Moisture management of live transformers

by Tom Dalton, Rotek Engineering

Transformers, while operating, produce moisture due to chemical reactions between gases and the decomposition of paper (cellulose). In a strategy to ensure the transformer's maximum life is obtained, an online moisture removal system is a prize technology. Ultimately, prevention is better than the cure.

Of the several factors that determine the life expectancy of a transformer, the main ones are water (moisture), oxidation by-products and heat. The most easily tackled of these is moisture.

On-line filtration is a simple and more effective way of controlling the moisture over a longer term than off-line or periodic moisture removal interventions. The molecular filter system offers a simple yet effective means of moisture management during the lifetime of the transformer, thus extending its life and saving the asset owner money.

Insulating materials

Paper and insulation board is the most vulnerable material found in a transformer. From the time a transformer is put into service we have to deal with moisture. This is due to the fact that most insulating products (cellulose based) have an affinity for moisture absorption, as cellulose based insulating board and paper has natural capillaries that are used to channel water to the top most branches of a tree. These same fibres are used to form the paper mat we call "Kraft paper" and the board we use as insulating material.

Many people ask, "Is there not a better material than paper?" However, the paper - oil system used for so many years is still the most cost effective for power transformers. Thus this leaves us with the fact that the moisture phenomenon needs to be managed. Firstly, there is a need to understand how moisture behaves in the system and secondly what influences the chemical reactions, the transfer and finally the removal of moisture from the system.

The sources of moisture in the life of a transformer.

There are two main sources of moisture, external and internal. The external sources include badly managed silica gel breathers and leaking gaskets. The internal sources are chemical reactions that are common in transformers.

While the outside influences that affect the ingress of moisture are mostly badly managed breathers on open breathing transformers, with new products and materials this has been eliminated on larger units by using air cells. Smaller units still using open breathing systems suffer the ills of bad silica gel management. Problems such as old silica gel and breathers that are too small for the air flow capacity are common. In the extreme cases it is negligence.

The leaking of gaskets is rarely a problem in an open breathing transformer, but can be a source of atmospheric air in a blanketed or air cell fitted unit, especially when a negative pressure is experienced. However, the effect is small in comparison to the internal production of moisture, which is due to chemical reactions that are always active in an energized transformer. Due to the level of hydrogen, a natural gas given off in an operating transformer, and the ever-present oxygen in the oil, the natural formation of moisture is an ongoing reaction. Added to this is the degradation of insulation paper and board that releases OH and other chemicals as the paper breaks down. These reactions can produce 1 to 2 ppm of moisture per year in a hard working unit. There is thus always the threat of moisture production and there is always the need to manage moisture in a transformer.

In a recent paper presented at Cigré [1], moisture is seen to be absorbed and desorbed by different material at different rates. Where moisture is released by thick insulation (e.g. barrier boards typically 2 to 5 mm and blocking > 5 mm) and is received by the oil, it is ideal to strip the oil of this moisture.

Moisture management strategies

Minimising transformer breathing is a good strategy to limit the amount of air taken into the conservator air space. This is done by either painting the transformer conservator white or applying a layer of temperature insulating (lagging) material. Further, an air cell can be fitted to separate the oil from the atmosphere. This means that the oil system is a closed system and also has the inherent advantage of reducing the available oxygen in the system, which will ultimately affect the recombination reaction that produces moisture.

In the management of transformer oil, sampling is a means to monitor a unit's health while the unit is still in operation.

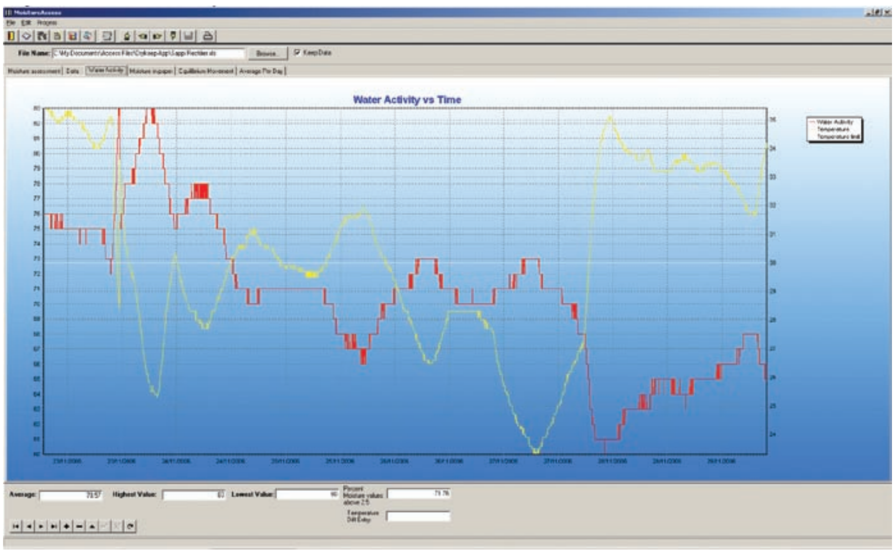

Fig. 1: Water activity.

