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SAFETY INSIDE

PROTECTING WHAT MATTERS

in Critical Power Transmission and Distribution

Author: Mark Lashbrook,
Senior Applications Engineer, M&I Materials

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The average cost of transformers has experienced a 5.5% annualised growth rate for approximately 20 years. This typically results in a 100% increase in the cost of a large transformer every 12-15 years, meaning a unit installed 30 years ago at a cost of £300,000 (EUR 390,000 / US$440,000) now has a replacement cost closer to £1.2million (EUR 1.56m / US$1.75m).

THIS WHITEPAPER EXAMINES THE RISKS TO POWER AND DISTRIBUTION TRANSFORMERS, AND HOW POWER UTILITIES CAN MINIMISE THE IMPACT OF UNPLANNED OUTAGES CAUSED BY FAILURE OF THIS CRITICAL EQUIPMENT.

INTRODUCTION

Continual supply of electricity is largely taken for granted in many developed markets and regions across the world. We expect that when we need to undertake any aspect of our daily lives, commerce and business, we can. This dependence on a continuous, and often perceived as endless, power supply is only brought into stark reality during an unexpected outage or power cut. At a time of ever-increasing energy demands, driven by a growing global population and the emergence of developing economies, the requirements placed on critical power transmission and distribution equipment highlight the risks many utilities are dealing with globally.

AN AGEING FLEET

Industrial growth from the 1950s to 1980s in both the USA and Europe created significant investments in critical infrastructure, particularly electrical power supply. However, in recent years this has not kept pace with energy consumption and the demand for power. While this demand has continued at a growth rate of 2 percent per year in established markets, including the USA, Europe and Asia, the number of new transformer installations is declining.

Design engineers anticipate transformers will operate under “ideal conditions” for 30-40 years, and around 20-25 years for industrial transformers, meaning that the majority of the equipment engineered and installed during the boom growth years is now in the ageing phase of its lifecycle. This context is particularly relevant given how the demand for power has changed during this time, which is now reflected in the evolving performance and application requirements of these assets.

Operating an ageing fleet of transformers raises a further concern when it comes to replacing or upgrading equipment in the event of failure. The lead times required from order to installation can be counted in years rather than months for larger, more complex power transformer designs. This is made even more challenging by modern performance criteria, based on external factors such as upgraded safety systems. The consequences of this delay can be significant, particularly where the transformer forms a business-critical role, for example at a manufacturing facility where large quantities of electricity are required to operate the plant.

Combining these factors with the rising cost of replacing utility equipment, and there is an even greater emphasis amongst Utilities, Planning Authorities and key stakeholders, such as insurance providers responsible for covering the asset risk, to focus on the safety and continued operation of the transformer. Despite the conservative nature of the power transmission and distribution industry, there is growing pressure to adopt new technologies that can enhance transformer safety and operating performance.

UNDERSTANDING TRANSFORMER FAILURE

Typically, transformer failures can be caused by a combination of electrical, mechanical or thermal issues. Insurer FM Global indicates that mechanical and electrical failure of components is the main cause of unplanned outages in power transmission and distribution in the UK and Europe. Of these failures, fire is commonly involved due to the use of a flammable liquid, such as a hydrocarbon-based mineral oil, as the dielectric and cooling agent. In the case of transformers, failure of an external piece of equipment, such as an oil filled bushing or on-load tap changer can lead to ignition of the bulk oil in the main tank. The mineral oil will then readily burn once ignited, potentially damaging surrounding equipment and placing lives as risk.

While these are the root causes of failures, the condition of the transformer also plays a significant role. For example, an overloaded transformer with a well maintained insulating fluid is much less likely to fail than the same unit that has had little or no maintenance. Within the above root causes, the most common factors in transformer failure tend to include;

- **Lightning / power surges**
- **Overloading**
- **Inadequate maintenance**
- **Loose electrical and mechanical connections**
- **Deterioration of insulation**
- **Moisture**
- **Criminal damage / sabotage**

Of the above, over the last 10-15 years the second leading cause of failure has been insulation deterioration, which is also linked to moisture ingress, since water accelerates the ageing of cellulose paper.
The dielectric strength of transformer oil also decreases rapidly with the absorption of moisture – as little as one part water in 40,000 parts oil (25ppm) can reduce breakdown voltage by 50 percent at ambient temperature.

