ABSTRACT

The moisture in the transformer has always been a matter of concern for its end users - power companies, utilities, and industries. Water is an enemy of electrical equipment, and the transformer is no exception. Several methods have been employed to deal with this challenge, which gets tougher with the age of the transformer. As power continuity must be maintained in most applications, it is not possible to take the transformer out of service for moisture removal. Moreover, the bigger the transformer, the longer the shutdown period and the higher the financial losses. Therefore, online moisture management systems are being adopted over conventional offline oil filtration systems.

KEYWORDS:

insulation, moisture, drying, aging, online system

Cover image: Skoda make transformer at Orlik dam, Czech Republic [1]

The insulation life is defined by the degree of polymerization, which represents the average length of polymer chains

Online moisture management for transformers

1. Mechanism of moisture in transformers and its impact on life expectancy

The transformer's life expectancy is directly linked to the condition of solid insulation (cellulose-based paper). Compared to normal kraft paper, thermally upgraded kraft (TUK) paper degrades slower.

The insulation life is defined by the degree of polymerization (DP), which represents the average length of polymer chains. In new insulation, the chains are long, and with aging these chains break down into smaller and smaller lengths. The longer the chain is, the higher the tensile / mechanical strength of the insulation. Breaking up of the polymer chains weakens the insulation, thereby making the transformer prone to failures. The DP value of the new insulation is 1,200, and it drops to around 200 at the end of its life.

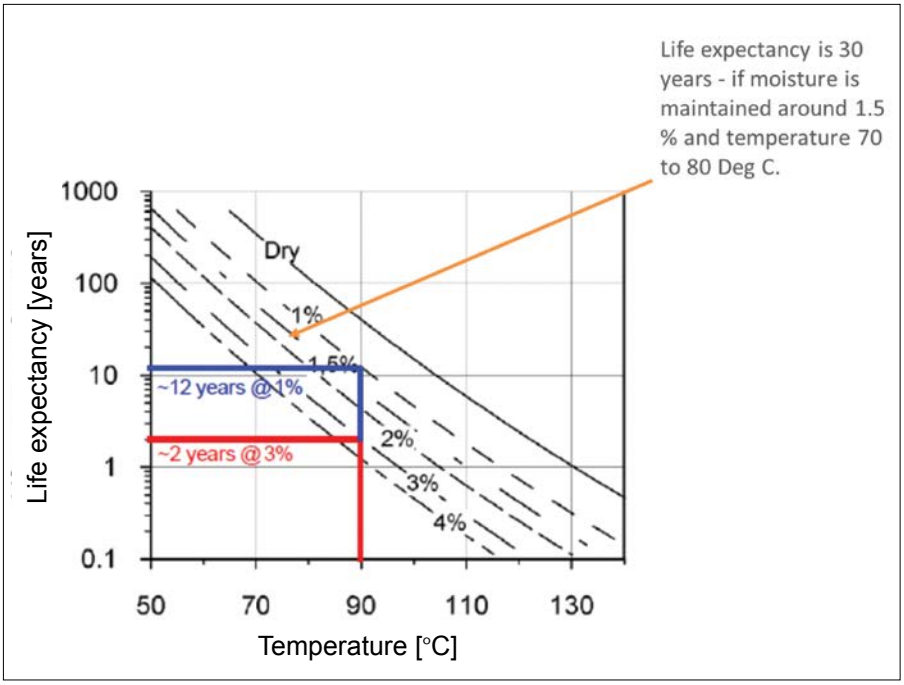

Figure 1. Relationship of life expectancy with operating temperature and moisture [2]

At lower temperatures, moisture is transferred from oil to paper, and at higher temperatures, it is transferred from paper to oil, and it reaches equilibrium at the constant load

The rate of aging of the insulation depends on the following factors:

1. Load on the transformers – the higher the load, the insulation ages faster
2. Operating temperature – the higher the temperature, the insulation ages faster
3. Moisture in the transformer – the higher the moisture content in the solid insulation, the insulation ages faster. Every 1 % increase in moisture reduces life expectancy by a factor of 2 [3].

The moisture in the paper also creates bubbles at higher loads, causing gassing and tripping of the Buchholz relay. A dry transformer can be loaded to the desired levels.

The dielectric properties improve with low moisture levels, and the transformer can better withstand electrical stresses.

