Natural Ester-Based Transformer Fluids...

The New Indoor Transformer

By Jonathan Piel

Distribution transformer selection, whether for residential, commercial, industrial, or utility application, has long-term ramifications. Transformers can have lives of 15, 30, and even 50 years or more, depending on their design, loading, application, protection, and maintenance. It is important to evaluate all of the transformer attributes that affect the purchase decision.

Liquid-filled transformers are often not considered as an option for indoor installations when they should be due to historical issues of fire safety, environmental concerns, and special containment. Because of these perceptions, vacuum pressure impregnated (VPI) dry-type and cast-resin transformers have often replaced liquid-filled transformers for indoor and adjacent-to building installations. With this trend, significant liquid-filled advantages have been lost like superior life, efficiency, sound level, overload capacity, contamination resistance, and online diagnostics. Changes in the transformer fluids and listing requirements now overcome the fire safety and environmental issues so that the benefits of liquid-filled transformers can be retained for indoor and adjacent-to building installations.

Developing Fire-Resistant Fluids

In the mid-1970s, several transformer dielectric fluid manufacturers developed fire-resistant hydrocarbon and silicone oils with a firepoint above 300ºC (572ºF). These less flammable oils have replaced traditional mineral oil in tens of thousands of transformers. In nearly 30 years of use and over one hundred thousand units, transformers with fire-resistant hydrocarbon fluids have never been the cause of a building or fluid-pool fire. VPI dry-type and cast-resin transformers cannot claim this same perfect fire safety record.

As a result of these decades of experience, third-party laboratories, insurance companies, and the US National Electric Code have come to recognize this safety record for less flammable dielectric fluids[1]. They now provide special categories classifying the use of transformers with these fluids in and near buildings. Indoor installations may be installed without the requirement of sprinklers, and clearance distances are significantly reduced. While hydrocarbon fluids and silicone oils have improved fire safety, they still fall short of improving environmental compatibility.

Developing Environmentally Preferred Fluids

Since the 1970s, the public has been sensitized to the PCB based transformer oils. While most PCB oil filled transformers have been retrofilled or replaced with PCB free mineral oil, fire resistant hydrocarbon fluids, or silicone oil, the replacement fluids have still not been environmentally preferred.

In the 1990s, Cooper Power Systems (CPS) developed a fire-resistant natural ester based dielectric coolant[2]. Vegetable-based fluids have flash and fire points well above 300ºC (572ºF), typically much higher than their hydrocarbon and silicone oil counterparts. As such, they have a similar exemplary fire safety record and are becoming a preferred technology in and near buildings.

In addition to superior fire safety, these natural ester

dielectric fluids meet the US Environmental Protection Agency criteria as having "ultimate biodegradability"[3]. Tests also show natural ester based fluids to biodegrade more than 97% in just 21 days[3]. Per the same test method, hydrocarbon oils biodegrade less than 30% and silicone oils do not biodegrade.

Fire-Resistance & Containment

Since 1981, based on the concept of a pool fire, the US National Electrical Code has required containment for all indoor liquid-filled transformers. With the 30-year positive safety record of no pool fires, there is a concerted effort to remove this requirement for less-flammable fluid-filled transformers. Beyond the field experience, there have been several "worst case scenario" tests designed and witnessed by nationally recognized testing laboratories. High temperature, high fault current, high voltage tests have been performed under Underwriters Laboratories witness resulting in no ignition of a pool of any listed less-flammable dielectric liquid tested. Similarly, high temperature, sustained high current, low voltage tests have been designed and performed under Factory Mutual Laboratories witness resulting in no ignition of a pool of any listed less-flammable dielectric liquid tested. Certainly, the environmental motivations for containment are significantly reduced with biodegradable natural ester based fluids. In light of experience, rigorous extreme testing, and industry mobilization, there is significant support to remove the current indoor containment requirement.

Containment is most often implemented as containment pans. These pans can typically be purchased from the transformer manufacturer and are designed to form fit the transformer, hold 100% of the fluid, and still be unobtrusive. Typical containment pans do not impede the associated clearance space and do not pose a trip hazard. An alternate to pans can be "room containment" whereby the door to the electrical room has a sill. In these instances, the entire room functions as containment. For multiple indoor transformers, curbing is also an option and may already be in use for hydraulic or heating equipment. In any case, containment can be achieved through simple and inexpensive solutions.

