Cold start recommendations for FR3® fluid filled transformers

Reference Data

R2120

IMPORTANT:

This reference guide applies to only transformers filled with FR3 fluid and is not intended to convey safety information. Refer to original manufacturer's Operation and Maintenance guide for additional considerations. All applicable safety codes and procedures must be followed.

INTRODUCTION

Cargill FR3® fluid behaves differently at low temperatures compared to mineral oil. Its pour point is much higher than mineral oil (-21 °C (-6 °F) versus -40 °C (-40 °F) respectively), but this does not represent any limitation for transformer operation or energization under the defined “normal conditions” both in IEC 60076-2 and in IEEE C57.12.00. A transformer filled with FR3 fluid does not require special procedures for cold start (energization) within the lower temperature limits of the standards. Limitations defined by manufacturers of accessories should be observed.

The most critical aspect for the cold start of a transformer is the overall dielectric capacity. Mineral oil may shrink, crack, and create voids as it cools beyond its pour point temperature, representing a risk of dielectric failure. Additionally, and even more critical, is the tendency to condense out water, since mineral oil has a very low water saturation limit at low temperatures (see R2020). FR3 fluid shows a reduced tendency to develop voids when cooled beyond its pour point temperature compared to mineral oil. FR3 fluid has a high water saturation point and it is less likely that water will condense out of the FR3 fluid upon cooling because of FR3 fluid’s higher water saturation point. About 425 mg/kg (ppm) moisture in FR3 fluid is required to saturate it at -20°C (-4°F), while mineral oil is saturated with just 8 mg/kg at the same temperature. The breakdown voltage of dielectric liquids is proportional to the relative moisture content, being typically considered a maximum limit of about 40% for the safe operation of the transformer.

Presence of particles in a transformer dielectric liquids usually lowers the relative saturation limit for reducing the dielectric breakdown strength even further before dielectric breakdown strength is affected.

WHAT HAPPENS TO FR3 FLUID WHEN IT’S COLD?

Cargill’s reference document, R2020: FR3 Fluid Behavior in Cold Temperature Environments[1], presents more details, but, overall there are two aspects to consider:

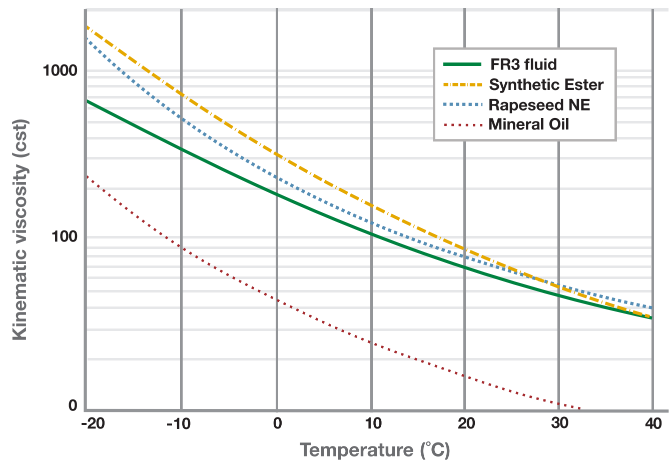

Figure 1
Kinematic viscosity of FR3 fluid, Synthetic ester, Rapeseed NE and Mineral oil.

Physical

As discussed in R2020, there are other parameters aside from pour point to take into consideration for assessing the applicability of the dielectric fluid in transformers operating in cold regions.

Effectively, at temperatures near -25°C (-13°F), FR3 fluid becomes increasingly more viscous and slushy. The total volume of FR3 fluid and the proportion of volume to external contact surfaces are key parameters to estimate how many days of an average temperature lower than the liquid pour point would be required to affect the flow of FR3 fluid inside a transformer. For example, even for a small distribution transformer (single phase 15kVA -25°C (-13 °F)), more than three days would be required to its FR3 fluid content to become slushy.

Electrical

Increasing the viscosity of FR3 fluid, which may eventually lead to crystallization, is a very slow process. As FR3 fluid does not have a well-defined solid/liquid phase transition, voids are not expected. The high solubility with water is also key for maintaining the dielectric capacity of the equipment even at low temperatures. In general at ambient temperature, the moisture content at about 40% of relative saturation is considered a safe maximum.

For a mineral oil transformer to be energized at a temperature of about -20°C, the moisture content should be less than 3 mg/kg, while at this same temperature, an FR3 fluid filled transformer could contain up to 160 mg/kg.

HOW COLD IS COLD?

Transformers, due to their large mass and thermal time constant, require several days to reach equilibrium with ambient temperatures. This is the case even when de-energized. As a result, daily low temperatures do not reflect the true transformer temperature. Daily average temperature (hourly temperatures averaged over 24 hours) is a more realistic measure of operating conditions.

