ZERO DOWNTIME MAINTENANCE OF TRANSFORMER OIL AND INSULATION LIFE EXTENSION

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The blackout of 14 August 2003 was preventable. Industry experts concluded that there were several direct causes and contributing factors, too many to list here. Likewise, there is a host of recommendations to avoid future incidents, foremost on the list being to maintain a high degree of reliability in the electric grid. This reliability encompasses many areas, one of which is improving the reliability of a critical component in the grid: transformers.

Many transformer owners and operators aspire to extend life, increase capacity and reduce maintenance costs. Yet, conventional methods of transformer oil maintenance make this difficult, if not impossible. So how are the aforementioned objectives achieved? The answer is to understand the effects of water and oxygen content on paper insulation aging and how controlling these leads to longer life. To improve reliability, a relatively new maintenance method can be used while the transformer is online, reducing maintenance costs and at the same time extending insulation life.

AGING AS A FUNCTION OF OXYGEN AND WATER

Millions of dollars have been invested in researching better liquid and solid insulating materials for transformers. Nevertheless, paper insulation and mineral oil have remained the economical and performance choice. Despite the advantages, great care must be taken to maintain the paper and oil in a clean and dry condition. As the saying goes, 'Transformers do not die from old age. They die from neglect'.

Figure 1. The relationship between oxygen content and paper life

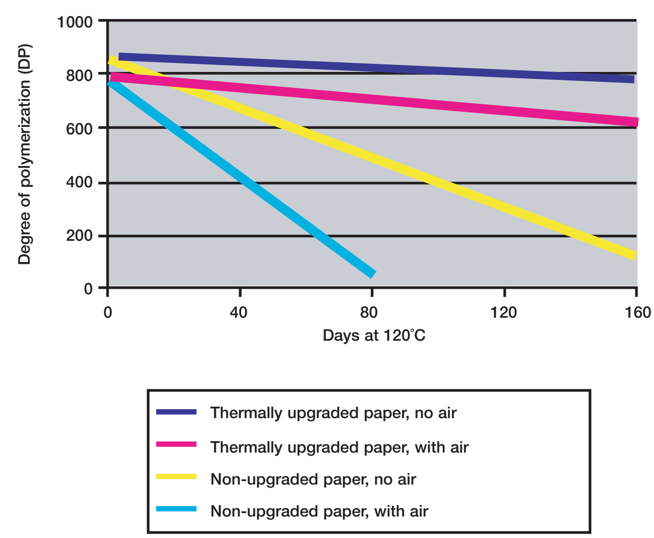
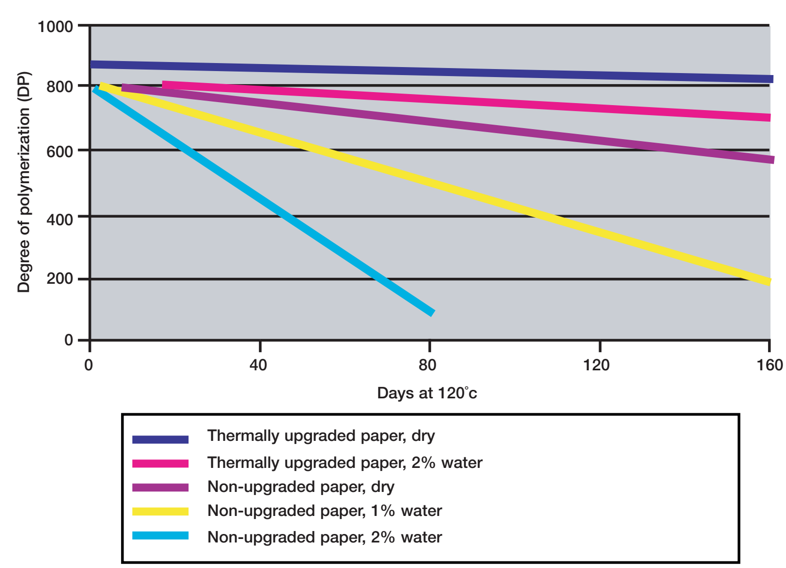


Figure 2. The relationship between water content and paper life



Experts from all over the world agree that the life of a transformer depends upon the condition of the paper insulation. Rather than neglecting this fact, prudent maintenance practices would dictate a careful and earnest effort to ensure that the paper is in the best possible condition. The end of life for paper is considered to be 200ppm or less degree of polymerization (DP). Therefore, the goal would be to keep the DP value as high as possible. Perhaps the best place to start is to address two major factors that cause paper degradation: oxygen and water.

