APPLYING AN ON-LINE DRY-OUT PROCESS TO POWER TRANSFORMERS

By Michel Bélanger, P.Eng.

Transformers accumulate water over their operating life. When a transformer has reached an unacceptable moisture level, it is time to extract that water from the insulation.

Typically, a transformer leaves the factory with water content, which is a function of the BIL and the operating voltage class. For transformers where the operating voltage is less than 69kV, the suggested moisture content is 1.0 per cent. For transformers over 230kV or with a reduced BIL level, the moisture content should be 0.5 per cent. The latter value can be lowered, at the request of the customer, to a challenging 0.3 per cent but is technically difficult to obtain.

Once commissioned, the initial moisture content should be measured (see Table 1). As the transformer ages, it will accumulate moisture. The maximum suggested moisture content for an in-service transformer is listed in Table 2.

MOISTURE EQUILIBRIUM CHART

To obtain the insulation moisture from oil sample, we use an equilibrium chart. From an oil sample we get the dissolved water and the oil temperature is estimated from the average

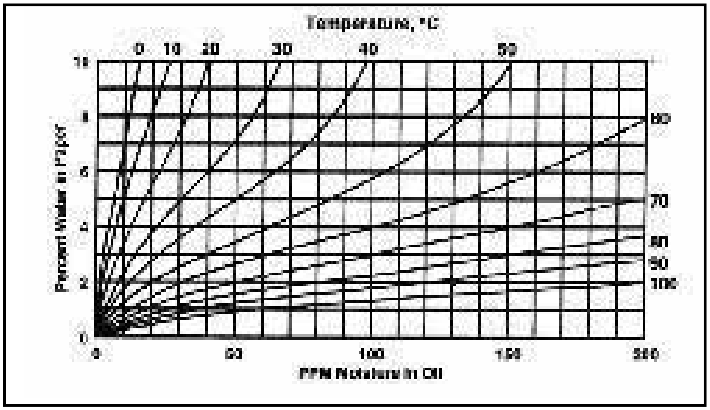

Figure 1. Paper moisture equilibrium from dissolved water in oil and oil temperature. Source Oommen [3].

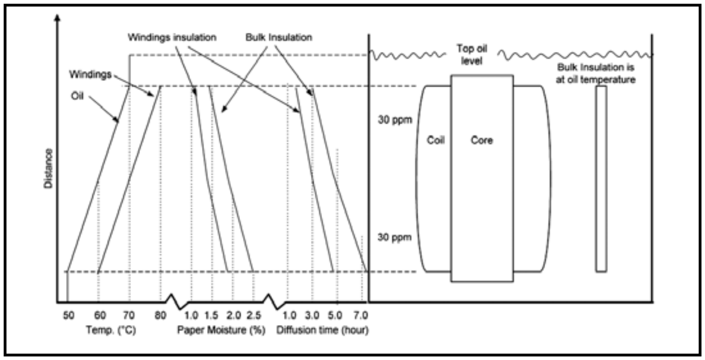

Figure 2. Case of moisture profile as a function of oil temperature profile inside a transformer [2]. The distance axis represents the height from the bottom of the tank.

due to the oil temperature gradient from top to bottom of the tank and because insulation directly in contact with current-carrying parts is warmer. Because of these temperature gradients, there is a static moisture gradient within the insulation. There is a dynamic moisture gradient that takes place within the thickness of the insulation and comes from the water diffusion time. This will be covered more in detail later.

The moisture content in the insulation increases from top to bottom, because the insulation expels moisture as a function of temperature: the lower the temperature, the higher the moisture content in the insulation.

Consider the example in Figure 2. The dissolved water in the oil is the same throughout the tank, in this example 30 ppm. To calculate the bulk insulation moisture profile, the values of the oil temperature profile are applied, with the 30 ppm figure, to the moisture equilibrium graph (Figure 1).

The figures for the insulation moisture profile are similarly applied and the

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Table 1. Usual moisture contents as shipped from the factory.

