Options for moisture control in power transformers

With on-line moisture abatement, transformers not only perform better, they also last longer

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Layers of specialty grades of paper impregnated with transformer oil still constitute the insulation par excellence for the copper windings of a power transformer.

There is just one little problem: the paper has a great affinity for moisture. Unabated, moisture inevitably accumulates over the years, even in the most well-maintained transformers, until it eventually begins to show what it can do to dielectric strength… and to transformer service life, cut short by a decaying insulation system.

There are now technical solutions for two strategies for dealing with moisture. There are the conventional methods of rapid paper dry-out while the transformer is de-energized that traditionally are deployed when electrical performance finally becomes threatened by high levels of moisture built up in the paper over many years.

And there is the moisture abatement systems introduced in the past several years designed for use while the transformer is on line. They provide designers and maintenance personnel of electrical plants with a temporary way of dealing with normal moisture accumulation through frequent dry out of the oil — in one case, even continuously, as permanent adjunct to a transformer installed at the factory or in the field.

The problem with moisture

As a practical matter, moisture accumulates in all transformer designs over the years. Some 98 to 99 percent of it becomes diffused in the tons of paper (cellulose) insulation, the rest in the transformer oil.

Without moisture maintenance (not just monitoring), every power transformer over 15 to 25 years of age can be expected to be “wet,” that is, containing 2.5 to 5 percent of moisture by paper weight, or more.

The dielectric experience — and the potential for serious damage to the transformer — at these levels of moisture is well known and traditionally the reason for dehydration.

The paper becomes scarred by electrical phenomena that occur in the presence of moisture, such as flashovers between windings, treeing, and creeping discharges. And dramatic temperature changes can bring on the sudden migration of moisture to or from the paper insulation that give rise to the formation of “free water” (or “rain”) slowly draining to the bottom or water vapor rising to the top — events that jeopardize the unit.

You can think of three principal sources of the moisture building up in the transformer. The paper insulation brings with it some moisture from the factory — in the range of 0.5 to 1.0 percent (bone dry paper is brittle).

Over time there is inevitably some ingression. Free-breathing units can add 0.2 percent per year, and sealed units don’t entirely prevent ingression.

And then there is a third, and significant, source: moisture produced as a byproduct of the natural aging of the paper insulation.

The speed of the aging process — and the rate at which it yields moisture — is contingent on the amount of moisture in the insulation. It is an exponential relationship, for all practical purposes that cuts both ways: the higher the rate of degradation, the more moisture byproduct, and the accumulation further speeds the aging process.

The process becomes materially detrimental (debilitating) at fairly low levels. At 2.5 percent to 3 percent of moisture in the insulation by weight, the rate of aging begins to accelerate. (This is also where dielectric breakdown strength takes a critical turn for the worse.)

During years of build-up, serious damage is done to the insulation. At 4 percent moisture, the paper ages at a rate that is 20 times faster than at factory moisture level. And high temperatures spur the degradation on.

As a result of the aging process, fibers become loosely bonded and the paper weak, as it begins to shed fibers and disintegrate. Cellulose particles shed from decaying paper insulation saturated with moisture, and other aging byproducts, now further reduce dielectric performance.

Ultimately, the transformer's usefulness is determined by the condition of the insulation. Years or decades of service can easily be lost.

Which brings us to the important new benefit of on-line dehydration: the opportunity to extend service life. Applied in the field, a wet transformer can gradually be dried out and kept dry. Applied on a new unit at the factory, or in conjunction with major repair in a service shop, an on-line dehydration system can be used to perpetuate a factory dry state, removing moisture as a factor affecting service life and electrical performance.

This is, of course, the best strategy to safeguard service life – and electrical performance: avoiding long periods of moisture build up; ideally, keeping the paper insulation factory dry throughout its service life

Off-line drying

Conventional methods work directly on the paper insulation.

In the field, the most commonly used methods involve transferring all or most of the transformer oil into some temporary storage vessel (such as a tank trailer) in order to expose the paper insulation. Then, in a cyclical fashion, the exposed insulation is heated to drive moisture out of the paper, followed by the application of a vacuum to remove released moisture.