Moisture content is one of the key results that are obtained in this condition monitoring exercise. However, there are many pitfalls in the interpretation of these results which can lead to incorrect application of moisture removal systems.

In the determination, it is strongly suggested that temperature is used to calculate the percentage of moisture in the paper, because most of the water will stay in the paper for most of the life of a transformer. This is especially so for units that operate at a temperature lower than about 30°C, as the moisture does not move from thick insulation readily. The determination of moisture in paper is quite a tricky task and there is no simple method.

A single determination, taken from a routine sample should only be used as an indicator, and the more data that is acquired, the better the picture. It must be remembered that all moisture in oil data are related to temperature. If the oil sample data is corrected to include temperature (% moisture in paper or relative saturation), this can then be compared with other samples. However, it must be remembered that moisture moves between the paper and oil in a flip-flop action as the temperature changes. As the insulation is heated up the moisture will move from the paper into the oil, and as the temperature rises (as can be seen in Fig. 1) and the water will move back as cooling of the paper and oil takes place.

Oil has a unique property that it can dissolve moisture into its structure. Just like sugar in cup of tea the sugar will dissolve more readily in hot tea than cold. The same action happens with oil and moisture. However, oil has its own temperature boundaries and this works on the relative solubility curve. The temperature of oil determines the amount of moisture that can be dissolved and, added to this, the more oxidised the oil becomes the more the moisture that can be absorbed by the oil.

There are limits and boundaries to this, and as we can see the oil will only absorb a certain amount of moisture at a given temperature. Thus there are risks when operating a transformer that is generally wet. A transformer that is loaded very rapidly is at risk of producing a low dielectric strength where the oil is unable to dissolve the amount of moisture present. It must be remembered that it takes time for a large body of oil to reach a higher temperature. The equilibrium movement can be seen in Fig. 2. The aim of plotting this data is to understand the dynamics of the moisture being absorbed by oil and desorbed by the oil. Understanding this dynamic makes it easier to determine a major threat and risky moisture movement.

If the transformer is allowed to cool with a large amount of moisture dissolved in the oil, the oil will become over-saturated if the paper is unable to absorb the moisture and moisture droplets will be formed, literally causing rain in a unit's tank. You may ask, "Will the paper not absorb the moisture?" yes it will, but there is a time constant and the absorption will not happen at the same rate. Ultimately, moisture is not a good companion in a transformer, thus keeping it to a minimum is a worth while strategy.

Removal methods

The main aim with removal systems is reduce the risk of low dielectric strength caused by rapid moisture movement and the long term effect moisture has on insulation. Removing these risks results in less ageing and damage. There are three mainstream methods that are used currently, which can be done on-line or off-line. The three methods use heat and vacuum (if necessary), cooling and filtration.

Fig. 3: Heat and vacuum moisture removal system.

Heat and vacuum is not normally done on a unit in operation. The process encourages the moisture to migrate from the paper into the oil and by using a coalescer and vacuum in this process the moisture is then drawn off the oil. A typical unit can be seen in Fig. 3.

The vacuum chiller method will take the oil at the transformer's operating temperature, draw it into a chamber, apply a vacuum and cool the vapour drawn off, thus removing the moisture. Although this method can be used on-line, experience shows that the system is not as efficient as the filtration type systems.

Filtration on the other hand uses filters that operate on the moisture at a molecular level trapping the moisture in the filter material structure. Traditionally this method would only operate on a level of separated (undissolved) moisture. With new technologies this has changed and dissolved moisture can be targeted. There are two distinct technologies that are used currently, namely the paper filtration, membrane filters, specially manufactured ceramic filters and "zeolite" bead filters (a molecular level filtration material method).

The molecular filter (such as dry keep: as in Fig. 4) uses a zeolite bead to target moisture. The small beads are especially manufactured with the pore size engineered to effectively trap moisture in its structure thus removing moisture from the oil.

There are other patented filtration systems (such as MMS 1000 from Expiotech) that are used (filtration materials used are not disclosed). These filters are very effective

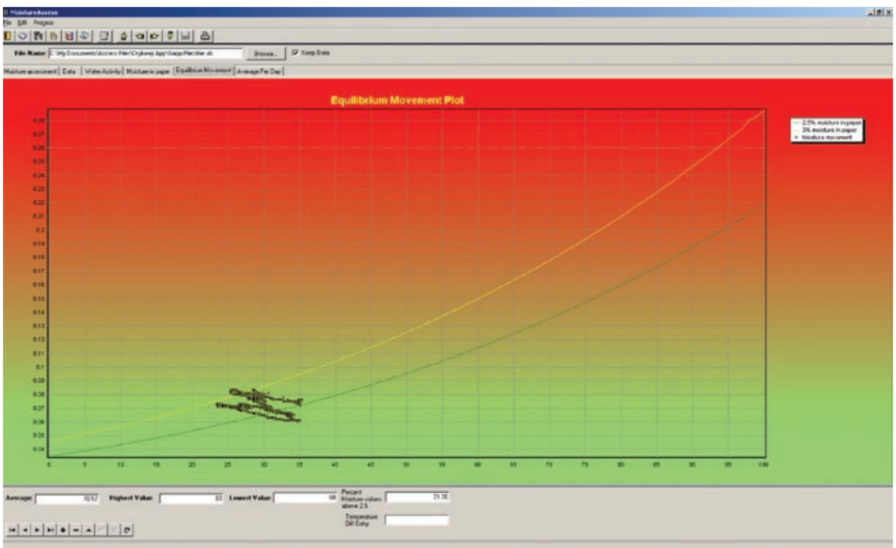

Fig. 2: Equilibrium movement.

in removing moisture. These units have a degree of intelligence built into the unit and will monitor the moisture in the oil, once this level has been determined, the unit will begin to filter. Once the desired moisture level is reached the unit will then stop and inform the operator.