A fire event, caused by the ignition of flammable insulation oil, will cause catastrophic failure of a transformer. Such fires cause many problems beyond the direct impact of asset failure and loss. In urban areas the life safety risk is a major concern, and secondary issues can include coordinating an evacuation of the surrounding area, and managing the downtime and power outages following the blaze. It is the protection against this risk, alongside the trend for more environmentally friendly alternatives, that is driving the adoption of more advanced and innovative dielectric fluids.

DRIVING TRANSFORMER FLUID CHANGE

Mineral oil has been commonly used for many years for both cooling and electrical insulation purposes in transformers. However, the development of power transmission equipment to carry much higher electrical loads, plus the need to install these components in more extreme environments, has exposed the shortcomings of this fluid.

> Despite mineral oil being an effective coolant and dielectric insulating fluid in transformers, its drawbacks in terms of flammability and environmental damage risk are substantial.

Electrical and design engineers are now pushing the capabilities of transformers, while still looking to achieve a balance in relation to performance and safety. Advanced electrical and thermal computer modelling is now widely used, which in many ways reduces, rather than widens, the margin for error regarding the safety of the transformer. In previous decades, the safety tolerance designed into the transformer reflected the uncertainty of how the unit would perform when pushed to its operational limit. This rightly led to a more conservative and cautious approach to the design and engineering of the transformer in order to maximise safety.

While this is still the case today, the emergence of more advanced design techniques has placed greater emphasis on anticipating how the transformer performs during higher loads. Therefore, the additional margin of safety that would have been designed into the unit previously has now been reduced. Driving these changing operational trends are asset owners and utilities looking to optimise fleet performance. This is reflected by the emerging practice of increasing the load through an existing transformer, or by extending its intended operational life to minimise the impact of significant capital expenditure.

ESTER FLUIDS AND THE CHANGE IN TRANSFORMER DESIGN

The demand for fire safe, environmentally friendly transformers is growing and both synthetic and natural ester fluids are an ideal dielectric solution for this type of equipment. Synthetic ester is based on a natural source and is referred to as “synthetic organic ester” in accordance with IEC 61099 and 61203 standards. Natural esters are derived from organic sources, such as rapeseed and soybean oil. Despite the possible need for a change in design, there is a growing trend for larger transformers with ester fluids, with these now seen in power transformers up to 433kV. In terms of cost saving, even if the fluid and transformer are more expensive, the removal of ancillary equipment such as fire suppression systems, or reductions in containment, can generate significant savings, help to shorten the installation time and bring the transformer online faster - all of which very quickly offsets the extra capital expense. In addition, there is evidence to suggest that insulating paper will have a 20-25% longer lifespan if immersed in an ester, when compared to mineral oil. This extra lifetime can help to minimise maintenance requirements and reduce the overall cost of an installation if considered over the asset’s whole life cycle.

Key

- Mineral oil transformer
- Ester transformer
- Containment
- 2-hour fire resistant barriers
- Area of substation

