Transformer Bushing Failure Signs

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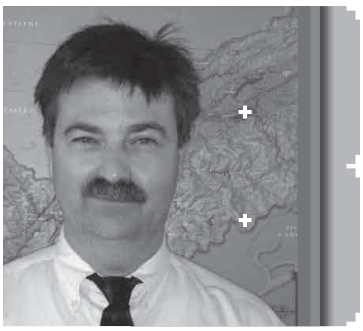

Mark Goff has 34 years of experience working for one of the largest electricity providers in the U.S. where he spent seven years working as a field test engineer and 25 years working as a system engineer for the TVA transmission organization. At that time, Mark actively worked to build an effective transformer, breaker and infrared testing and maintenance program as well as to build talent to support the maintenance and programs. His last position at TVA was manager of the Electrical Energy Conversion group in Generation Engineering. Mark holds BSc and MSc degrees in Electrical Engineering. He is a registered professional engineer in the state of Kentucky since 1988. He is also a member of the T&D World Executive Insights Board.

Small Avoid stakes

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The power industry experience shows that a failure of a high-voltage oil-filled bushing will most likely lead to a catastrophic transformer failure. The fire triangle requires the coexistence of fuel, oxygen and an ignition source. First, the transformer has a large volume of oil as a fuel source. Second, the atmosphere is the source for oxygen. And third, the ignition source which is created by an internal arc from the faulted bushing completes the fire triangle. As the bushing fails, the pressure wave created by an electrical short circuit inside of a faulted bushing will crack the bushing insulator, thus allowing the bushing oil to atomize. Next, the massive amount of oil from the transformer tank is exposed leading to a catastrophic failure. In extreme cases, the transformer tank will split thus releasing the transformer oil at a higher rate. If the electrical protection scheme is slow to operate, then the fire suppression system will have a difficult time in extinguishing the fire.

What is a high voltage bushing?

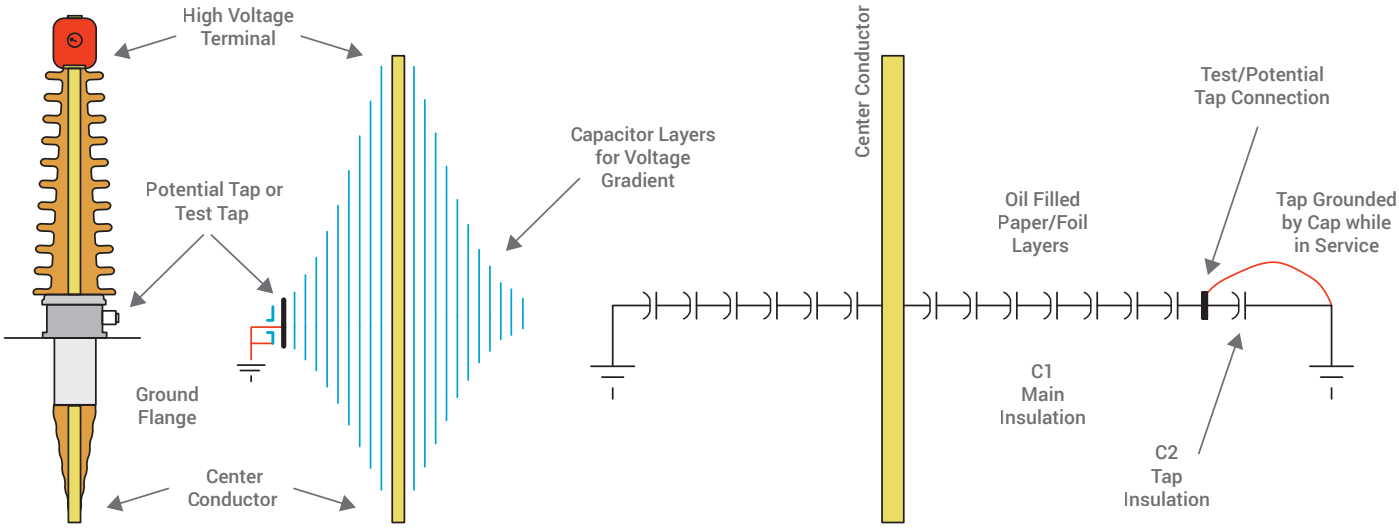
A bushing is a combination of electrical and mechanical components that allows current to pass through a barrier while providing electrical isolation from the barrier. In most cases, the barrier is at ground potential. The core is a conductor usually made of copper or aluminium. The current rating is based on the size and conductivity of the material used. The inside conductor is surrounded by some type of electrical insulation. Lower voltage bushings (34 kV and below) can be made of a solid material such as solid porcelain or some type of oil/resin composite.