THE PRESENCE OF OXYGEN

Transformer oil is organic, so it will oxidize and decay. In turn, oxidation byproducts destroy the paper insulation. So, aging is caused by the oxidation process. Controlling the access of oxygen to transformer oil is therefore critical. Oxygen is introduced through the venting pipe of the expansion reservoir. Oil preservation systems, including oil expansion tanks with rubber bags or nitrogen cushions, have been developed to reduce oxygen content. However, these systems only protect the oil from oxygen.

There has been little emphasis on the impact of oxygen on paper insulation. Studies have shown that oxygen content in the paper insulation has an adverse effect on its lifetime (Figure 1).

Figure 1 reveals that oxygen content must be controlled in both the oil and the paper to ensure longer lifetime, especially for transformers with non-upgraded paper. So how much oxygen can be tolerated in the oil? According to some experts, the target should be 2000ppm or less to prevent excessive aging.

What about the paper? Because it is cellulose, it naturally contains a certain amount of oxygen within its molecular structure. However, external sources of oxygen accelerate the aging process. It is nearly impossible to access the insulation when it is surrounded by oil. However, controlling the oxygen content of the oil will limit access of oxygen to the paper, resulting in longer life.

Figure 3. The equilibrium of water in paper and oil

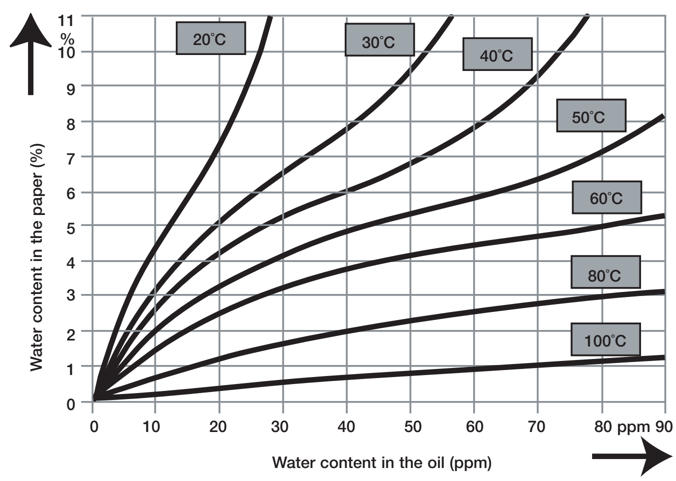


Figure 4. Vacuum type dehydration and degassing system oil flow diagram

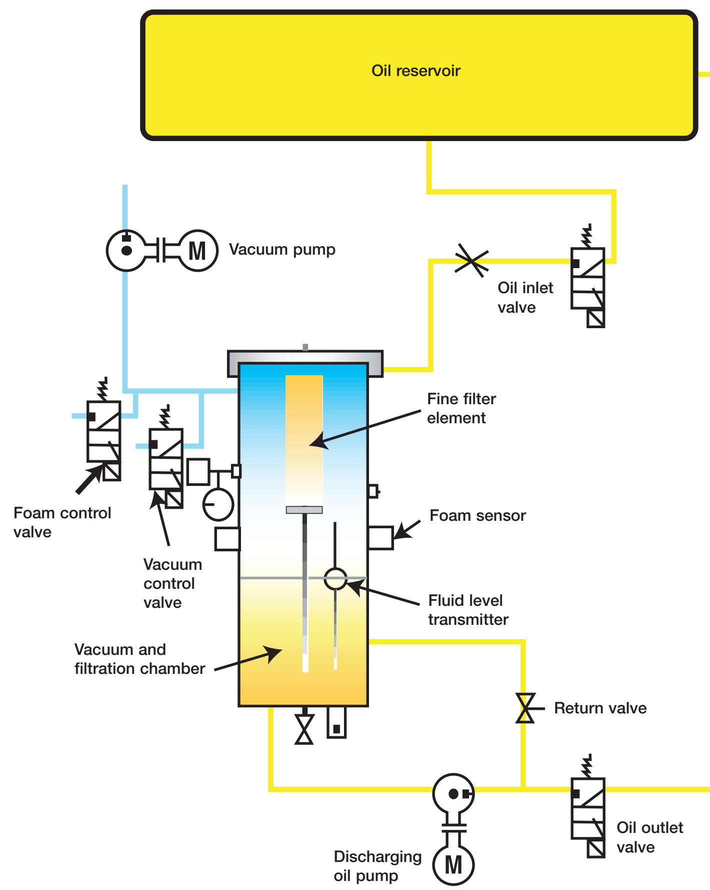


Figure 5. Online dehydration and degassing system in operation

To extend the life of the transformer it is important to control the levels of oxygen and water. We cannot turn back the hands of time but we can slow them down dramatically

THE PRESENCE OF WATER

It is no secret that water has an adverse effect upon the dielectric strength of oil and paper. It also reduces the mechanical strength of paper. Just like oxygen, water accelerates the aging process (Figure 2).

Figure 2 shows that lowering the water content one percent in non-upgraded paper extends the life by a factor of at least 2.5. Obviously controlling moisture is necessary to extend life.