Notes

Transformers contain between 19,000 and 38,000 ltr of fluid

Spacing based on FM global datasheets 5-4 April 2016

Spacing based on fire clearances only

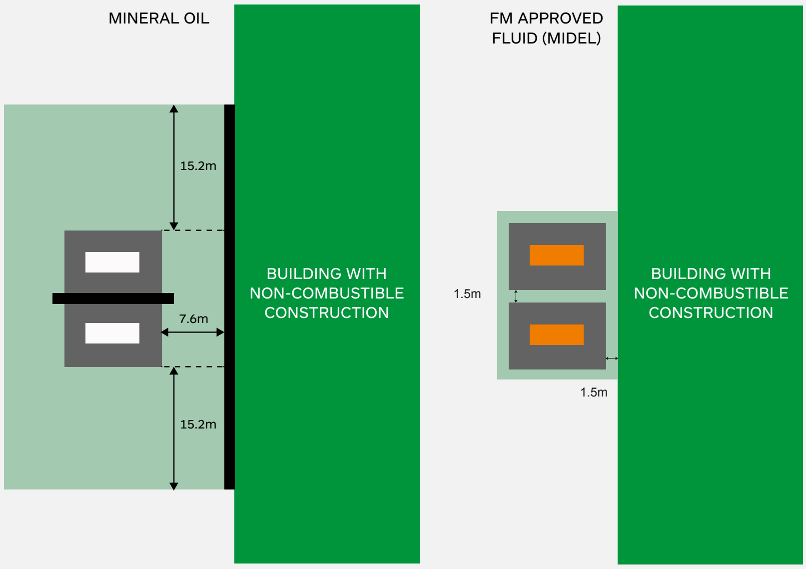
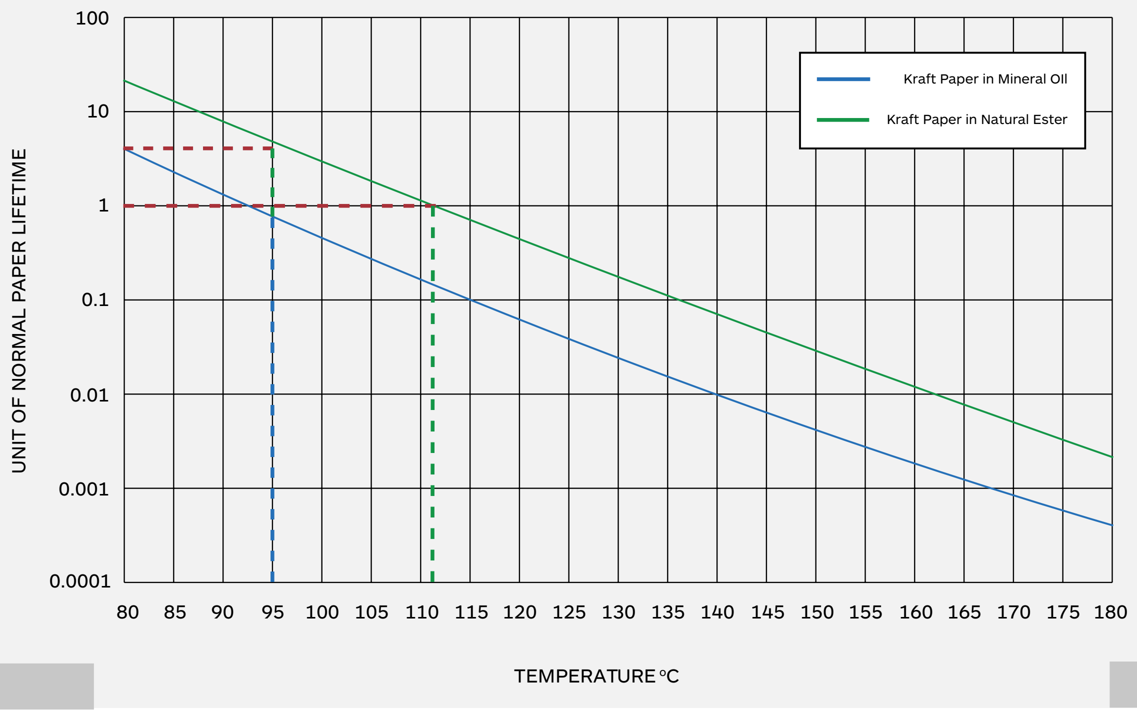


Figure 1: Flash and Fire Points - IEC 61039

FLUID	FLASH POINT ISO 2719	FIRE POINT ISO 2592	CLASSIFICATION TO IEC 61039
Mineral Oil	150°C	170°C	0
Synthetic Ester	260°C	316°C	K
Natural Ester	>260°C	>350°C	K

Transformer fires are a constant threat to power networks worldwide and are particularly unforgiving, spread very quickly and cause extensive damage, often with a tragic loss of human life. Ester fluids are fire safe, helping to minimise or eliminate fire safety measures, and allow for the use of transformers inside buildings and other critical areas where mineral oil would not be acceptable. Figure 1 shows the flash and fire points of mineral oil compared to synthetic and natural esters in relation to the guidance provided in IEC 61039.

