smallest detail and carefully selected components. Global reliability surveys indicate that reliability is heavily dependent on excellent quality bushings, tap changers, and the active part. Only the highest quality will suffice; no compromise can be made on these components. First-class certified suppliers ensure the continuous supply of high-quality materials – even during periods of raw material shortage.

"Factory acceptance testing and compliance specifications can't guarantee longevity. One of the best indicators of a design's robustness is short circuit testing of designs and looking at the history of tests from the same design system," it is cited in a white paper by ABB [4].

Specifications have evolved to address changing customer requirements and expectations. This evolution has brought about its own set of challenges; as a result, most specifications don't do as good a job as anticipated. They do not ensure a failproof system to guarantee the desired transformer life.

A common misstep in specification creation is simply adding to past specs, rather than looking critically at the actual performance requirements. It makes more sense to understand the application and requirements, and then design to the material limits while maintaining sufficient margins, than increasing margins unnecessarily. The power grid has evolved over the last few decades – it is more interconnected, with more sources and destinations. This leads to more issues with frequencies and more opportunities for electrical disturbances, the most significant source of failures for transformers and other transmission devices. The point is to include items in the specifications that will influence the unit's longevity.

With all this said, without an efficient maintenance program, the best transformer may fall short of the proposed lifetime expectation. Even if you buy the best vehicle on the market, you can be sure to have problems without the correct application and maintenance.

So, we can argue how much of the reliability is dependent on the design, how much on the application and environment, and how much on the maintenance.

The role of standards

The tightest, best-written specification can't guarantee a 40-year transformer life. The critical issue is the manufacturer's ability to produce a transformer that fully complies with the specification and the buyer's expectations.

Thirty years ago, the customer would personally qualify the facility and a team of auditors would evaluate every function in the factory. The buyer must rely on the manufacturer's quality documentation and standardized systems like ISO. They require documentation of the manufacturers' quality system and plan, inspection and hold points. The buyer wants to understand how quality is assured in the manufacturing facility and during all the processes. That is a critical requirement.

While it provides an excellent foundation to rely on national and international standards for a specification, they don't cover the exceptional cases or specific parameters the customer may need, even for the active parts of the transformer.

Once in service, there are factors that might impact the life of a transformer. The buyer needs to conduct appropriate maintenance. Is the load within the specifications for the unit? Are there significant variations in the load on the unit? Will there be frequent and intense disturbances?

All of this said, it still gives the buyer peace of mind to buy from a proven manufacturer with a recognized quality system in place.

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Selection of transformer fluids and comparison of characteristics to ensure optimum application suitability

The fluid in a transformer directly affects the operation and reliability of the transformer's components. The cooling capability and the unit's reliability depend on the fluid type and quality.

In the transformer industry, we have a choice of three basic fluid types: mineral, silicone and ester fluids.

Fire safety performance

Insulating fluids in transformers are used to cool down the transformer. Where there is heat, there is also the risk of fire. Fires in areas where many people move through or stay might be disastrous. Therefore, fire safety performance of transformer fluids is essential.

1. Fire danger grade comparison

The ignition point for silicone fluid was found to be the highest [5], see Table 1.

Parameter	Test Method	Mineral Oil	Silicone liquid	Synthetic ester fluid
Flashpoint	ISO 2719	150°C	260°C	260°C
Ignition point	ISO 2512	170°C	>350°C	316°C
Fire danger grade	IEC 61039	0	K3	K3

Table 1. Fire performance comparison results [5]

2. Ignition-resistant properties comparison
The ignition point of mineral oil is much lower than that of synthetic ester fluids.

Additional third-party fire certification for the synthetic ester fluid include:

1. UL fire certification – Underwriters laboratory – EOUV Dielectric Medium Classification
2. Factory Mutual Global – FM approved less-flammable transformer fluid
3. SGS BASEEFA, UK – ATEX Certification (Use authentication in potentially explosive atmospheres)

Thus, the higher fire safety performance of transformer fluid can significantly improve the safety performance of various transformer applications.

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Environmental performance

Biodegradability comparison
Biodegradation is when the matter is decomposed and broken down into harmless components, bio-available to the environment, and incorporated into the ecological cycle.

Synthetic esters are non-toxic and biodegradable. The degradation percentage of synthetic esters are 10% by day three, 71% by day ten, and 89% by day 28.

The biodegradation of both mineral oil and silicone oil is less than 10% by the end of the 28-day test period in the study [5].

