Reliability Ireland Conference 2016,

Grand Hotel Malahide, 12-13 April 2016, Dublin, Ireland.

Use of On and Offline Oil Analysis on the ESB, Distribution and Generation Networks

J. Carpenter*,
ESB International,
Ireland

*** jonathan.carpenter@esbi.ie**

SUMMARY

Condition based maintenance is an industry standard as a maintenance strategy for power transformers. This paper describes the experiences of the Irish electric utility – ESB in applying online monitoring technology, supplemented by off-line oil analysis to help monitor its aging fleet of power transformers.

In recent years, over one hundred online gas in oil and bushing monitors have been installed on the Irish utility's power transformers. This is in keeping with an industry trend towards more online monitoring, which allows for early detection of developing faults. It also provides a deeper understanding of the health of a transformer which can enable deferred maintenance, increased loading and ultimately extend the lifetime of the transformer.

To supplement this on-line monitoring, it is our policy to take oil samples from our transmission transformers (220kV and above) every 6 months and from our 110kV transformers yearly, along with 3 yearly samples from our 38kV transformers. This routine analysis consists of a full Dissolved Gas Analysis (DGA) and Oil Screen tests, with moisture, IFT and acidity also measured. In addition to this, every 8 years a condition assessment of our transmission transformers is carried out which consists of both off line electrical measurements coupled with oil analysis which includes furanic compounds analysis tests which give a good indication of how the transformer is aging & it's predicted remaining life.

The first type of transformer online monitor installed on the Irish utility network was a composite gas in oil Dissolved Gas Analysis (DGA) monitor. This measured the combustible gases dissolved in the oil, but did not give a breakdown of individual gases, and could not be monitored remotely. It was the first DGA monitor to become commercially available and was useful as a trigger/early warning to take an oil sample and send it to the laboratory for DGA analysis.

When multi-gas monitors became available, these became the standard for us to use on new transformers, and were also retro-fitted to critical existing transformers, along with transformers that had major repair works carried out. The breakdown of individual gases allows us to perform diagnostics, as well as alerting us to high gassing levels via text messaging which affords us the possibility to reactively decide upon the next course of action.

At present almost all of our fleet of DGA monitors have GSM modems installed, allowing us to monitor these remotely, however our next challenge is to endeavour to find a way of implanting this technology for use in our Bushing monitors so Tan Delta and Capacitance readings as well as partial discharges can be trended remotely to help predict any impending bushing faults.

Some of our DGA monitors installed as policy and most of the bushing monitors are installed on transformers with type faults while replacements are being procured. For example, a GSU transformer from a family of transformers with known failures around Europe was retrofitted with a multi-gas DGA monitor in case it contains the same manufacturing defect as its failed counterparts.

The paper also covers discussion centred around the factors considered when choosing particular brands of monitoring systems, communications and data retrieval, along with various case studies to highlight the benefits of this technology on the Irish utility network.

KEYWORDS

Online monitoring, transformers, DGA, bushings, remote communication, furans

INTRODUCTION

In recent years, the electric utility in Ireland has installed over 100 online DGA monitors on its extensive fleet of Transmission, Distribution and Generation transformers. This is in keeping with the current industry trend towards more online monitoring, which allows for early detection of developing faults. These monitors, along with manual samples also provide us with a deeper understanding of the health of a transformer which can be utilised to make informed decisions in relation to deferred maintenance, increased loading and extending the lifetime of the transformer.

The Irish utility has over 350 power transformers in the 110-400kV voltage classes, located in both substations and power plants. With this number of transformers in our fleet it was of vital importance that the monitors we installed were the proper fit for each transformer to be monitored. We also had to develop criteria for transformer selection, to ensure those transformers we perceived as being the most vulnerable were given preference. We currently have a ‘Live' transformer risk matrix' and this was utilised to facilitate this selection process. Another pre requisite for selection was the facility of the monitors to allow the possibility of remote communications, which is essential as this affords us the ability to be reactive in the event of any signs of impending/developing faults.

EVOLUTION OF TRANSFORMER ONLINE MONITORS

The first type of transformer online monitor [1] installed was a composite gas DGA monitor. This was the first commercially available type of DGA monitor and measured a number of combustible gases dissolved in the oil, but did not distinguish between them, so that only an overall gas concentration was given. This overall gas concentration is called the TDCG (Total Dissolved Combustible Gases) and can be used to evaluate the condition of the transformer [2]. It was also used as a prompt to take an oil sample and send it to the laboratory for further analysis and diagnosis.