Average oil temperature	Suggested max. water content in oil and corresponding paper moisture when shipped from factory		
	< 69kV	69-230kV	> 230kV
50°C	7 ppm	2 ppm	2 ppm
60°C	12 ppm	4 ppm	4 ppm
70°C	20 ppm	7 ppm	7 ppm
Percentage water saturation	6%	2%	2%
Paper moisture	1%	0.5%	0.5%

Table 2. Recommended maximum limit of water content in mineral oil of operating gas blanketed, sealed, or diaphragm conservator transformer as per C57.106-2002.

Average oil temperature	Suggested maximum water content in oil and corresponding paper moisture		
	< 69kV	69 - 230kV	> 230kV
50°C	27 ppm	12 ppm	10 ppm
60°C	35 ppm	20 ppm	12 ppm
70°C	55 ppm	30 ppm	15 ppm
Percentage water saturation	15%	8%	5%
Paper moisture	3%	2%	1.25%

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resulting insulation moisture profile in Figure 2 is clearly not a straight line. From the diagram, we can conclude that most of the solid insulation is at oil temperature, thus to obtain an approximation of the moisture content inside a transformer, we shall only consider the average oil temperature within the tank along with the measure of dissolved water in the oil.

It is important when evaluating insulation moisture content to estimate the average oil temperature in order to compare the calculated moisture with the values from the C57.106-2002 standard.

Table 3. Transformer operating conditions effects on water diffusion time

Parameters	Variations	Increased diffusion time
Temperature (°C)	- 10	doubled
Moisture (%)	halved	approx. doubled
Thickness (mm)	doubled	quadrupled

MOISTURE DIFFUSION TIME

A moisture content equilibrium exists between the oil and the paper. When that equilibrium is altered, either by a temperature change or a dryout process, the water migrates to reestablish equilibrium. The migration of the water from one medium to the other requires time and this time measurement is called diffusion time.

Moisture diffusion from paper to oil is dependent on insulation thickness, moisture level and temperature as expressed in [4]. Moisture diffusion controls the speed at which water is transferred between the paper and the oil. For a 1mm thick oil-impregnated pressboard with 0.5 per cent moisture content, the diffusion time at 20 degrees celsius and 70 degrees celsius is respectively 260 hours and 5 hours. Figure 2 gives an idea of the diffusion time that takes place within the tank with average oil temperature of 60 °C.

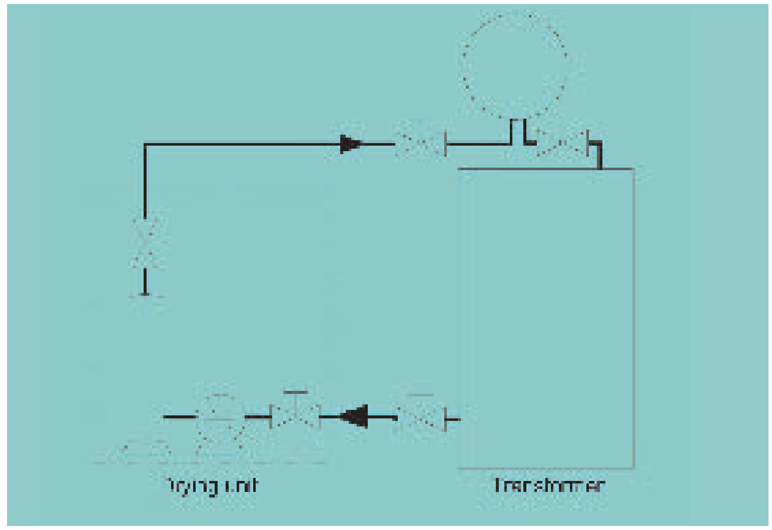

Figure 3: Diagram of the principle of a filtration project

Figure 4. Dryout site example. Rectifier transformer, 9300 kVA, 13.2kV/.624kV, 16,000 litres have been dried. Observe the hydraulic connection at the bottom of the main tank and the expansion tank.

WHY USE ON-LINE DRYING?