The important question is where does the water come from? The answer is not as well known as one might think. Sources include the manufacturing process and ingression from the atmosphere, although these account for very little compared to the primary source, internally generated water. During the paper and oil aging process large quantities of water are generated. It has been said that transformers are water makers. A closer look at the facts reveals this to be true.

The water content of the oil is a reflection of how much water is in the paper, something known as the equilibrium of water in paper and oil (Figure 3). As the temperature rises, moisture moves relatively fast from the paper into the oil. When the temperature decreases, the moisture moves back into the paper but at a slower rate. After a sufficient dwell time at a steady temperature, the water in the paper and oil reaches equilibrium. An examination of Figure 3 reveals some surprising facts.

Assume that a certain transformer has 5000 gallons of oil and 7500 pounds of paper. The water content of the oil is 30ppm and the paper contains approximately two percent water. With this data, we can calculate the percentage of water in the oil and in the paper:

- Water in paper = (.02 * 7500) = 150lbs
- Water in oil = (5000 * 0.000030) = 0.2gal * 8.34lbs per gal = 1.25lbs
- Percentage of water in the oil = 1.25/(150 + 1.25) * 100 = 0.82%
- Percentage of water in paper = 100 – 1.09 = 99.18%

This calculation tells us some very important things. The vast majority of dissolved water is bound in the paper. Because of the equilibrium, water removed from the oil will be replaced by water from the paper. Temperature influences the rate at which the water transfers, with higher temperatures producing a higher flow. That is why all dehydration should be performed while the transformer is in operation. Furthermore, the dehydration process should be allowed enough time so as to permit the water to travel from the paper, into the oil, and out of the system. Therefore, a continuous process is preferred versus a high velocity batch cleaning that will only remove water from the oil.

How much water should be removed? The straightforward answer is as much as possible. To be more specific, less than one percent water in the paper is a good place to start for a target. One reference paper suggests that removing water down to less than 0.5 percent is not necessary.

From the above we can conclude that water and oxygen indeed are a major factor in the degradation of the insulation system. To extend the life of the transformer it is important to control the levels of oxygen and water. We cannot turn back the hands of time but we can slow them down dramatically. So how can we do this?

