REMOTE TRANSFORMER INSULATION OIL MONITORING, PURIFICATION AND DISSOLVED GAS ANALYSIS (DGA) - THE IMPACT ON SERVICE LIFE

ABSTRACT

Electrical transformers are the backbone of modern electrical distribution networks. From government owned national networks to privately-owned distribution networks for mining sites and other large businesses, transformers perform a crucial function and as a result are heavily relied upon for the day to day operation of business. The leading cause of transformer failure in modern networks is due to moisture contamination within the transformer oil and cellulose paper [1]. This cause of failure is totally preventable by performing maintenance. The often-heavy dependence on the transformer, combined with the physical environment in which transformers operate, being at very high voltages, can make performing maintenance a difficult and potentially hazardous endeavour and are reasons why regular transformer maintenance is not conducted.

Significant cost savings can be achieved when effort is made to accurately monitor a critical transformer asset. By incorporating a stand-alone system to remotely monitor the condition of a transformer's insulation oil, it is possible to establish an accurate assessment of the 'health' of that transformer. If this system also has the capability to maintain and repair the oil at the same time, it is possible to dramatically reduce instances of unexpected or unplanned transformer outages. The capacity to monitor this remotely gives owners the ability to schedule planned transformer outages only when they are strictly necessary, greatly reducing the lifetime maintenance costs associated with that asset. In addition to this, remote, continuous monitoring removes risk and simplifies data analysis for the transformer owner, since it allows the involvement of off-site experts to interpret the data captured by monitors.

KEY ISSUES

- **OIL AND WATER DON'T MIX!**

Large electrical distribution transformers typically use an insulating oil to surround the electrical windings within the transformer. Oil insulated transformers offer several advantages over other transformer designs however the primary function of this oil is to assist with cooling of the transformer and protect the cellulose paper layers insulating the transformer windings. As a result, transformer insulation oil must have excellent thermal conductivity and a very high dielectric strength. The performance of transformer insulation oil will gradually deteriorate over time, mainly due to contaminants being introduced into the oil. Moisture is a particular concern to insulation oil, as the moisture content in the insulation oil is doubled, the life of the transformer is cut by half [1].

Moisture can enter the transformer in several ways, including directly through damaged or incorrectly installed seals when it rains, or more commonly through humidity within the air. As the transformer warms and cools throughout a normal daily cycle, the density of the air within the transformer rises and falls. When the transformer is warm, air is expelled from within the transformer. As the transformer cools, air is pushed back into the transformer. As the air within the transformer cools, moisture in that air condenses and water is introduced to the insulating oil. The problem is compounded by the accumulative effect of this happening on a daily basis. Since the oil surrounds the cellulose paper protecting the windings, moisture is transferred into the cellulose from the oil. This severely diminishes the ability of the paper to function as an insulator.

In addition to impacting the dielectric strength of the insulation oil and cellulose paper, the presence of moisture within a transformer causes oxidation and this in turn leads to the formation of acids within the insulating oil [2]. Acids contribute to the formation of sludge in the transformer and that build-up of sludge reduces the efficiency of heat transfer, from the transformer windings to the insulation oil. The rate of oxidation and subsequent acid production, is also dependant on the temperature, so as the formation of sludge causes the temperature to increase, this in turn causes more sludge to be generated [2]. This is a vicious cycle that if left unchecked, can dramatically reduce the service lifespan of the transformer.

If contamination reaches a critical level without being rectified, this can cause the cellulose insulation paper to break down completely and stop performing as desired. The result can lead to electrical arcing between the windings and this in turn can lead to a premature destruction of the transformer.

The potential costs of such an outcome can be counted in the tens of thousands of dollars and may range into the hundreds of thousands of dollars, depending on the size of the transformer. This cost estimate only considers the replacement cost of the transformer unit and does not take into account the loss of revenue, from operations being impacted by the loss of the electricity supplied by the transformer. Failures due to moisture contamination are by far the most common cause of transformer failure [1].

- **HARMONICS IN MODERN POWER NETWORKS – THE IMPACT ON OLDER TRANSFORMERS**

Modern electronic equipment has provided considerable benefits to industry, spearheading improvements in efficiency and industrial processes. At the heart of every modern piece of electronic equipment is the electronic power converter. Electronic power converters by the nature of their design, introduce harmonics into the power supply. Harmonics are generated by nonlinear loads, or any time current is drawn in short rapid pulses, rather than in a smooth, continuous manner. Electronic power converters are located in most modern industrial and office equipment, including;

- Switch Mode Power Supplies
- Variable Frequency Motor Drives
- Electronic Ballasts
- Oven and Furnace Controls
- Rectifier Circuits

Once generated, harmonics tend to propagate throughout the entire power supply or transmission network, including back to the transformer supplying the network.