Production losses may be too costly to allow for the use of traditional drying, because traditional drying requires shutting down the transformer and isolating it. The oil must be drained and a full vacuum applied to the tank. Once dryness is achieved, the process is reversed to prepare it for service. This procedure can take two to three weeks depending on the transformer size. Other reasons to consider this method include: the main tank may not have been built to withstand full vacuum, the transformer is physically difficult to reach, or production cannot be stopped.

Transformer insulation may age to the point where it becomes risky to move the unit. Transformers are risky to move because aged insulation becomes brittle. Moving the transformer may cause winding displacement and permanent insulation failure. On-line drying may also be beneficial in this case because the drying process is gradual as opposed to off-line full vacuum (tank drained of oil and vacuum applied directly).

Live dryout requires that insulation be maintained at all time. This means that no air bubbles or particles should be introduced in the main tank. No oil leak can be tolerated, especially not to exposed live parts. In all cases, even if drying time is not an issue, significant savings can be achieved from on-line drying as compared to off-line full vacuum.

ON-LINE DRYOUT SYSTEM

The general principle is to remove water accumulated in the immersed insulation via the oil. Using a recirculation loop between the transformer and a system for extracting water from the oil gradually reduces the moisture content of the insulation.

The flow varies from 8 litres/min. to 20 litres/min. Some systems may go to double that value. The selected system is currently operated at 10 litres/minute. Flow is varied with a variable speed drive. There is no gain in speed attributable to drying at a higher flow rate due to the constraint of moisture diffusion time between the paper and the oil. It is sufficient then to maintain a saturation differential between the paper and oil that is adequate for diffusing the water toward the oil. There is no advantage to continuous on-and-off cycling of the drying process [for example three days off and three days on]. This is because there is no gain in terms of drying time and the entire hydraulic circulation system, the dryer and the expansion tank, would be continually subject to changes in temperature that would reduce the reliability of the equipment.

If the bottom valve of the expansion tank is used as the return path, quick oil flow may not be desirable because it could result in conveying particles accumulated in the bottom of the expansion tank to the main tank. Also, the hydraulic restriction between the expansion tank and the main tank could cause negative pressure in the main tank. We have experienced this at 20 l/min in 25 MVA transformers (however the negative pressure differential was only a few inches of mercury). If the return path is located at the top of the main tank, then there should be no restriction on the oil flow.

PAPER MOISTURE EVALUATION

The moisture content is evaluated with the help of Oommen's chart. His method of constructing the chart provides traceable and reliable results [5].

Moisture evaluation from oil samples can be tricky because you must know the load and temperature history of the transformer. It's like trying to estimate average sea level from a single measurement without knowing what part of the tide cycle is under way.

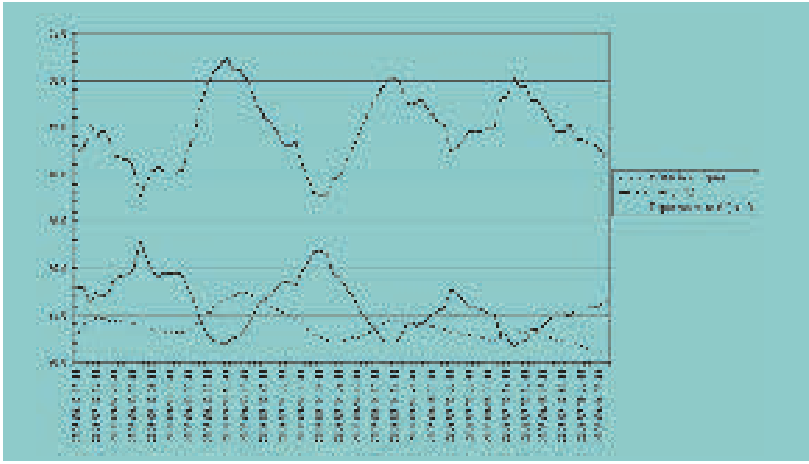

Figure 5. Moisture evolution during a nearly four-day period on a rectifier transformer. Note how the paper moisture changes from a maximum of 3.3% to a minimum of 2.2% on Sept 13.