Approximately 98 % of the total moisture in the transformer is retained in the paper insulation. In oil, it is only < 2 %. **The water content test (IEC 60814) of oil only detects this to be 2 %.**

The moisture content has a dynamic nature. At lower temperatures, moisture is transferred from oil to paper, and at higher temperatures, it is transferred from paper to oil [5].

The moisture equilibrium is reached when the load is constant. That means the moisture is no longer transferred from paper to oil. To break the equilibrium, the first two of the below conditions are required:

1. Temperature of the paper insulation should be high.
2. Moisture from the oil is being removed continuously.
3. In an offline / conventional filtration system above, conditions cannot be achieved. As the transformer is switched off, the insulation cools down. As it is cooler than the oil, moisture of the oil transfers into it.

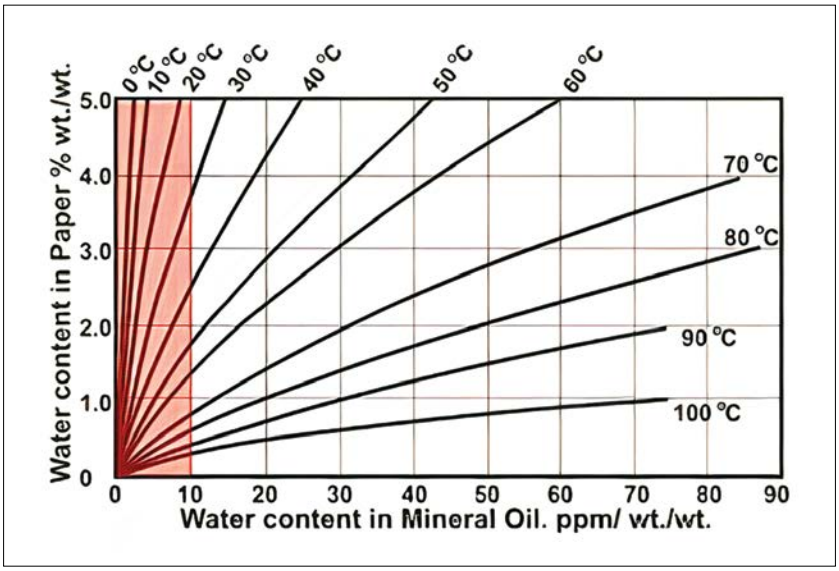

Figure 2. Moisture equilibrium curves of water in oil and in solid insulation [4]