Harmonics negatively impact transformers in several ways, however the primary side effect that we are interested in, relates to the additional heat generated within the transformer due to increased AC losses produced by the presence of the harmonic currents. The negative effects of harmonics on transformers commonly remain unnoticed and are disregarded until an actual failure occurs [3]. Some transformer designs are able to mitigate the effects of harmonics, or simply cope with the presence of harmonics better than others. Harmonics are a particular problem in older transformers, since in many cases these were simply not designed with harmonics in mind. It is the presence of this additional heating, augmented by a lack of regular transformer maintenance, that is often responsible for a reduction in the expected life span of the transformer.

Harmonic (nonlinear) loads are often assigned with a 'K' factor, to assist with calculating the severity of the impact they will have on a transmission system. For example:

- A transformer that was designed to operate with a load at '**K-1**' and has total conductor losses of 2800W + (135W x **1**) = 2935W. These losses generate a temperature rise of **92°C** in this transformer.
- The same transformer now operates with a load at '**K-20**' resulting in total conductor losses of 2800W + (135W x **20**) = 5500W and generates a temperature rise of **154°C** in the transformer. [4]

Having already discussed the negative impact that heat can have on unmaintained transformer insulation oil, it becomes evident as to how older transformers may be more susceptible to failure or unplanned outages, when efforts are not made to ensure insulation oil is kept free from moisture and impurities.

- **COST OF SERVICE**

Labour hours combined with transformer downtime, process downtime and associated laboratory costs for oil analysis, make traditional bottle sampling techniques a potentially expensive and often inefficient way of monitoring transformer insulation oil condition. A laboratory analysis report is typically returned 2-4 weeks after the sample is taken, during which time a serious fault could have gone unnoticed.

Industrial sites may have one, several or tens of transformers, all of which should be maintained to a similar standard. The state of the cellulose paper within the transformer, is directly associated to the condition of the transformer insulation oil. The more frequently the transformer's oil is sampled, the more accurate understanding you have, of the 'health' of the transformer. Most transformers should be sampled at the very least, on a biannual or annual basis. Critical assets should be monitored far more frequently. Traditional bottle sampling is time consuming and can be unreliable, since the process itself introduces the opportunity for the sample to be contaminated, i.e. when transferring the oil sample to the bottle and if contaminated bottles are used, etc. The dissolved gasses within the oil can also be impacted if the sample bottle is made from the wrong material. The temperature of the oil at the time of taking the sample must be accurately recorded and this can be overlooked or inaccurately measured. In short, the small quantity of fluid in the sample bottle simply may not reflect the actual oil condition of the transformer.

In spite of this, the biggest downfall with traditional oil sampling techniques is that they do not provide a live oil analysis, making it extremely difficult to understand the real time condition of the transformer. Measuring the behaviour of the transformer as the load on the transformer changes, gives the most accurate understanding of the transformer 'health' and this allows one to accurately plan scheduled maintenance outages as problems are identified.

IMPROVEMENT – REMOTE MONITORING

Monitoring the quality of the insulation oil in real time, allows operators to accurately analyse the 'health' of their transformer. When the level of moisture within the transformer insulating oil is monitored, preventative measures can be taken as increases in these levels are detected. The most effective way to monitor the general 'health' of a transformer, is by independently monitoring both the moisture levels and the dissolved gasses in the oil. Moisture is monitored using a dedicated device which continually samples the oil. It is possible to use a device that can monitor both the moisture content and the particle count of the insulation oil and send the results remotely, allowing them to be analysed immediately.

By far the most effective way of monitoring the dissolved gasses within transformer insulation oil, is by means of Dissolved Gas Analysis (DGA). DGA employs specialised sensors to detect and analyse the types and amounts of gasses that are dissolved within the transformer insulation oil. Traditional transformer insulation oils are mixtures of different mineral oils and the decomposition of these oils, due to thermal or electrical faults, generates several key gases. The types of these key gasses that are generated, help to give an indication of the nature of the fault. The quantity of these key gases helps to give an indication of the severity of those faults.