A real-life example shows how the transformer moisture can vary on a daily basis. Figure 5 shows the average oil temperature (top + bottom temp. /2) dissolved water and calculated paper moisture using the equilibrium moisture graph (Figure 1). The data came from a 9.3 MVA, rectifier transformer load at its nominal prior to starting the dryout. We recommend running the dehydrator with the cartridge bypassed to record the dissolved water and temperature in order to get the

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average moisture in the paper. Once the actual moisture is known and the targeted moisture has been set, it is then possible to estimate the time duration of the dryout [Figure 4].

Table 4. Corresponding temperature and dissolved water daily extremes from Figure 5.

Date	Dissolved water (ppm)	Temperature (°C)	Paper moisture (%)
Sept. 13, 2002, 1:41	23.7	37.5	3.3
Sept. 13, 2002, 15:41	26.7	52.2	2.2

As you can see, the calculated paper moisture varies from 2.2 per cent to 3.3 per cent, a 1.1 per cent change during that 24-hour period. The paper moisture is calculated for each point on the graph from the dissolved water and the average oil temperature. These extreme values have been reproduced in Table 4. Even if the operator is careful, it is difficult to obtain a sound evaluation from a single measurement. An on-line measurement, for example, would help considerably in obtaining a better picture.

CASE STUDY

This technique was used recently on a rectifier transformer located within a smelter plant with the specifications: 9.3 MVA, ONAN/ONAF, 13.2/.624 kV, 16,000 litres. Before treatment this transformer had a moisture level of 4.4 per cent.

The particular radiator design on this type of transformer produces a relatively large temperature difference between top and bottom. On September 13, 2002, the top and bottom temperatures were 67°C and 38°C. The transformer was located outdoors and operated near its nominal load. To improve the drying process, use of the cooling system was reduced as we progressed in the season.

The dryout was started at the beginning of September 2002 and stopped at the end of November. At that time, the outside temperatures had fallen below zero, making the water extraction process too slow to be practical. A higher average temperature would have decreased the process time substantially. This is valid for any live dryout technologies such as percolation or vacuum.

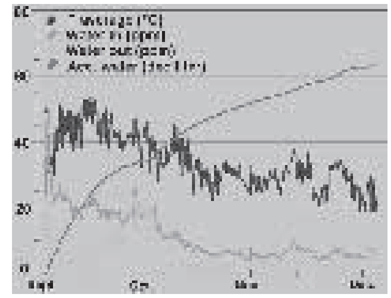

Figure 6. Volume of water extracted from the insulation. Oil flow is 10 litres/minute. T average is the average oil temperature of the main tank.

Approximately 6.2 litres of water were extracted from the insulation. After the drying had been completed, the water content in the oil had improved substantially. At an average oil temperature of 40°C, the dissolved water went from 38 ppm (beginning) to 18 ppm (end).

DRYOUT EQUIPMENT USED

The system used is manufactured by Siedel, under the brand name TransfoDryer. The TransfoDryer uses two items important to the drying process. InsulProbe, a dissolved water sensor, and Cactus, a dryout cartridge, both designed and developed by Siedel. InsulProbe can accept a configuration of one or two dissolved water measurements probes (patent pending).

The latter configuration, used in TransfoDryer, measures the filter saturation and is a key element to predicting the filter replacements.

CONCLUSIONS

- Moisture evaluation requires careful attention.
- Use the C57.106 standard for the maximum moisture allowable.
- At sampling time, use an infrared gun to obtain the temperature profile and calculate the average oil temperature.
- Use Oommen's chart to determine paper moisture.
- On-line drying has low performance when operated at temperatures lower than 40°C. Transformers operating in cold regions will have shorter drying seasons.
- The dryer used has proven to be safe for workers, production and the environment. Its use is straightforward. The dryer comes with tools to diagnose its operation.
- Consider the drying site as part of your Xfo and make decisions accordingly. This is valid during installation and operation.
- For on-line drying we recommend the use of checklists.
- Dried transformers can also be treated for acid simultaneously.

Michel Bélanger, P.E., attended Laval University in Quebec City where he received a B.Sc. in Electrical Engineering in 1981. He founded Seidel Inc. in 1990 and offers consultation services on transformers. He is responsible for product R&D and technical support. He is a member of the IEEE. **ET**