In bushings greater than 34 kV, the inside has a different design to deal with the unevenness of the voltage gradient. This design consists of concentric layers of insulation and conductor foils that are contained in an outer porcelain or composite shell. The paper/foil layers form concentric capacitors, which allows the voltage to be graded in a uniform method between the high voltage core and the bushing flange which is at ground potential. This design has a voltage/potential or test tap. While in service, this point is normally tied to ground through a tap cover, but for bushings rated greater that 69 kV, the cap can be replaced with an adapter to feed other instrumentation. In all cases, this tap is used while performing offline electrical test.

The bushings are the most stressed components on a power transformer because the voltage gradients are much higher than the internal windings and components. In simple terms, the physical distance between the high-voltage points and ground potential in a bushing is much smaller compared to the distance from the high-voltage components inside the transformer tank and ground.

In most modern bushings above 26 kV, paper provides the skeleton for the insulation system. The paper is impregnated with mineral oil to provide more insulation and allows for better heat transfer. The outer shell is typically porcelain; however, due to the availability and long lead time for the porcelain shell, bushing manufactures are moving to other designs. But until all of the oil-filled bushings are replaced, a good understanding of the failure signs is needed to prevent catastrophic transformer failures.

Figure 1. Three Illustrations of the same bushing

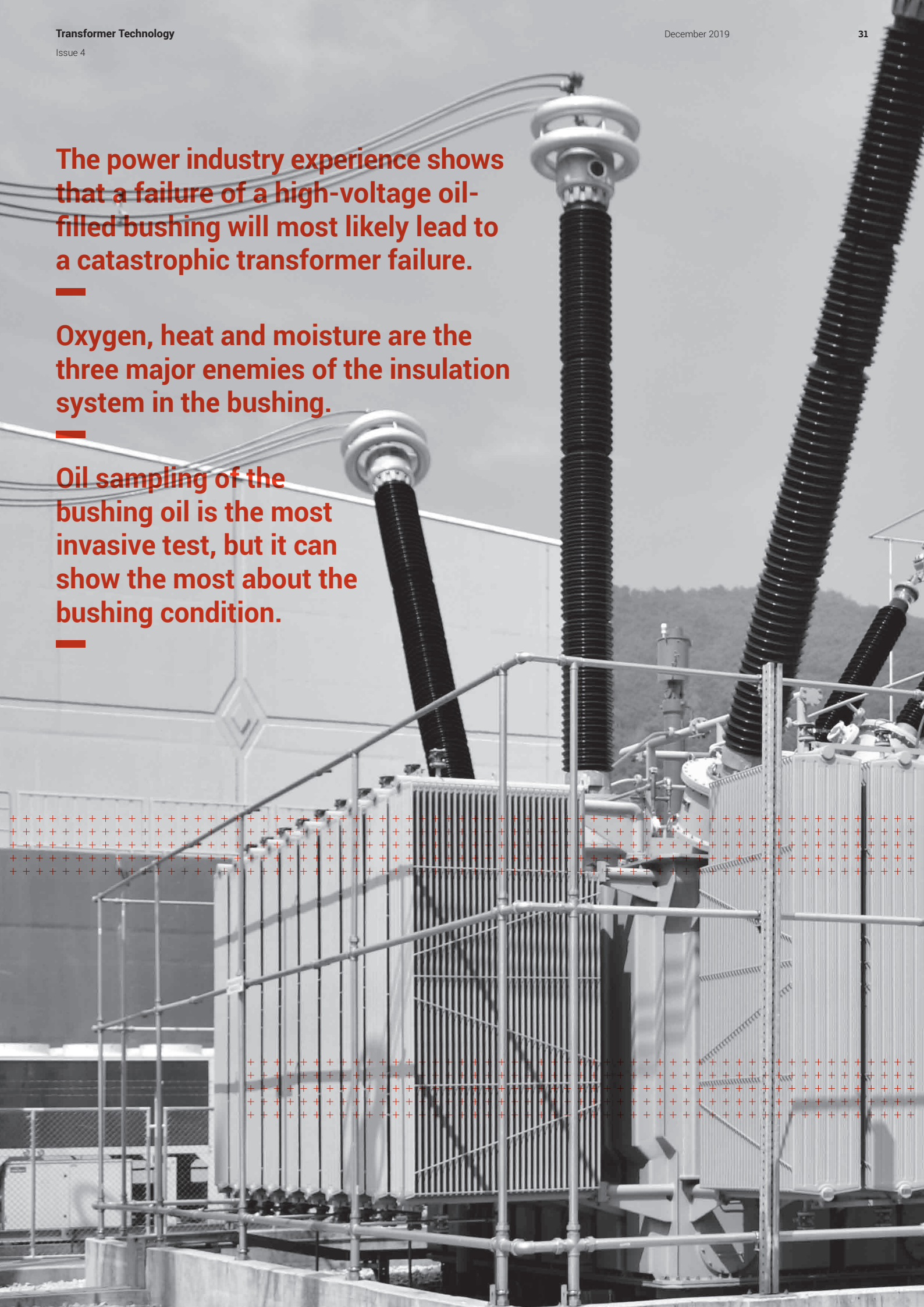


Enemies of the bushing

Oxygen, heat and moisture (Ohm's Law for an insulation system) are the three major enemies of the insulation system in the bushing. Since bushings are sealed from the outside atmosphere, any break in the seal will allow oxygen and moisture to enter the bushing. A good visual indication of a break in the seal are oil level and oil stains. C1 and C2 power factor test is another indicator that contamination has entered the bushing.

Heat is usually caused by a loose external connection. Infrared (IR) imaging, while the transformer is in service, is the tool of choice when looking for a bad or hot connection. IR can also be used on transformers to see the oil level. While oil sampling of the bushing oil is the most invasive test, it can show the most about the bushing condition. Oil sampling can quantify the amount of moisture that has entered the bushing, and also, allow the detection of fault gas accumulation, which gives a good idea of the deterioration of the internal insulation.

Photo: Shutterstock



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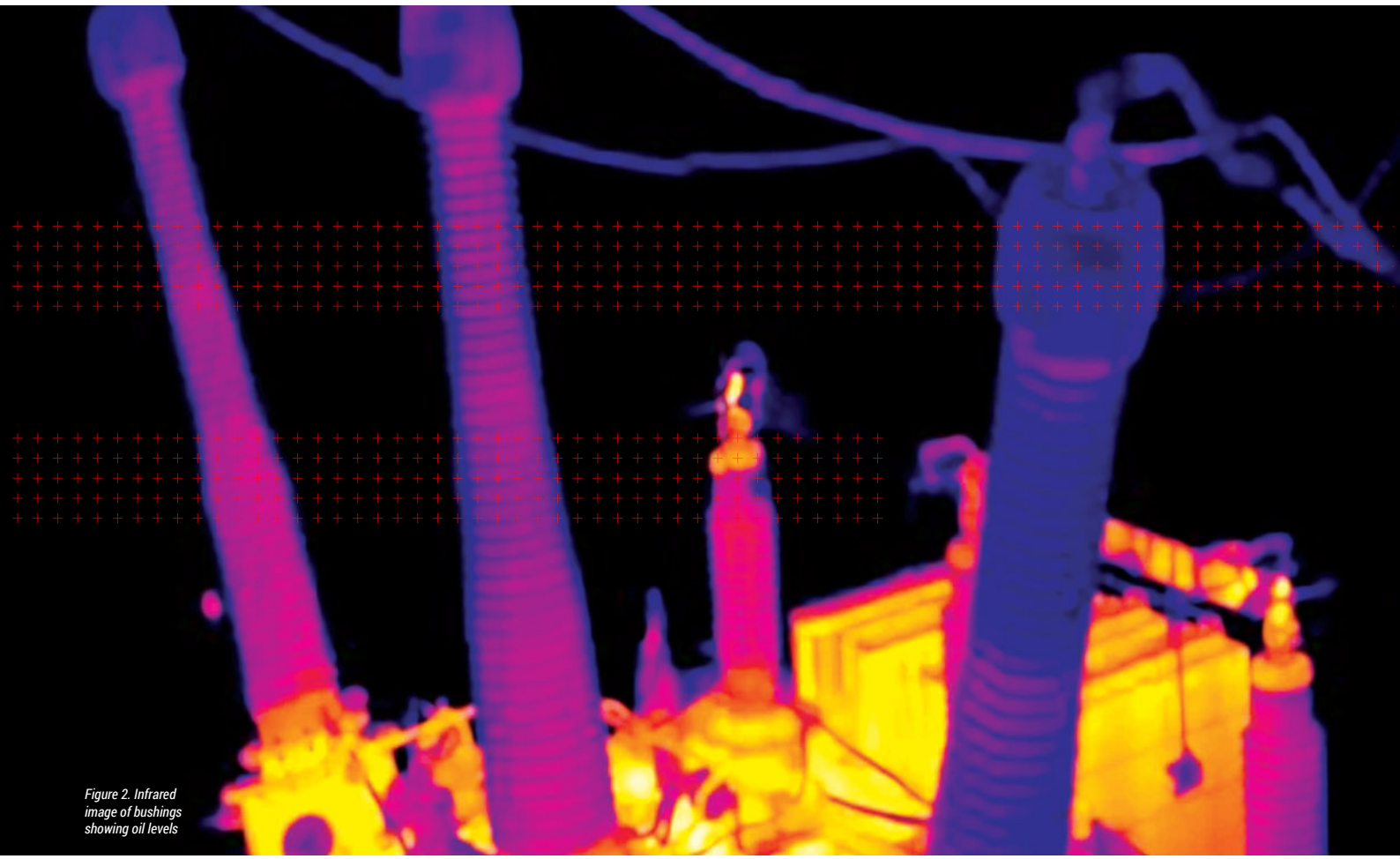