As an example, the U.S. National Oceanic and Atmospheric Administration maintains many years of temperature data (readings taken at the nation's weather stations on an hourly basis, and used to report daily weather conditions). Two noteworthy conclusions can be drawn from the data:

- Daily average temperatures are not as extreme as daily low temperatures reported by local weather people, due to daily cyclical heating.
- Less than 1% of the contiguous U.S., and less than 0.1% of installed transformers experience average daily temperatures of -25 °C (-13 °F) for prolonged periods of time (longer than 3 days), such as Alaska.

More than 1,000,000 transformers filled with FR3 fluid are in service around the globe, including installations in Norway (30,000+ transformers) and Canada (15,000+ transformers). There have been no cold ambient transformer start-up problems reported.

WHAT DOES THIS MEAN IN PRACTICAL TERMS?

It is important to recognize that for transformers in service, the temperature of fluid is significantly higher than ambient. Even "NLL" (no load losses) are sufficient to keep the fluid temperature above any pour point temperature concern. In the event of prolonged outages or extended periods of time where unenergized equipment is exposed to temperatures that are continuously lower than -25°C (-13°F), the viscosity of the fluid would increase, resulting in reduced fluid flow. However, full scale tests[2] confirm that upon energization, transformer losses quickly warm the fluid such that normal flow and cooling result, without undue aging of the insulation system.

GENERAL RECOMMENDATIONS FOR COLD STARTING TRANSFORMERS

The energization of transformers, especially power transformers, should always be performed exclusively by trained personnel under supervision. When this procedure needs to be performed at low ambient temperatures, additional measures are recommended by manufacturers. As an example, the procedure described in clause 3.8.3 of IEEE C57.93-2007[3], has the following statement for mineral oil transformers: "For start-up temperatures below -20°C (-4°F), it is recommended to energize the

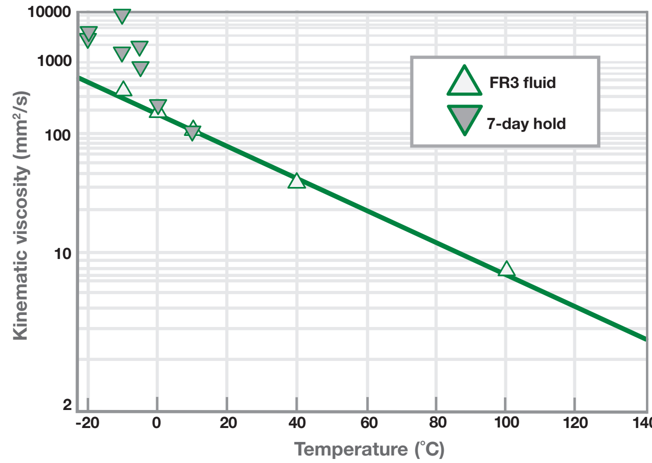

Figure 2
FR3 fluid viscosity versus temperature including values of a 7-days hold test[4].

transformer, hold at no-load for at least 8 hours and slowly increase the load in 10-25% increments, allowing a minimum of 30 minutes between each increment. In cases of directly connected generator step-up (GSU) transformers where energized operation at no-load may not be reasonable because of turbine or steam conditions or fuel cost considerations, other means of heating the oil may be a more reasonable approach.

As described in the referenced standard, the main reason for applying such procedures in mineral oil-filled transformers is the risk of having low dielectric strength at low temperatures due to condensed water in the oil.

Alternatively, for a FR3 fluid-filled transformer, the concern is not the dielectric strength, but the importance of flow as it relates to cooling the transformer. The key concept is to preheat the dielectric liquid before the loading application. The recommendation is to cold start an FR3 fluid filled transformer using the same procedure as used for a mineral oil unit.

MAIN POINTS OF CONCERN

If the main issue is higher viscosity at cold temperatures, no moving components should be actuated before the insulation liquid is warmed sufficiently. Tap changers and pumps are examples of attention points.

Small volumes of fluid, such as in external piping, may also be more prone to cold temperature induced crystallization. The temperature of the fluid during the cold start energizing period should be monitored and confirmed to be adequate before reestablishing the cooling pumps. The transformer manufacturer should be consulted to review their recommendations.