The heating techniques can involve hot air, or hot oil sprayed from a manifold at the top of the unit.

The methods are old, cumbersome, and not very effective. Furthermore, the cost associated with performing these procedures, and with keeping the transformer off line; often influence the decision on how far to reduce the moisture level.

Most effective is "vapor phase" dehydration, which restores dryness to its original factory level. The vapor of hot kerosene is used to heat the paper insulation while the whole transformer is situated in a vacuum environment. However, the process can only be performed at a factory or by a well-equipped service facility.

Strategically, the conventional dehydration methods are fundamentally reactive moisture maintenance tools used for the purpose of upgrading the electrical performance of a wet transformer. A reluctance to use them frequently on individual transformers is understandable: off-line process, high cost, lost DGA signature and other transformer history. And, of course, the moisture buildup starts all over again as soon as the unit is brought back on line.

On-line dehydration

The on-line methods dehydrate the paper insulation via insulation oil. The idea is premised on the migration of diffused moisture that takes place between the paper and the oil insulation at normal operating temperatures of power transformers. To the extent that the oil is dehydrated over an extended period of time — the migration is slow — it becomes possible to reduce the moisture in the paper insulation.

The methods are not intrusive; the operating history of the transformer is preserved. And they are economical; on balance providing a feasible way of leveling off the moisture build up, and through frequent or continuous application, maintaining a reasonable moisture level, or a factory dry state.

One method brings about dehydration in a vacuum condition. In one such process, the oil from the transformer is pumped into a vacuum chamber through a nozzle that produces a cone-shaped film with a large surface. An air stream injected into the chamber, which — because of the sudden drop in air pressure and relative humidity of the air stream — captures moisture diffused in the oil. Dehydrated oil collects at the bottom of the chamber, and is returned to the transformer via particle filtration and de-aeration.

Another method is based on filtration. The transformer oil is continually circulated through vessels filled with some type of filtration medium — notably cellulose or hollow glass fibers — that gradually absorb moisture diffused in the oil.

A third technology is based on molecular sieve a**d**sorption. Transformer oil is circulated through a series of cartridges filled with a granular ceramic material (ceramic silo beads) that through a process of adsorption removes moisture diffused in the transformer oil.

The medium permits slow and gentle moisture removal, compatible with the pace of the migration between the insulation paper and the oil, and effectively retains trapped moisture.

System characteristics

The filtration and vacuum type systems are typically mounted on small trailers so that they easily can be moved between transformers or plant sites. Other designs are stationery, and must be positioned adjacent to the transformer on its concrete pad.

Hose connections are used to draw oil from the transformer — typically from bottom drain connection of a transformer — and returning oil to a top fill valve. The systems are equipped with alarms and valves that shut down and isolate the equipment from the transformer in case of an emergency.

Programmable logic control supervises the operations and archive progress data. Different systems allow continuous, fully automated, and unattended operations for weeks or months at a time, with the exception of intermittent manual inspection of instruments and replacement of filtration media.

The molecular sieve process is designed for permanent use on a transformer; the system is all stainless steel construction. Besides one to three dehydration cartridges, the system design comprises only a small circulation pump, along with oil particle filter and de-aerator prior to the exit valve.

Applied on new or just repaired and dried transformers, the system can be configured to perpetuate the factory dry state of the paper insulation. By adding molecular sieve cartridges, more aggressive drying can be achieved with a field-installed system intended to first dry out wet transformers.

The system is frequently installed directly on the transformer, usually on the side of the main tank, or on a cooler (radiator). It can also be mounted on a freestanding rack.

Hard plumbing is used for the connections. The location of the insertion point in the transformer's oil systems is not critical. It is usually most convenient to incorporate the dehydration system with the main oil pipes leading to and from the radiator bank. This provides access to hot oil in close proximity to moisture laden winding insulation.

The frequency with which cartridges are replaced depends on the amount of moisture removed — every few months on a large, wet transformer, every five or six years when perpetuating a dry state.

