



INTRODUCTION

The power factors of transformers filled with Cargill FR3® fluid are usually higher than similar transformers filled with mineral oil.

Power factor testing is more common for power than distribution class transformers (and IEEE C57.12.00 states that power factor is not applicable to distribution class transformers). Some customers request the measurement for both factory quality assurance criteria and for establishing a baseline for preventive maintenance analysis.

Power factor is the ratio of resistance current to capacitance current in an insulation system. The power factor value depends on, among other things, the level of insulation dryness in new transformers. For operating transformers, changes in power factor can indicate increased levels of moisture or other contaminants in the insulation system. Power factor is a diagnostic property most effectively used to monitor trends over time.

There are several variables that impact power factor measurements, even for new, essentially dry uncontaminated units. For liquid filled transformers, the insulation system is comprised of cellulose based solid insulation and a dielectric coolant. The ratio of solid to liquid insulation varies with transformer design. Solid and liquid insulation differ in their dielectric properties. Different types of insulating coolants will also differ in their dielectric properties. Finally, as temperature varies, the power factor will also vary.

To properly evaluate power factor measurements, it is important to understand the variables and their relative impact. This bulletin focuses on the key variables of distribution and power class transformers, and FR3 fluid vs. mineral oil for both classes.

INSULATION SYSTEMS COMPONENT DIFFERENCES

FR3 fluid and mineral oil dielectric loss differences

The chemical makeup of natural esters has a slightly more polar character compared to mineral oil. This translates into a higher dissipation factor, all other variables equal. A comparison of the ASTM and IEEE standards for each fluid type shows this difference (Table 1).

The dissipation factors of fluids and solid insulation also increase with temperature. As a result, the transformer power factor increases with temperature. Temperature correction factors convert power factors to their equivalent at 20°C so that values can be compared. The corrections to 20°C are not precise, and can vary even between the different measurements within the same transformer. Figure 1 shows the approximate range of dissipation factor versus temperature of mineral oil and FR3 fluid.

Table 1
ASTM and IEEE standard fluid dissipation factors for mineral oil and natural ester

Fluid	ASTM, IEEE Standards		IEEE Standards			
	New fluid		Fluid in new equipment		Continued service	
	25°C	100°C	25°C	100°C	25°C	100°C
Mineral oil ¹	0.05%	0.3%	0.05%	0.4%	0.5%	5.0%
Natural Ester ²	0.20%	4.0%	0.5%	-	3.0%	-

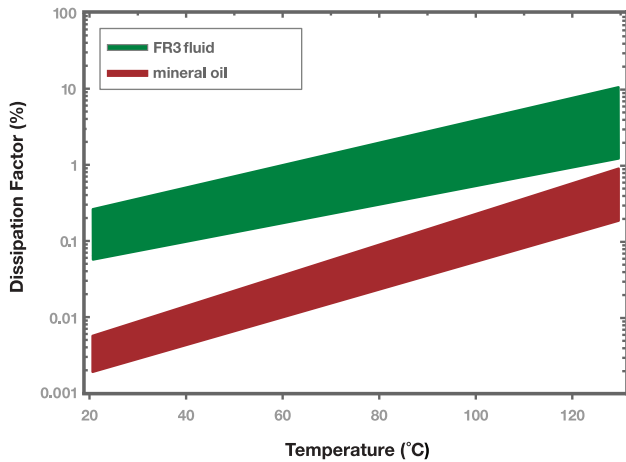


Figure 1
Dissipation factor versus temperature of mineral oil and FR3 fluid

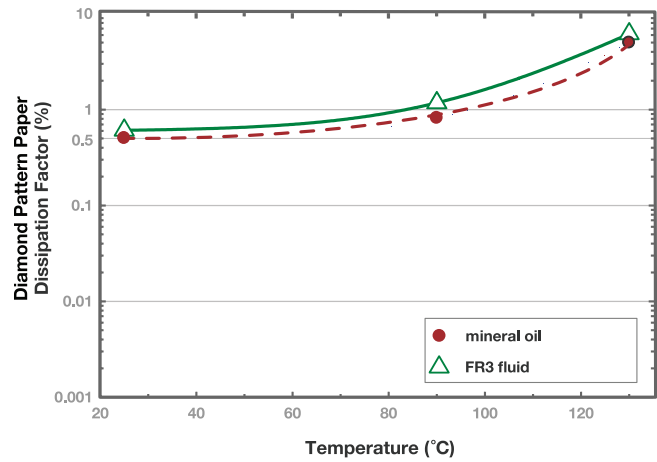


Figure 2
Dissipation factor versus temperature of diamond pattern paper impregnated with mineral oil and FR3 fluid

NOTE: The dissipation factors of the dielectric fluid and solid insulation account in large part for a transformer's power factor.³ Regardless of dielectric fluid type, distribution transformers using the same fluids will have a higher power factor compared to power transformers, even when each transformer holds exactly the same amount of water in its insulation.