With advancements in technology, multi-gas DGA monitors became available. These became the standard for installation on new transmission transformers and were used to replace the older DGA monitors on important or troublesome existing transformers. Multi-gas monitors are capable of indicating the gas concentrations of each individual fault gas, as well as an overall TDCG reading. This allows for the use of various diagnostic tools such as Duval's Triangle [3] and Roger's Ratios [2] to determine the nature of the developing fault. These methods can be used in conjunction with historical data of each of our transformers to assess their overall health and gassing trends.

Most multi-gas monitors and newer composite gas DGA monitors have the capability to also measure moisture within the oil, another important aspect in determining the overall health of a transformer.

More recently on the ESB network, bushing monitors have been installed on a number of transformers fitted with bushings that are known to have a specific failure mode. These monitors are not only useful from a transformer operational viewpoint, but also from a health and safety point of view, due to the fact these bushings are of porcelain make up and pose a serious safety risk to those working within close proximity. Effectively, these monitors allow us to monitor the degradation of the bushing's insulation, which is an early indicator of the failure mode associated with this bushing type. As a matter of course, these types of bushings are being replaced as part of a major work programme. However, as these bushings are fitted onto a large number of our critical transmission transformers, it was not operationally possible to switch these out to facilitate bushing replacement work. Initially as an interim measure, exclusion zones were placed around these transformers, which were proving to be unworkable. However, with the express permission of the Irish Network Operator an agreement was reached, wherby these transformers could continue in service with no exclusion zones present on the proviso that they were monitored by on-line bushing monitors.

At present the ESB has 48 composite DGA monitors, 74 multi-gas monitors and 10 bushing monitors installed on the network. It is envisaged this number will rise significantly over the next few years, due to the fact that significant investment is planned for the network that will see the addition of many new transformers that will be supplied with multi-gas on line monitors as standard. On the other hand with the increasing age of much of the fleet, it is inevitable problems will arise due to ageing and it will be crucial that these transformers are monitored.

USING DGA INFORMATION TO DIAGNOSE TRANSFORMER CONDITION

A cautious approach must be taken, when trying to diagnose a transformers condition based on DGA data. Conclusions should not be made on the basis of a single sample. If a fault is suspected based on the analysis of DGA data, the first thing to do is to take a second sample and repeat the analysis. If the repeat sample confirms the initial diagnosis, the previous historical data for the transformer must be looked at, to confirm what gases have changed and to what extent. Loading profiles should also be considered and different scenarios discounted like “Could the gases have diffused from the diverter-switch compartment of an on-load tapchanger?” or “has someone topped up the transformer recently using contaminated oil?”

Once all these possibilities have been discounted and it is believed a fault is present a number of diagnostic tools can be utilised to determine the nature of a developing fault. Primarily Roger’s Ratios [2] and Duval’s Traingle [3] are used.

MONITOR SELECTION CRITERIA

The following factors were considered before choosing the brand of monitor to meet our needs:

- What is monitored: As a prerequisite we decided that as well as the various fault gases, moisture must also be measured. We had to also decide upon the correct combination of fault gases we measured, to facilitate us applying our preferred methods of diagnosis. In terms of our bushing monitors, some manufacturers offer on line partial discharge measurements in addition to capacitance and power factor measurements.

- Hardware capability: It was decided the best approach for us to garner an evaluation of hardware capability, was to purchase a number of different monitor types and evaluate their performance over a period of time.

- Communication capability: It was a fundamental requirement of ours that remote communications with online monitors was possible. This allows us get the most benefit from the monitors, as it allows us view real time data and take reactive measures where required. At present all of our gas-in-oil monitors and most of our bushing monitors can be monitored remotely over the GSM network.

- Manufacturer support: As we were to embark on a programme of installing a large number of online monitors on the Irish utility network, this was another fundamental requirement of ours. With such a large number of units to be installed, it is inevitable we would need support from manufacturers in terms of both repair and general use, so it was important manufacturers could respond to our requests for support quickly as it is an added risk to have a transformer unmonitored for long periods of time.

- Software :We were looking for software that was easy to install, had user friendly functionality, displayed information on trend graphs and also had the requisite number of licences so all the relevant personnel could have a copy. In terms of remote communications, it was essential the software made it easy for us to dial in and download results, set alarm threshold levels, alter sampling intervals etc.