TRANSFORMER COMPONENTS

Each transformer design should be considered unique, making it challenging to define techniques that would fit all cases. However, the following typical constructions represent attention points to consider:

Relay Piping

Using piping for connecting the main tank to the oil conservator (volumetric expansion tank) is a very typical construction for power transformers, most having a Buchholz Relay. The common diameter applied for this piping is 2 in. (DN50) or 3 in. (DN75), while its extension can reach several feet. The large pipe contact surface area at cold ambient temperature versus the small volume of liquid may result in higher viscosity and reduced flow through the piping in comparison to the main tank. Similarly, reestablishing the flow in the piping may take longer than inside the main tank. A sudden loading of the transformer, resulting in volumetric expansion of the liquid, will require flow of the liquid to the conservator, however, a more viscous liquid condition may limit this. In such cases, adding an external heating source, such as a “heating tracer”, may allow the liquid inside the piping to start flowing quickly.

The possibility of using alternative solutions for handling the volumetric expansion is also a topic for consideration.

Radiator Bank

Cooling units independent from the main tank are applied in special transformers. In some cases the oil conservator is installed above the radiator bank, connecting to the main tank by larger single piping. The combination of large contact surface area and small volume may create additional difficulties for liquid flow to start. Some cases may require an independent heating system for the radiator bank and piping. It is important to take into consideration the expected initial loading of the transformer, the separation distance from the main tank to the bank, and the size of the transformer in relation to the cooling unit.

Pumps

Circulation pumps may be damaged if activated while the dielectric liquid viscosity is too high. It is recommended to have an interlock to block pump operation if the oil temperature is too low. The pump manufacturer should be consulted for the appropriate models and operational limits, especially regarding the maximum acceptable viscosity. The values of viscosity at very low temperatures may be taken from the chart in Figure 2.

Fans

The cooling fans are not in contact with the fluid, so, initially, there would be no concern. However, the additional cooling effects enabled by the forced air flow may increase the time for restarting the flow through the radiators. The typical control of the fans is based on top liquid temperature, largely used for transformers with different cooling stages, which minimizes the required time for the fluid to start flowing.

No-Load Tap-Changers (NLTC or DETC) & On-Load-Tap-Changers (LTC or OLTC)

As a general recommendation for new applications, contact the tap changer manufacturer to verify compatibility and operational limits. Where design and climate data warrant it, transformers with automatic on-load tap changers for controlling voltage that are filled with FR3 fluid, should be equipped with a low temperature relay to lock out the automatic control when the fluid temperature is below -10°C (14°F).

For No-Load-Tap-Changers, the mechanical strength of the components is the main concern. Moving the contact ruler inside slushy liquid may require excessive force that can damage the components. To avoid this risk, it is recommended not to operate (or change the tap) the tap changer if the oil temperature is lower than -10°C (14°F).

Other accessories

Follow the manufacturer’s recommended practice.

SPECIAL CONSIDERATIONS FOR SAMPLING THE FLUID

Since the sampling valve (typically located at the lowest point of the transformer) contains a small volume of liquid and the valve component metal “transmits” the cold, there is a higher probability of having very viscous or even crystallized liquid inside the valve. In this case, the service pipe and drain valve should be heated for restarting the flow. It is recommended to follow the procedures given in ASTM D923 Standard Practices for Sampling Electrical Insulating Liquids.

CONCLUSION

The use of FR3 fluid in both power and distribution transformers in regions with very low temperature yields a similar concern as that which already exists for mineral oil transformers: the proper cold starting of the equipment. However, the difference is the type of risk involved. For an FR3 fluid-filled transformer, the concern is related to reduced flow and possible damage caused by mechanical movement of equipment, while in a mineral oil-filled transformer the concern would be the possibility of dielectric failure caused by low dielectric strength.

The important primary statement for safe energization is: “apply the same cold start procedure to an FR3 fluid-filled transformer that is currently practiced for a mineral oil filled transformer. The concept is to preheat any dielectric liquid until the top oil temperature reaches a range of -10°C (14°F) ~ 0°C (32°F), using no-load losses or a liquid processing machine (external source of heat) before applying load.

The hundreds of FR3 fluid-filled transformers such as those in operation in Norway and Canada since the early 2000’s, supports the applicability of the FR3 fluid in such climates.

REFERENCES AND FOOTNOTES

[1] R2020, "FR3 Fluid Behavior in Cold Temperature Environments" Cargill Industrial Specialties, Plymouth, MN, 2017.

[2] K. J. Rapp, G. A. Gauger e J. Luksich, "Behavior of Ester Dielectric Fluids Near the Pour Point," IEEE Conference on Electrical Insulation and Dielectric Phenomena, Austin, TX, October 17-20, 1999.

[3] IEEE C57.93, Guide for Installation and Maintenance of Liquid Immersed Power Transformers, 2007.

[4] The values of kinematic viscosity per ASTM D445 at low temperatures present a relevant fluctuation due to the impact of some early formation of small crystals clogging the small tube used for the test. Measuring the dynamic viscosity per ASTM D7042 and converting to kinematic may offer a more accurate result.

Contact us -
FR3fluid.com

Helping the world *thrive*