Fig. 4: Dry Keep system (RT9).

However, it must be remembered that in any filtration system the removal of moisture is dependent on the amount of moisture that is made available by the paper and board. This is temperature, pressure (vapour pressure) and surface area dependent. The majority of these systems are applied when the transformer is regarded as "wet" and the filtration system will be applied either by condition monitoring or in a cyclic time window.

As stated earlier the transformer is always producing moisture on an ongoing basis. A molecular filter system, if fitted prior to the commissioning of a unit, will keep the transformer dry all the way through its life, reducing the most common ageing phenomenon of the transformer and thus extending the unit's paper life at a low cost.

With minimal maintenance required on an on-line molecular sieve filter system and gentle oil flow through the filter cartridges (a mere 1,5 l/min or 90 l/h approximately), there is no risk to the operation of the transformer. Continuous removal of moisture from the oil prevents problems from occurring. In comparison to a workshop dry out, the molecular filter system is considered to be one of the most cost effective prevention methods. The system is normally permanently fitted to a transformer to continuously dry the oil and is not normally moved from one unit to another.

The molecular filter technology has been used on a very wet unit with great success, and improved the dielectric strength and oil quality while in operation until the unit was finally decommissioned. However, any moisture removal technology being applied must take into consideration of all the factors influencing the life of the unit. The main objective must be to reduce the moisture but not eliminate it. Careful monitoring is a must and it is imperative that the moisture content is checked regularly. Some systems do this very well and will control the moisture removal to a specific moisture target and then stop the process.

If thick insulation is allowed to absorb moisture over a long period (>5 years) there is a tendency for the insulation to swell. This places additional pressure and stress on the material (board). Thick insulation will deform over time as the material starts to deteriorate and its elasticity diminishes. As moisture is removed the swelling will subside but the deformation of the material will remain.

Over-drying of insulation will cause the insulation to shrink. This can cause the windings to become loose and thus if the transformer does undergo a fault the winding may not survive the mechanical forces that are produced in these circumstances. It is a common thought that the oil molecule will replace the moisture molecule once it has been removed. This not so as the molecular sizes are vastly different and an oil molecule will not fit in a gap that has been left by a moisture molecule. Thus there is small collapse in the paper structure and this causes the shrinkage.

In the past there has been some concern with regards to the molecular filter filtering or blocking some of the dissolved gases that are used to indicate short term problems such as over heating or arcing. The only effect that may happen is that the molecular filter will trap a small amount of acetylene (C_2H_2) and some carbon dioxide (CO_2) during the first month of operation but these values are very small in comparison to the general bulk of oil and are not of concern. Other filtration systems will also remove some gases but to what extent is unknown.

If there is any doubt the filter should be shut off or/and isolated and left off for the period in which the problem is being encountered.

There are other methods of removing moisture from paper that are effective, however these methods are more aimed at the cure and the removal of moisture during the manufacturing or repair process. The vapour phase process uses a kerosene vapour to remove moisture from all the materials in the unit. In the strategy to prevent moisture from insulating material the vapour phase method would almost eliminate moisture in the manufacturing stages and thus start off on a "good footing" or as a major intervention. With the vapour phase the transformer is removed from the tank and this is costly and should only be used if a major intervention is needed.

Conclusion

If the transformer's life is dependent on the condition of the oil and the amount of moisture that is present in the paper and oil system, proactive measures instead of reactive, allow moisture to be controlled more effectively. Online systems that gently remove moisture are preferred to the interactive systems that are used at prescribed intervals. It is not to say that these interactive systems are not effective, but prevention is ultimately better than a cure. With chemical reactions always taking place that eventually produce moisture and the natural affinity paper has for moisture, prevention is the key to maintaining the integrity of the insulating system.

A small cost for prevention can save a big cost for a later major intervention or cure!

References

[1] J Aubin, H Vogel, G Bennett, J Eitzel: Determination of moisture in transformer insulation from long-duration measurement of moisture in oil, CIGRE paper 27, Brugge 2007

[2] V G Davydov, O Roizman: Moisture assessment in power transformers – Lessons learned, VAISALA News.

[3] Michel Bélanger, Stéphane Larouche: Application of on-line dry-out process to power transformers, Doble Engineering 2003.

Acknowledgements

This article was presented at the ABB Power Transformer Health Monitoring and Maintenance Symposium 2008 and is republished with permission.

Contact Tom Dalton, Rotek Engineering, Tel 011 629-4702, tom.dalton@eskom.co.za ❖