- Weather-proof capability: Being an Island country corrosion poses a serious problem in Ireland, so the monitors need to be able to withstand this coastal environment, as experienced in many of our substations.

- Installation: Many of our gas in oil monitors were able to be installed on energised transformers, which negated the need for costly transformer outages. Most DGA monitors require two sampling points (valves) and can leave limited options for accessing oil for the purposes of, e.g. oil removal in the event of a repair. Also, as space it at a premium around a number of our transformer, the size and mounting arrangements of the various monitors was another important consideration that needed to be considered.

TRANSFORMER SELECTION CRITERIA

Following on from the decision with regard to selecting the best monitor to meet our requirements, the next requirement was to look at a selection criteria that would ensure the most vulnerable transformers were fitted with these monitors. A live Risk Matrix proved invaluable in facilitating us with these decisions. This risk matrix we have has helped us decide on our transformer choice based on the following factors:

1) Available electrical test results
2) Historical loading profiles
3) Oil test results (Transformer Oil Analysis Database)
4) Age

Also taken into consideration were factors such as criticality of transformer to the network and known previous manufacturer and type failures.

Our transmission transformers are electrically tested every 8 years and annual oil samples taken, so we believe our risk matrix affords us a good overall insight into the overall health of our transformer fleet, leading us to prioritise transformers most at risk of potential failure.

COMMUNICATION

To help gain maximum benefit from these DGA on line monitors remote communication was a necessity. The main benefit of this is the fact that the right people with experience in the field of transformer oil diagnostics can now see real time information, thus enabling reactive decisions to be made where applicable. This technology is a vast improvement to the simpler DGA monitors that had alarm outputs hard wired into the stations SCADA system, which fed into the national control centre (NCC). The pitfalls with this setup were:

1) A general gas alarm was received when a specific threshold level or alarm set point was surpassed and the actual gas concentration level (ppm) could only be determined by personnel visiting site to view the monitors display.

2) Even with this a Total Dissolved Combustible Gas (TDCG) value is displayed in parts per million (ppm) and to gain an appreciation for what might be occurring within the transformer, an oil sample must be sent to a laboratory for further analysis.

3) With the simpler DGA monitors these general alarms were notified to operations staff, whose interest is in the immediate implications of alarms, rather than the maintenance staff, whose interest is in the long-term health of the transformer. In essence the information was being received by the wrong people who did not have the relevant skills to appreciate the possible implications and due to this the perceived importance of these alarms as early indicators of possible developing faults was diluted and were quite frequently ignored.

Due to the obvious issues highlighted and not to leave any of our transformers exposed, it was clear a solution was required that would bring all the relevant data directly to the correct people, who in turn could make informed decisions. The need for this became even more apparent with the introduction of the more complex multi-gas in oil monitors.

It was agreed the best solution to achieve this objective, was to establish a communication link outside of the existing SCADA system, as gaining access to this for maintenance staff would prove difficult and IT security issues associated with establishing a remote link were not as stringent.

Much of the transformer fleet in Ireland are located in remote areas with little or no 3G coverage and the majority of substations themselves are not equipped with network or internet connections. This led to a straightforward decision to use GSM, as it offered the simplest and most reliable solution. GSM modems were sourced from the monitor manufacturer, who also provided setup support. The GSM solution was applied to all our existing fleet of multi gas DGA monitors and desktop modems were supplied to key maintenance engineers and the transformer specialist team to allow remote connection to any of the monitors at any time. The modems also provide the functionality to send text messages in the event of any alarm levels breached and these text messages are received by key maintenance engineers.

Presently work is being carried out to investigate the possibility of utilising these GSM modems with our on line bushing monitors and also our composite DGA monitors.

DATA MANAGEMENT

With the introduction of ~80 of these multi gas on line monitors onto our system the need to efficiently manage this vast level of data became apparent. These monitors typically have the facility to store a few years worth of data. At the minute with our remote data retrieval method that allows any of our key maintenance engineers to retrieve the relevant data, this is primarily done in response to an alarm, or if transformers with known problems are being closely monitored. This is not an effective and efficient means of data management, as it results in each engineer having records from large numbers of transformers on their local computers, but not all of them, and not the same records that a colleague may have. With over one hundred of these monitors now installed, data management has become a more critical issue and the need for a centralised data management system has become apparent. In future it is hoped to roll out a system that will meet the following requirements:

- Server located in head office that will automatically download the most recent records from each monitor and store these in a location that is accessible to all the key maintenance engineers

- System needs to alert key maintenance personnel in the event of alarms immediately

- System needs to give a macro view of all monitor locations on a map in the office, utilising traffic light colour coding to distinguish between healthy, gas alarming and service alarming monitors

- System should be able to strip relevant raw data from each individual monitor and import into a tailored software program that is independent of individual manufacturers

With over 350 Power transformers (110kV and above) on the network and from a cost benefit point of view, it is clearly apparent that on-line monitoring is not practical for every Power Transformer on the EBS's Network, so a database called the T.O.A. (Transformer Oil Analysis) is utilised to data manage and store historic and recent off line transformer oil analysis.

We feel that effective on line and off line monitoring and successful data management will help us to:

- Avoid unplanned and expensive transformer outages

- Mitigate against possible damage due to early detection of possible impending transformer faults

- Overload transformers for brief periods of time without causing damage

- Keep possible transformers with known faults/potential faults in service

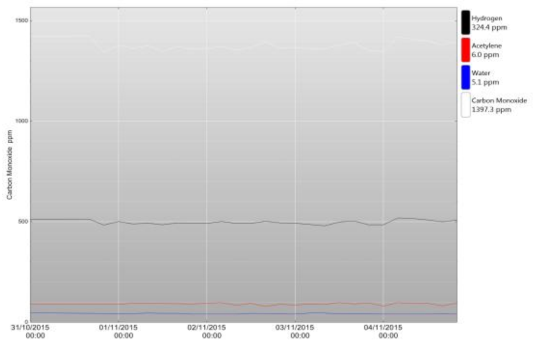
- Extend the service life of our transformer fleet

CASE STUDIES:

The following case studies give an appreciation of just how important on and off line transformer oil monitoring has become for ESB International, allowing us to keep our clients transformers in service and to ensure associated risk exposure levels are minimised.

CASE STUDY 1 – DGA Oil Monitoring:

A 250MVA Power Transformer began gassing and was detected on one of our 3-gas DGA on line monitors. Decision was made to install 8-gas equivalent monitor to see detailed overview of all the overheating gasses. The Transformer was de-energised to facilitate off-line electrical measurements. These measurements showed no electrical anomalies with the transformer. So based on the oil results and the increase in various overheating gasses, namely hydrogen (H2), methane (CH4) and ethylene (C2H4), an in-tank inspection was carried out which revealed that the insulation around nuts and washers used to keep the magnetic flux deflectors in place had broken down (see fig. 4 below), leaving a path for a circulating current to circulate causing overheating and gassing in the transformer oil.



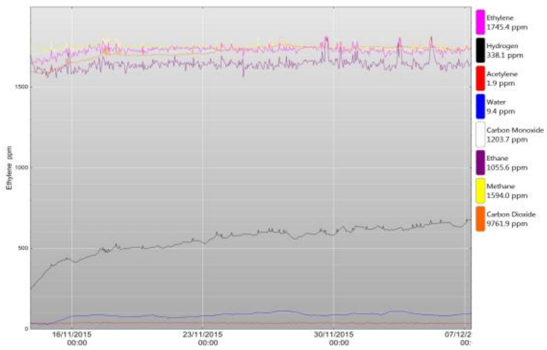


Figure 1. 3-Gas on Line Monitor

Figure 2. 8-Gas on Line Monitor

Figure 3. Inside View of Transformer

Figure 4. View of Metallic Shield

The repair consisted of re-tightening and insulating the nuts and bolts holding the magnetic shields to the transformer tank and also a new and improved insulation material was used to insulate these fixing points. Since the transformer was re-energised the on line and off line oil readings have been acceptable.

CASE STUDY 2 – Distribution Transformer Fault Investigation/Repair:

A 10MVA Distribution transformer tripped on Load due to activation of the Buchholz relay caused by gassing in the transformer oil. Evidence from both electrical offline measurements and DGA analysis, indicated that the likely cause of the fault was overheating contacts on the Dual Ratio/Off Load Tap Changer.