The ceramic medium used in the molecular sieve cartridges can be regenerated. It does not allow the adsorbed moisture to flow back into the return oil stream to the transformer. The beads must be baked at 180 deg. C in order to release adsorbed moisture.

Compared to the direct costs associated with off-line dehydration, the on-line system solutions are highly economical to purchase and use. There are examples of electric utilities that draw on fleets of trailer-mounted filter-type systems to service transformers in a grid. A field installation of a the molecular sieve system will dry out a wet transformer at approximately one-fifth the cost of conventional vapor phase dehydration at a service facility, and at one-third the cost typically associated with field-use a heat-and-vacuum process.

In the dehydration of a wet transformer, the systems can be set to gradually reduce the moisture level in the paper insulation to a predetermined level in order to safeguard against the possibility of "over-drying" and consequent possible need for re-clamping.

Re-clamping is difficult to perform in the field and not possible with some transformer designs. It is also obviously intrusive and best performed in a shop.

Stopping the dehydration of a wet transformer at about 1.3 percent moisture by weight of dry paper, in most cases will avoid the need for re-clamping. This is a safe level dielectrically, and if maintained slows insulation aging considerably. If the transformer is equipped with "back-to-back" springs, re-clamping becomes a mute point.

The systems can be equipped with moisture sensors to monitor the progress. The Doble *Domino* instrument is easily adapted to the DryKeep™ system.

Selection considerations

Experience gained from the various design strategies and the use of on-line systems over the last several years point to a few considerations with regard to choice and operation:

- Size (the rating) of the transformer, load conditions and load requirements, the nature of the ambient environment, moisture levels and a host of other factors should guide the development of system specifications.
- Moisture flow back is detrimental and should ideally be counteracted in the system design. The phenomenon involves the sudden, inadvertent release of retained moisture into the return oil stream.
- The return flow should be filtered for particles and de-aerated to prevent the introduction of oxygen.
- Safeguards should be in place against "over-drying," a condition which would require re-clamping of the coils if back-to-back springs are not employed.
- The operation of the dehydration system should not disturb ongoing dissolved gas analysis, remove oil inhibitors, upset oxidation stability, or introduce other side effects affecting the condition of the oil.
- Filter cartridge replacement should be effected while transformer is on line.

- Means of monitoring and recording the rate of moisture removal, whether with a permanent instrumentation or portable gauges, are essential.
- Other considerations include the cost of the moisture removal media; worker safety and electrical risk to the transformer; labor and associated requirements with regard to the operation and maintenance of the systems.

A word of caution concerning the rate at which the oil is dehydrated. Gauging the moisture levels in the oil streams entering and exiting the system provides an excellent indication of the effectiveness of the removal of moisture in the oil. But is not necessarily indicative of the rate of dehydration of the paper insulation; it may be much slower.

The oil dehydration rates of the on-line systems are contingent on many factors: operating principle, moisture content of the oil, the oil's temperature, viscosity, and the stability, the types of additives present in the oil, and others.

However, lowering the moisture content in the paper insulation is ultimately linked to the rates at which moisture migrates from the paper and is diffused into the oil during normal transformer operation. It is a slow, steady, and gentle process. The oil can be dried in a matter of days or weeks, but bringing the paper from a wet condition to 1.3 percent, most likely will require many months.

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About the author

Mr. Carbery has 40 years of domestic and international experience in the engineering and marketing of products for electric utility networks, most recently as a vice president of The Ardry Group, an international trading company representing leading suppliers of transmission and distribution equipment to electric utilities around the world. A former lieutenant of the US Navy Reserve, Mr. Carbery was affiliated with Westinghouse Electric Corporation for 10 years, working on submarine and surface nuclear programs of the US Navy. He holds a Batchelor of Marine Engineering degree from the State University of New York Maritime College, and studied at New York University's Downtown Graduate School of Business Administration.

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Illustrations

DryKeep Installation

Decayed paper insulation

Moisture vs Aging Rate vs. Transformer Life