Figure 2. Infrared image of bushings showing oil levels

100 kV – 765 kV bushings

If one of the following statements is true, then use extreme caution around the transformer until it can be de-energized:

- Bushing oil level pegged high or pegged low according to the oil level gauge, sight glass(es) or infrared (IR) image.
- Bushing is showing signs of leaking around the oil level gauge/ sight glass(es)

If one of the following is found while testing, DON'T return the bushing to service:

- C1 power factor is in the "Investigate" range according to Engineering Limit file.
- C1 capacitance is greater than 10 percent of nameplate.
- C1 capacitance is greater than 5 percent of nameplate for a unit more than 25 years old.
- C2 power factor is in the "bad" range according to Engineering Limit file.
- Moisture in oil is 20 ppm or greater.
- Acetylene is 1 ppm or greater.
- PCB is 50 ppm or greater.

Samples are recommended to be taken by only one crew for the entire company to keep consistency with company's oil sampling procedures.

Bushings rated above 345 kV are NOT recommended to be refurbished. If the bushing shows NO acetylene and is rated below 345 kV, it can be refurbished by disassembling, drying, inspecting, re-gasketing, and re-assembling the bushing, which MUST be performed by the OEM or a trusted bushing shop with expertise. After refurbishment, the bushing must pass the overall C1 and C2 power factor test (any voltage level) as well as a partial discharge test (100 kV – 230 kV units).

Special bushing testing recommendations and criteria

It is recommended to perform one-time bushing oil sampling in the following circumstances:

- 345 kV – 500 kV bushings are more than 25 years old.
- 100 kV – 230 kV bushings are more than 30 years old.
- Any bushing greater than 100 kV that shows signs of an oil leak.

Photo: Snell

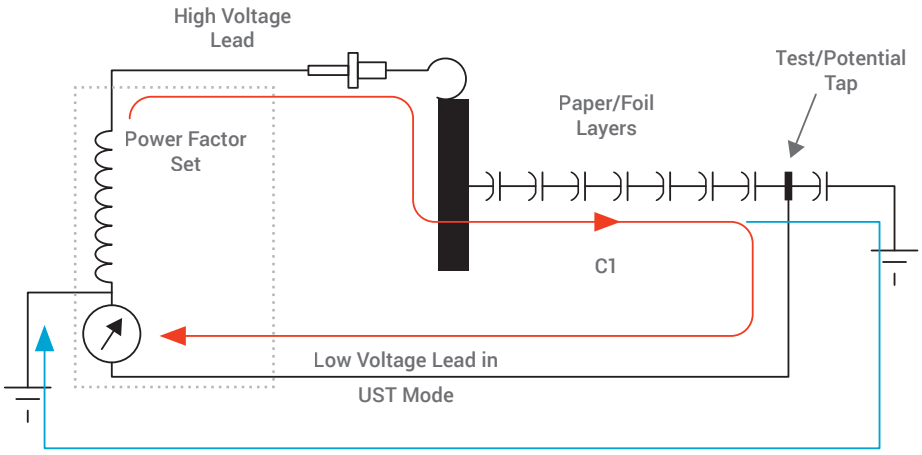

Figure 3. Power factor testing of a bushing (UST test measures C1 power factor and capacitance)

Samples are recommended to be taken by only one crew for the entire company to keep consistency with company's oil sampling procedures [1].

Caution: Oil sampling requires extreme precautions not to introduce contamination into the bushing.

References

[1] Mark B. Goff and Ahmed H. Elton, "Oil Filled Bushing Secrets Revealed," Appendix A, IEEE 978-1-4673-5202-4, IEEE IACC Conference, 2013