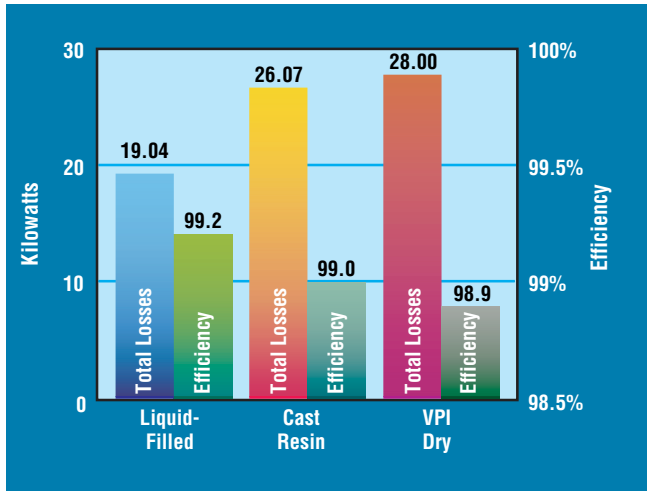
Restoring Performance Benefits

Fluid-filled transformers with less-flammable natural ester based fluids are gaining tremendous momentum. Advances in technology and regulations have overcome traditional reservations about fire safety, environmental concerns, and cumbersome containment. Returning to fluid-filled transformers for indoor and adjacent-to building installation restores performance benefits previously lost. An entire generation of engineers who have never used liquid-filled transformers are re-learning the science behind these advantages.

Efficiency

A small difference in energy efficiency can be significant when valued over the life of the transformer. A differential of just one-half percent efficiency can easily add energy costs that exceed the original purchase price. Standard designs for liquid-filled transformers are typically more efficient than dry-type or cast-resin. This is because liquid-cooled designs are inherently more compact and operate cooler. These advantages allow for a wide range of winding and core materials selection for core and coil construction.

Transformer Losses and Energy Efficiency



2500 kVA transformer.

Liquid-filled transformer in Cathedral Place Office Complex, Milwaukee, WI. Containment pan for 100% fluid.

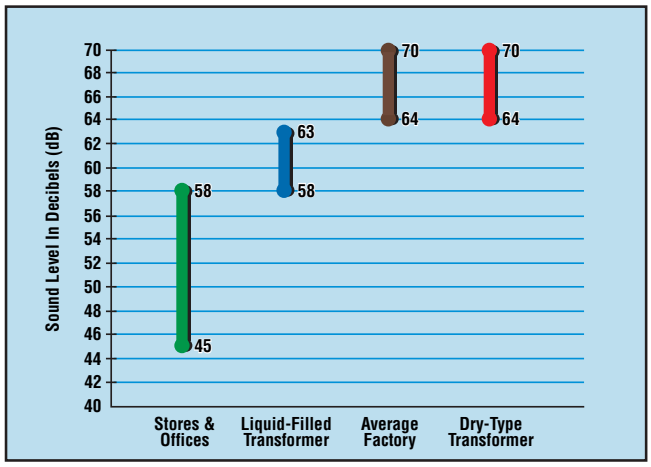
VPI dry-type transformers are commonly designed with a 150ºC temperature rise; and for a 1000kVA unit the efficiency is 98%, resulting in losses of 20kW per hour. In contrast, liquid-filled transformers are commonly 65ºC temperature rise; and for a 1000 kVA unit the efficiency is 99%, resulting in just 10kW per hour. The cost differential is $24 per day or $8760 per year for a fully-loaded transformer.

Recognizing this performance gap, Canada's Energy Efficiency Regulations now require that dry-type transformers meet minimum energy performance standards (effective January 1, 2005). The US Department of Energy is considering similar transformer efficiency regulations. This will effectively eliminate some current dry-type models from the market. VPI dry-type and cast-resin transformers can be designed with the same losses as liquid-filled, but without the cooling and materials advantages, the higher efficiencies come at a significant cost premium.

Sound Level

As illustrated at right, typical sound levels for different locations and transformer types. Decibels, shown on the y-axis, are a logarithmic scale; sound level pressure doubles for each 3 dB. Commercial locations require a transformer noise level much below that of an industrial location. As a result, many dry-type transformer specifications now require sound levels that are lower than dry-type NEMA guidelines. By design, standard liquid-filled transformers run more quietly than standard VPI dry-type or cast-resin transformers. This lower noise level makes them more suitable for sound-sensitive locations. Dry-type and cast-resin transformers can be designed with the same sound levels as liquid-filled, but again at a cost premium.