ZERO DOWNTIME MAINTENANCE OF TRANSFORMER INSULATION SYSTEMS

Conventional methods of removing oxygen and water from transformers have

CASE STUDY:

REAPING THE BENEFITS OF ZERO DOWNTIME MAINTENANCE

Recently, an electrical engineering and service organization located in North America installed an online dehydration and degassing system as described above. This type of system was a considered a new technology but it had some distinct advantages. Number one was the ability to install the unit with no downtime required of the transformer. The cost of the system compared to a large processing unit was approximately six to one.

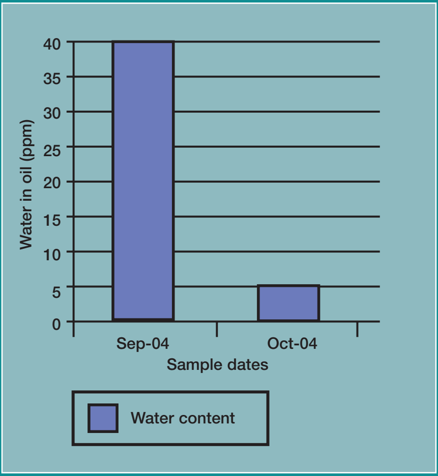
The transformer in question was rated at 11.4MVA and 115kV. The volume of oil was approximately 5380 gallons. Prior to installation of the dehydration and degassing system, moisture had reached 39ppm @ 55∞C and the oxygen content was 26,100ppm. Dielectric breakdown was on a steady decline from 51.8 to 34. The process unit was installed and continuously operated for 1 month.

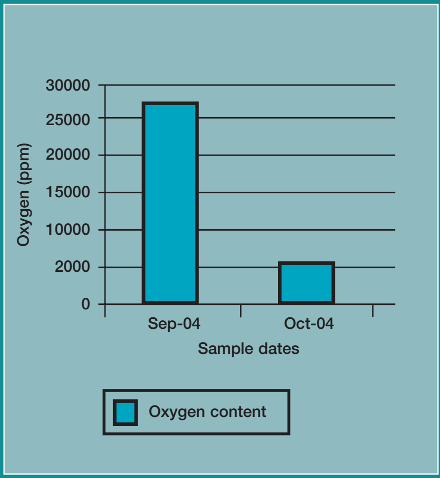
A sample was drawn one day prior to start up and five days after it was uninstalled. The results prove that it was effective in lowering the oxygen and water levels (Figure 6). As a result, dielectric breakdown stopped falling and resumed an upward trend of 44.4. Using the equilibrium chart in Figure 3, water in the paper can be calculated as approximately 4.25 percent before and one percent after. This represents a reduction of 75 percent. Furthermore, the oxygen level was reduced by roughly 84 percent.

Although no life extension tables can be referenced as with other types of lubricating oils, some assumptions can be made and a conservative life extension can be calculated. Referring back to Figure 2, a non-upgraded paper with one percent water has a life extension factor of 2.5 compared to the same paper with two percent water. Assuming that the above referenced transformer has the same type of paper, we can add a life extension of 2.5, even though the water reduction was greater. Figure 1 also reveals that the same paper will also have a life extension of at least two when the oxygen is removed. Therefore, the cumulative life extension factor is 4.5. With these conservative life extensions, a return on investment figure could be calculated.

In this case study, however, reduced maintenance costs were realized upfront. Compared to conventional methods, the online process was only US$2,500 compared to US$15,000. Using these figures, a project value can be calculated (Figure 7).

From this calculation we can estimate that, if selected for implementation, the zero downtime maintenance processing system will produce more than $US40,000 profit after discounting to adjust for the time value of money. This works out to an internal rate of return of 399 percent. In accounting terms, this means that in order for a company to equal a proposed investment of this quality, they would have to find a fund or bank paying 399 percent interest annually on the money invested. Similarly, the project hits black ink after a mere four months.