SOLID INSULATION IMPREGNATED WITH FR3 FLUID OR MINERAL OIL

Impregnated solid insulation shows a higher dissipation factor with FR3 fluid compared to mineral oil. EHV Weidmann (St. Johnsbury, VT) evaluated the dissipation factors of three types of solid insulation impregnated with mineral oil or FR3 fluid.

Diamond epoxy coated insulating TUK insulating paper, medium density pressboard, and high density pressboard all have similar relative difference in PF, approximately 50% increase, if impregnated with FR3 fluid rather than mineral oil. Figure 2 shows the relative dissipation factor differences vs. temperature.

Insulation systems using FR3 fluid or mineral oil

Insulation system models were constructed using relative proportions of fluid and solid insulation to simulate the high to low winding insulation space of distribution and power transformers. The distribution models had impregnated solid insulation between the windings and the power transformer models had approximately 85% fluid between the paper wrapped windings.

The power factor measurements of the distribution system models using FR3 fluid were approximately 50% higher than the same models using mineral oil. These measurements, in conjunction with distribution production data, indicate that a typical new distribution transformer impregnated with FR3 fluid would have a power

factor measurement around 0.75% vs. an identical unit impregnated with mineral oil of approximately 0.50%.

The power factor measurements of the power system models using FR3 fluid were approximately 100% higher than the same models using mineral oil. This higher relative value for the power models is due to the higher ratio of oil to paper in the insulation system being measured. These measurements, in conjunction with power OEM production data, indicate that a typical new power transformer impregnated with FR3 fluid would have a power factor measurement around 0.40% vs. an identical unit impregnated with mineral oil of approximately 0.20%. See Figure 3.

The above relative differences also apply to retrofilled transformers initially impregnated and filled with mineral oil. However, the initial change in power factor will be less than that of the new FR3 fluid system due to the time it takes for the mineral oil in the solid insulation to exchange and equalize with the FR3 fluid. In general, the time to reach power factor equilibrium will be slower for retrofilled distribution transformers, again due to the much higher paper to oil insulation system ratio.

Figure 3 shows the increase in power factor compared to mineral oil resulting from using FR3 fluid.

The power factor of transformers filled with FR3 fluid is usually higher than similar transformers filled with mineral oil, all other variables equal.

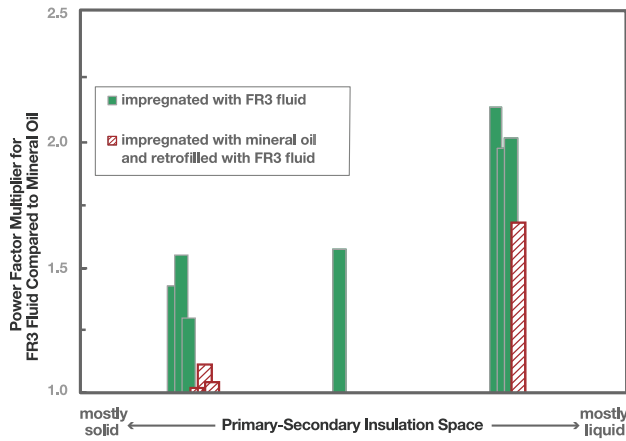


Figure 3
Power factor increase over mineral oil of various winding-winding insulation models using FR3 fluid

TRANSFORMER POWER FACTOR AND DOBLE ENGINEERING

IEEE/ANSI C57.12.00 indicates that power factor should not be considered for distribution class transformers. In power class transformers, IEEE/ANSI C57.12.00 acknowledges the power factor test, however acceptance criteria is not established. Doble Engineering recommends a power factor of 0.5% at 20°C for new power class mineral oil-filled transformers. As an example of how the type of dielectric fluid can affect the transformer power factor, note that the Doble Engineering power factor recommendation for PCB-filled transformers is 3.0% at 20°C.⁴

CONCLUSION

TRANSFORMER POWER FACTOR AND WATER

Generally, when reviewing power factor readings, assumptions are made regarding water content, since reducing water from insulation systems has been proven to lower power factor. As noted throughout this paper, FR3 fluid is inherently different than mineral oil, and distribution transformer insulation systems differ from power transformer insulation systems.

If a power factor is normally specified for new power class transformers, and until Doble Engineering publishes new recommendations for natural esters, Cargill recommends doubling the current mineral oil power factor limit.

IMPORTANT:

If a transformer's solid insulation has been impregnated with FR3 fluid, and is deemed 'wet', hot air drying is an unacceptable process for reducing power factor. See Cargill Storage and handling document S10 for acceptable dry out recommendations.

REFERENCES AND FOOTNOTES

¹ ASTM D3487 Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus, IEEE C57.106 Guide for Acceptance and Maintenance of Insulating Oil in Equipment

² ASTM D6871 Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus, IEEE C57.147 Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers

³ The insulation power factor ($\cos \Phi$) is the ratio of the resistive current to the total current flowing in the transformer's insulation structure. Dissipation factor ($\tan \delta$) divides the resistive current by the amount of capacitive current flowing through the insulation. For very small current values, power factor and dissipation factor of an insulation system are nearly identical.

⁴ From Doble Engineering Test-Data Reference Book TDRB-199, 1992