Typical Transformer Sound Level Ranges



Transformer data taken from ANSI-C89.1 and NEMA TR1

Overload Capacity

Liquid-filled transformers have superior ability to withstand overloading compared to VPI dry-type transformers. The huge thermal storage cooling system of liquid-filled transformers provides better protection from severe overloads that can lead to significant loss of life, and sometimes failure, in dry-type transformers. Under the same ambient and continuous loading conditions, liquid-filled transformers can tolerate greater overloads for longer periods of time without abnormal loss of insulation life[4]. For example, a liquid-filled transformer with a 50% continuous equivalent base load at 30°C ambient temperature could be loaded to 128% of full load nameplate rating for eight hours without loss of insulation life. Under identical base loading and ambient conditions, a dry-type transformer could only provide one hour of 128% overload without loss of life. For a peak-load duration of four hours, dry-type transformers could not exceed 110% load, while liquid-filled transformers could take as much as 150% load without loss of insulation life.

Cast-resin transformers feature a favourable overload capability compared to VPI dry-type transformers but still do not feature the thermal capacity of liquid-filled transformers. Cast-resin transformers are typically twice the cost of dry-type and liquid-filled transformers. Additionally, cast-resin transformers are receiving increased scrutiny for their potential to crack under cyclical load conditions over time.

Contamination Resistance/Maintenance

Dry-type transformers require being de-energized for regular maintenance and inspections. Corrosion and contamination can occur for ventilated transformers and may be accelerated by harsh environments with moisture or fumes. Expensive cast-resin transformers mitigate the problem to a degree because their coils are encased in resin, but they also require periodic cleaning. For all air-cooled transformers, windings should be inspected for dirt, which may restrict airflow and promote insulation breakdown. Maintenance for these transformers typically includes removing contaminates with a vacuum or compressed air (not to exceed 25lb/in2)[5]. Use of liquid cleaners is undesirable because they have a deteriorating effect on the insulating materials. In contrast, liquid-filled transformers are sealed units ideally suited for indoor and outdoor locations and do not require this periodic cleaning.

Diagnostics

VPI dry-type transformers do not offer a simple method of gauging the condition of the insulation. This can result in "melt down" type failures with no advance warning. For dry-type and cast-resin transformers, any diagnostics are typically an offline function. The only popular online diagnostic is a relatively expensive infrared scan. While liquid-filled transformers can also benefit from an online infrared scan, they also feature inexpensive oil sampling and diagnostics. Most three-phase liquid-filled transformers feature a spigot through which trained personnel can draw a small "blood sample" of insulating fluid while energized. For around US$75 this sample can be analyzed and provide traceable information about potential overheating, internal hotspots, corona, arcing, and insulation damage. This "health chart," covering over a dozen attributes, is making liquid-filled transformers the preferred selection for standard and mission-critical facilities alike.

New Choices

Fire-resistant natural ester fluids have redefined the liquid-insulated transformer value proposition. Consultants, engineering firms, contractors, and end-users are rethinking their transformer selection based on the many benefits of using liquid-filled transformers indoors. Since the introduction of ester-based fluids five years ago, dozens of indoor applications are leading the way to restoring these advantages at the lowest first cost and lowest operating costs. Adopters already include major theme parks, steel producers, internet-hosting facilities, insurance companies, religious institutions, office buildings, and manufacturing facilities to name a few. In today's economic, safety, and environmental climate VPI dry-type and cast-resin transformers are no longer the clear alternative they once were for indoor applications. New fluid insulation technologies preserve and improve on the performance advantages of liquid-filled designs while providing excellent environmental and safety benefits. **Ω**

Footnotes

[1] Less and Nonflammable Liquid-Insulated Transformers, Approval Standard Class Number 3990, Factory Mutual Research Corporation, 1997.

[2] C. P. McShane, "Relative Properties of the New Combustion-Resistant Vegetable Oil-Based Dielectric Coolants for Distribution and Power Transformers," IEEE Trans. on Industry Applications, Vol.37, No.4, July/August 2001, pp.1132-1139, No. 0093-9994/01, ©2001 IEEE.

[3] "The Environmental Technology Verification Program", U.S. Environmental Protection Agency, Washington, DC, VS-R-02-02, June 2002. [Online] http://www.epa.gov/etv/pdfs/vrvs/06_vs_cooper.pdf

[4] IEEE Guide for Loading Mineral-Oil-Immersed Transformers, IEEE Standard C57.91-1995, 1996.

[5] Transformer Maintenance [Online].
Available: http://www.alfatransformer.com/transmaint.htm

Jonathan Piel is Envirotran Field Engineer with Cooper Power Systems in Waukesha, Wisconsin.