Figure 2: Impact of transformer operating temperature on insulation paper lifetime



Source: (IEC 60076-14 Annex C - (2013))

Ester transformer fluids have a very high moisture tolerance and can absorb far greater amounts of water than mineral oil and silicone liquid, without compromising their dielectric strength. Laboratory studies also show that the interaction between water and esters can lead to a slowing of the degradation rate of cellulose paper. Figure 2, created from the guidance contained in IEC 60076-14 Annex C, shows lifetime predictions for kraft paper in both mineral oil and ester-based fluids. The longer predicted lifetime when immersed in esters can be used in one of two ways; either the operational lifetime of the transformer can be extended, or the transformer can be run at a higher temperature to increase the available power output from a given footprint.

Other advantages of using ester-based liquids are a reduced risk of bubble formation during overloads, due to drier paper, and the elimination of free water condensation from the fluid during cool down.

Figure 3: Breakdown Voltage vs. Moisture Content at 20°C (IEC 60156 2.5mm)

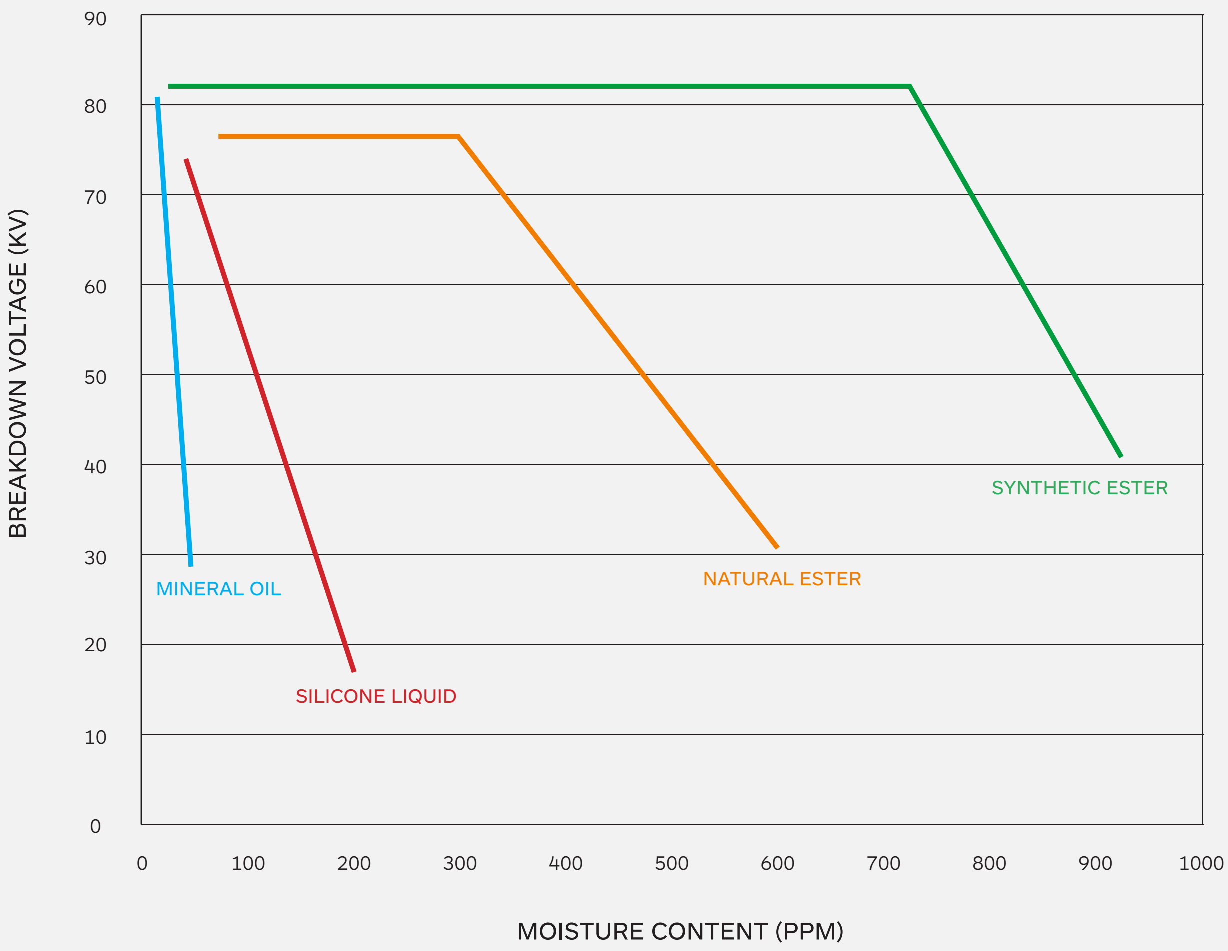


Figure 3 shows the breakdown voltage at ambient temperature of synthetic ester, natural ester, mineral oil and silicone liquid with increasing moisture levels. It clearly illustrates that even a small amount of water in mineral oil and silicone liquid causes rapid deterioration in breakdown voltage. In contrast, esters, and particularly synthetic products, maintain a high breakdown voltage of >75kV even when moisture levels exceed 600ppm.

Using moisture equilibrium curves it is possible to show that for synthetic esters at 60°C, water content in fluid of 200ppm would equate to water content in the cellulose of 1.1%. At the same temperature, mineral oil with a water content of 20ppm would lead to water content in the cellulose of 2.6%. The extra 1.5% of moisture would equate to at least a tenfold decrease in the life of the cellulose.

CONCLUSION