Risk of water pollution comparison
Umwelt Bundes Amt (UBA) assesses chemicals and divides levels based on biodegradability and the potential impact on aquatic organisms; the synthetic ester is classified as non-hazardous to water environments. Even at levels of 1000 mg/l of water, synthetic esters won't cause harm to aquatic systems. Mineral and silicone oil are classified as hazardous to water. In the case of pollution with mineral or silicone oil, the environmental pollution effects would be severe, and this would last for years.

Reliability
The main components of the transformer are immersed in the insulating fluid. The reliability of the fluid directly impacts the reliability of the transformer.

The transformer fluid might reduce the failure rate of the transformer components. The moisture resistance and oxidation stability might possibly reflect the reliability.

Moisture resistance comparison
When the moisture content of a dielectric fluid increases, the performance of the fluid will be affected. Increased water concentration will decrease the dielectric strength of the fluid.

The breakdown voltage and the water content of synthetic ester, mineral oil, and silicone fluid were compared under laboratory conditions [5]. It was found that the water content in mineral oil and silicone oil is very low; the breakdown voltage decreases rapidly when the water content increases. In contrast to this, the natural water content of synthetic esters is much higher than for the other oils; even when the amount of water increased dramatically (more than 600 ppm), the synthetic ester maintains a high breakdown voltage (more than 75 kV).

The increase in water content will cause accelerated aging of the insulation paper system.

Various studies show that the insulating paper aging rate directly relates to the water content. The increase in the water content of the cellulose paper by 1% reduces the life of the insulating paper by 10%. When cellulose ages, it will release water, aggravating the aging process. The excellent water absorption capacity of synthetic esters will reduce the water content, which will slow down the aging process of the insulating paper.

DES

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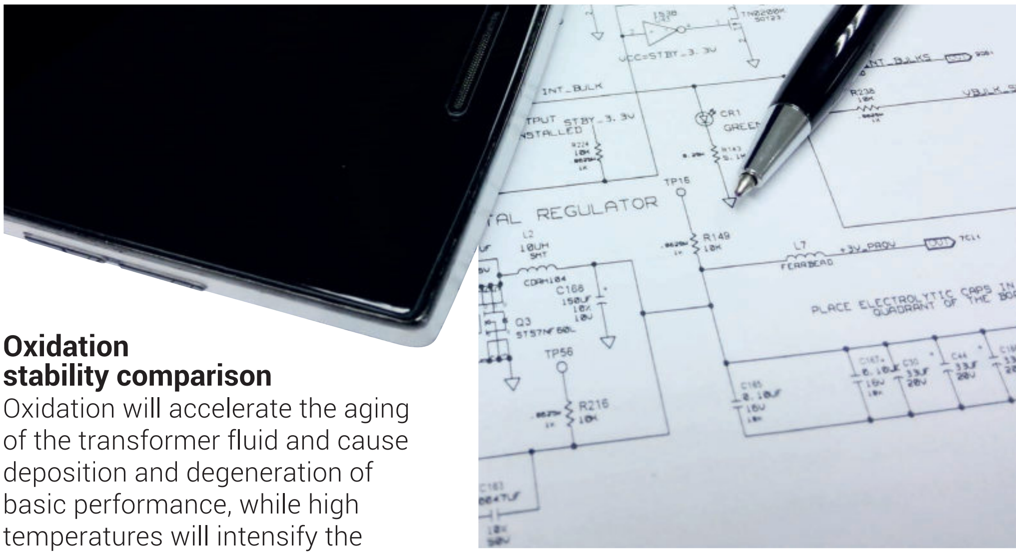

Oxidation stability comparison

Oxidation will accelerate the aging of the transformer fluid and cause deposition and degeneration of basic performance, while high temperatures will intensify the oxidation process. In the tests conducted, it was found that the oxidation stability of synthetic esters is high; however, the oxidation stability for mineral oil and silicone fluids was relatively poor [5].

Aging resistance comparison

The acidity is a crucial indicator of transformer fluid aging. In the study, it was found that synthetic ester did not produce corrosive sulfur or other sediments during aging experiments.

The power grid has evolved over the last few decades – it is more interconnected, with more sources and destinations. This leads to more issues with frequencies and more opportunities for electrical disturbances, the most significant source of failures for transformers and other transmission devices.

Conclusion

The average failure rate is described in a CIGRE survey [6]. In most cases, the faults in tap changers, bushings, and winding-related faults are the most significant causes of failures, while the solid insulation, together with liquid insulation, determines the transformer's life.

Knowledge of material science is indispensable in the transformer business. Reliable transformers are the result of a proven design, qualified manufacturing process and the right choice of materials for the desired application. Further developments in transformer design should be strongly related to the possibilities and limits of transformer materials.

References

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