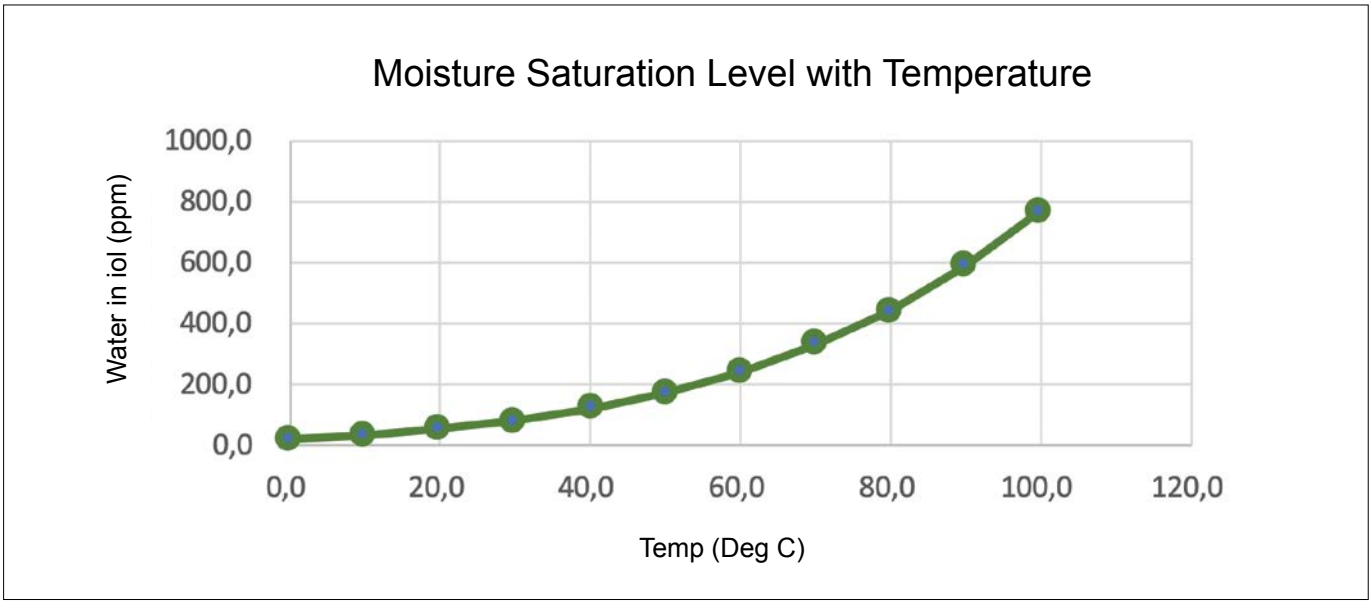

Figure 3. Moisture saturation level in mineral oil with temperature [6]

So, some moisture from the oil is extracted by the machine, and some get absorbed by the paper insulation. The result is that you get a very good oil BDV, but it is a false indication.

4. The moisture of the paper insulation, once the transformer is charged back and loaded, comes into the oil. As a result, you get low oil BDV short after offline filtration.

2. Online moisture management system

These systems employ a concept of mechanical separation of liquids at a molecular level. Transformer (mineral) oil and water have different molecular sizes and structures. A sieve, called a molecular sieve (zeolite or crystalline metal aluminosilicates) that has a pore diameter of 3 to 4 Å (Armstrong, 10,000,000 Å = 1 mm) is used for this purpose. These pores are larger than the oil molecules but smaller than those of water.

When the mixture of oil and water is passed through such a sieve, due to its typical pore size, the oil gets through, but water gets trapped. In this manner, moisture is separated from transformer oil. The number of rechargeable cartridges are provided with the system as per the transformer size and oil quantity. These cartridges are easy to replace upon their saturation.

Sophisticated and highly accurate sensing devices and analytics are used for monitoring the moisture in transformers, and they record the data in real-time.

These systems are different from conventional offline filtration systems. The conventional filtration system works on the principle of moisture evaporation. The oil is heated with electrical heaters to convert the moisture into vapour. Powerful degassing and vacuum systems are then used to suck out this vaporized moisture.

3. How the online system works

1. This is not a forced moisture extraction system. It is a passive system based on molecular-level filtration.
2. The special molecular sieves allow the oil molecules to pass, while restricting the water molecules.

When the mixture of oil and water passes through sieves, due to its typical pore size, the oil gets through, but water gets trapped

Figure 4. Molecular sieves [7]

Figure 5. Moisture in oil probe for continuous online measurement [8]

The online moisture management system is capable of removing 98 % of the moisture stored in the paper insulation, which otherwise would remain there

3. System is connected to the transformer through small pipes as the inlet and outlet. A small single-phase pump helps convection currents in circulating the oil through molecular filter cartridges.
4. The moisture in the oil and temperature are measured online by special probes, as shown in Fig. 4.
5. As the transformer paper insulation gets hot, moisture is released from it into the oil. The online system continuously removing moisture from the oil in order to break the equilibrium. This results in the extraction of moisture from the paper insulation. Over time, the transformer becomes perfectly dry. Whatever moisture is generated, it gets removed by the online system.
6. This system is capable of removing 98 % of the moisture stored in the paper insulation, which otherwise would remain there.
7. This is a mechanical filter, so it does not require any vacuum or heating of the oil (no heavy pumps, heaters – low operating costs).

4. Benefits of the online moisture management system

1. The life expectancy of the transformer is increased.
2. Periodic offline filtration gets reduced / eliminated with time-cost savings.
3. The dissolved gases in the oil remain undisturbed, leading to true DGA reports.
4. Transformer does not need to be taken out of service for oil filtration.
5. Smart sensors and measuring systems provide real-time data and trends – enabling effective preventive maintenance.

Online systems are widely being adopted due to their superiority and benefits. However, many end users resort to rented filter machines. Poor upkeep of such machines results in the adulteration of oil, causing more harm than good to the transformers. Online systems being a dedicated attachment to the transformer, do not pose such threats.

Bibliography

[1] Cover Image: *Skoda make transformer at Orlik Dam*, Czech Republic, By Draceane - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=95718341 inserted on 02/09/2022

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PEER REVIEWED

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