Industry pressures mean that careful consideration of the available transformer fluid options is needed. There is a growing demand for more fire safe and environmentally friendly transformers for a wide range of voltages. And in order to achieve this, transformer fluid specifications need to change from mineral oil to esters during the design phase. Changing specification from mineral oil to a more robust, fire safe and environmentally friendly ester-based dielectric fluid opens up the opportunity for enhanced benefits through increased reliability and reduced maintenance. Experienced manufacturers, such as the team responsible for the MIDEL range of transformer fluids, not only provide high-quality and proven products, but also the technical expertise and application understanding to support the need to go beyond mineral oil.

When mitigating risk is the driving force behind the design and installation of a transformer, there is a clear imperative – driven by sound business strategy and corporate social responsibility - to go beyond the conventional approach to dielectric fluids.

MIDEL across the globe:

CORPORATE HQ/EUROPE
M&I Materials Ltd
Hibernia Way, Trafford Park
Manchester M32 0ZD
United Kingdom
T: + 44 (0)161 864 5417
E: midelsales@mimaterials.com
W: midel.com

USA
M&I Materials Inc.
3441 Lawrenceville Suwanee Rd
Unit D
Suwanee, GA 30024
United States
T: +1 (404) 900 9229
E: midelsales@mimaterials.com
W: midelamericas.com

INDIA
M&I Materials India Pvt Ltd.
Unit No. 504, 5th Floor,
Elegance Tower,
Jasola District Center, Jasola,
New Delhi, 110 025
India
T: + 91 (0)11 6517 7114-16
E: midelsales@mimaterials.com
W: midel.com

CHINA
M&I Materials Ltd
8/F Yueda 889 Centre
No. 1111 Chang Shou Road
Jing'an District
Shanghai, 200042
P.R. China
T: +86 (21) 2230 1771
E: midelsales@mimaterials.com
W: midel.com

UAE
MI Materials Middle East Ltd
P O Box 17452
Office No. 122,
First Floor, LOB 06
Jebel Ali Free Zone
Dubai, UAE
T: +971 55 310 5804
E: midelsales@mimaterials.com
W: midel.com

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