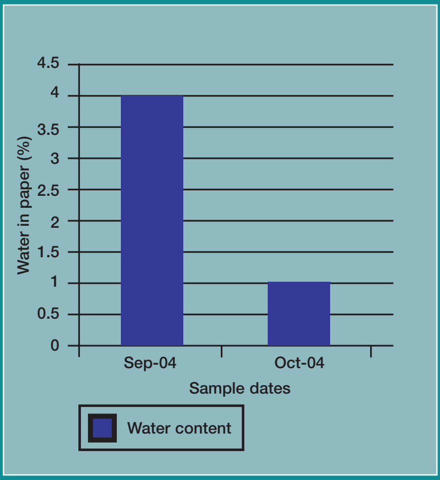


Figure 6. Transformer oil analysis results before and after online processing

involved high volume dehydration and degassing. Typically, this is done by means of a vacuum dehydrator system. The transformer oil is pumped out of the transformer and cleaned in batch type operation requiring the transformer to be taken offline. In some cases, downtime alone can cost thousands of dollars, if not more. The actual process unit can be a large truck mounted system. Typical processing costs can run US$350 per hour with a 24-hour minimum, plus the cost of travel time. There are, of course, many variables such as the size, voltage, and plant requirements but, in general, this traditional method can cost US$15,000 and more. One operator reported a typical offline processing unit cost their organization US$1,000,000!

Due to the high cost of such conventional methods, not to mention that it does little to address the water and oxygen contained in the paper, alternative methods have been developed. In recent years, methods of online, or 'energized dry-outs', have been introduced, which provide a zero downtime maintenance alternative. Many are relatively small, easy to transport, simple to install, and available for rental. Perhaps the single most important advantage is the continuous online operation, which allows for removing water and oxygen from the entire insulation system, not just the oil. At operating temperatures, the oil equilibrium will transfer water from the paper into the oil to be removed. This process may take several weeks.

A device such as this should be selected if water in the paper exceeds two percent or the oxygen level is over 2000ppm. Following are some practical considerations when employing such a system:

- Set a target of at least one percent water in the paper and <2000ppm oxygen in the oil.
- Purge air from the filter system and the hose lines.
- Discharge water completely so that it cannot return to the transformer.

Figure 7. Summary of cash flow, discounted flows and project value

	Year					
	0	1	2	3	4	5
Projected benefits	$0	$12,500	$12,500	$12,500	$12,500	$12,500
Projected costs	-	-	-	-	-	-
Upfront	$2500	-	-	-	-	-
Ongoing	-	$2500	$2500	$2500	$2500	$2500
Net cash flow	-$2500	$10,000	$10,000	$10,000	$10,000	$10,000
Discount rate (K=10%)	1.0	0.91	0.83	0.75	0.68	0.62
Discounted net cash flow	-$2499	$9100	$8300	$7500	$6800	$6200

Summary investment analysis	
Net present value	$40,399
Internal rate of return	399%
Discounted payback period	4 months

- If a filter cartridge is used in the system it must be non-migratory.
- What is the oxygen and water removal efficiency?.
- Total water and oxygen removal cost of the system including supervision and consumables.

Dehydration and degassing systems can differ, but operate on the same principle. Oil is pulled from the transformer, processed through the system, and returned to the transformer. Some utilize a vacuum process to remove water, gas or both (Figure 4 and Figure 5).

SUMMARY

Transformer life can be extended if the water and oxygen contents of the insulation system are controlled. As with most endeavors, an investment of time and resources is required to achieve lower oxygen and water levels. However, the cost will be offset initially by lower maintenance costs and certainly by extended life. Alternative methods such as online degassing and dehydration systems permit the transformer to continue in operation, eliminating downtime, and providing the ideal environment to remove moisture from the insulation.

Continuous online processing of transformer oil addresses the fundamental issue that the majority of water inside the transformer is bound in the cellulose. A slow, continual process gradually lowers oxygen and water levels in the paper, which, in turn produces longer life. Case studies document the effectiveness of this technique, providing the basis for a return on investment. This sound technical approach will yield a significant return on investment, providing owners and operators an opportunity to reach financial and reliability goals. ■

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