The key gases produced are; hydrogen (H2), methane (CH4), acetylene (C2H2), ethylene (C2H4), and ethane (C2H6) [5]. Further, when Natural Ester insulation oil is involved, thermal decomposition or electric faults produce methane (CH4), hydrogen (H2), carbon monoxide (CO), and carbon dioxide (CO2) [5]. The analysis of these gases can be complex and remote monitoring, allows for this critical process to be conducted by external experts. Table 1.0 can be used to give a general indication of the nature of the fault, when these key gases are detected.

Gas Description		Key Gas Concentration (in ppm)		
		Normal Limits* (<)	Action Limits** (>)	Potential Fault Type
Hydrogen	H_2	150	1,000	Corona, Arcing
Methane	CH_4	25	80	Sparking
Acetylene	C_2H_2	15	70	Arcing
Ethylene	C_2H_4	20	150	Severe overheating
Ethane	C_2H_6	10	35	Local Overheating
Carbon monoxide	CO	500	1,000	Severe overheating
Carbon dioxide	CO_2	10,000	15,000	Severe overheating
Total Combustibles	TDCG	720	4,630	

* As the value exceeds this limit, sample frequency should be increased with consideration given to planned outage in near term for further evaluation.

** As value exceeds this limit, removal of transformer from service should be considered.

This table is derived from information provided within ANSI/IEEE C57.104

Table 1- Dissolved Gas Analysis [5]

While under normal operating conditions, the amount of dissolved gas within the transformer oil is minimal. When an increase in the concentration of gasses is detected, measures can be taken to perform preventative maintenance and in so doing mitigate the damage caused to the transformer and the resultant impact on business [6].

IMPROVEMENT – OIL CONDITION

To effectively remove moisture from the layers of cellulose insulation paper surrounding the transformer windings, it is necessary to remove the water from the insulation oil over an extended period. Water propagates from a wet environment to a dry one, so water that is stored in the 'wet' oil will be absorbed by the layers of cellulose paper. This is how water is introduced into the cellulose paper layers over a period of time. The reverse is also true for removing moisture from the cellulose insulation paper layers. It is necessary to repeatedly 'dry' the oil over a period of time to allow moisture to be drawn from the cellulose paper into the 'dry' transformer oil. For this reason, simply drying the insulation oil in a one-off instance, as is the case with offline or one off drying of the transformer oil, may not have significant or long-lasting improvements to the moisture level within the cellulose insulation paper layers. Far greater results are achieved when moisture is continually removed from the oil over an extended period, since this allows the cellulose layers to become completely dried.

There are two very effective means for removing water from the transformer insulation oil and cellulose paper. One is through the use of specialist desiccant filters that when coupled with the ability to regenerate themselves many times over, provide a reliable and trouble-free means of removing moisture. Desiccant filters will also not impact the dissolved gasses within the oil, for instances where it is desired to simply monitor and not remove these. Alternatively, vacuum chambers can be used to reliably remove moisture and dissolved gasses from the transformer insulation oil. The reduced pressure within the vacuum chamber allows the water and dissolved gases to boil out of the oil, at a much lower temperature than would be possible at atmospheric pressures. The lower temperatures used by both desiccant filters and vacuum chambers ensure that the oil is not damaged by excessive heating, as may be necessary to boil off the water and gases if these methods were not utilised. Desiccant filters and vacuum chambers are a very efficient and cost-effective ways for removing moisture and dissolved gases, as they do not rely on a large and constant supply of compressed air, as is necessary with other types of oil dryers.

CONCLUSION

Electrical transformers are a vital component of modern industry since they are heavily relied upon for the smooth running of day to day operations. Unplanned transformer outages can have a substantial financial and operational impact on a business. Reductions in the frequency of transformer insulation oil sampling results in a lack of 'live' data with which to accurately monitor and predict faults. There are many seemingly valid reasons why some may consider it too difficult or expensive to perform regular transformer maintenance, mostly due to the heavy commercial reliance on the transformer and the inability to work on live transformers, due to the risk of electrocution.

Adopting a stand-alone system that incorporates remote monitoring of both oil condition and fault gas levels, ensures the task of upholding proper transformer maintenance is easily achievable, without impacting on the operation of the transformer and more importantly without endangering personnel.

The use of dedicated, stand-alone remote transformer maintenance equipment is redefining the way companies look at transformers and setting a new standard that will help ensure these critical assets achieve or exceed their designed service lifecycle.

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