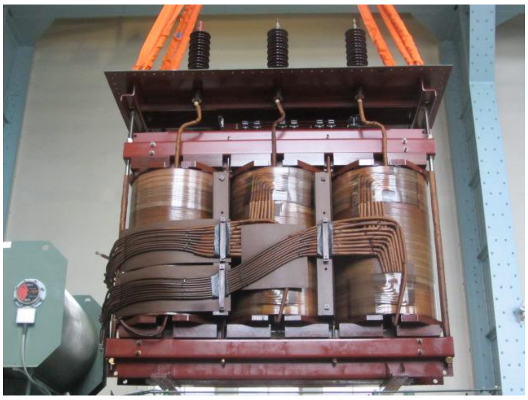


Figure 5. Transformer being De-Tanked

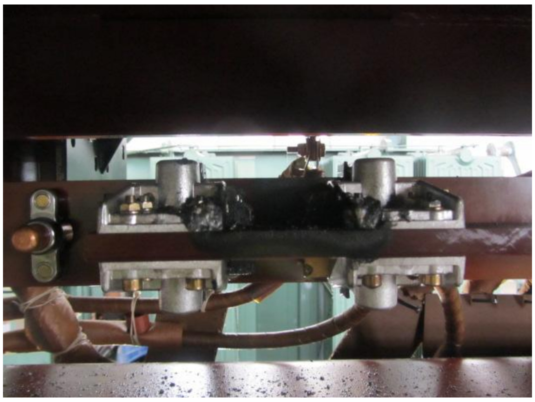


Figure 6. Damaged D/R switch Contacts

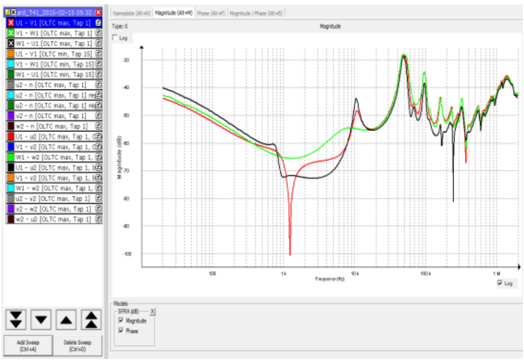


Figure 7. Frequency Response Analysis

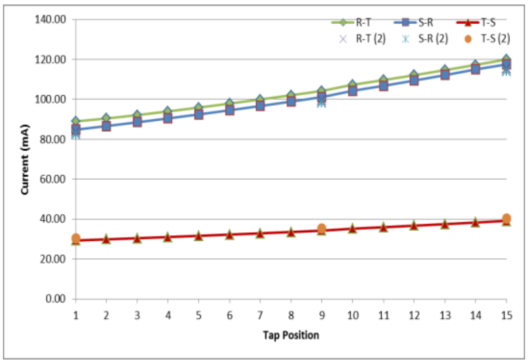


Figure 8. Excitation Current Measurements

Sampledate	Sample Point	H2	C2H2	C2H4	C2H6	CH4	CO	CO2	H2O
29/06/2012	MTT	13	0.3	1.7	9.9	3	25	522	22
16/12/2013	MTT	393	445	2096	1014	1249	260	1805	14
16/12/2013	MTB	512	384	1850	762	978	198	1333	14

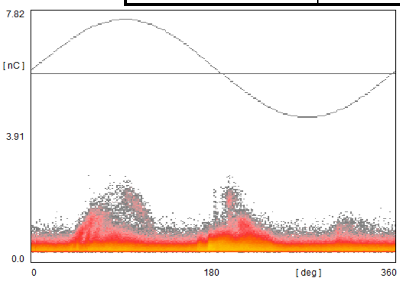
Based on the above mentioned FRAX and Excitation off line measurements, supplemented by the off line DGA analysis, the suspected fault was correctly diagnosed prior to transformer detanking. On foot of this, it has been recommended to increase the oil sampling frequency on all these type of Distribution transformers. Going forward, ESBI design section have also updated their current transformer specifications and are now requesting these Dual Ratio Switches be accessible by means of a link box, which will negate the need for expensive detanking in the event of further failures.

CASE STUDY 3 – DGA Monitor Application with PD Measurements:

A 25MVA Hydro Power Station transformer was exhibiting relatively high values of hydrogen, which led to us believing the possible causes were PD within the transformer or stray gassing in the oil.

Figure 9. Transformer Overview

sampledate	C2H2	CO	H2	H2O
01/02/2014	0	298.2	142.3	16.2
28/12/2013	0.4	299.8	143.4	16.5
01/11/2013	0.2	274.4	157.7	21.4
27/09/2013	0.4	198.9	119.6	23.6



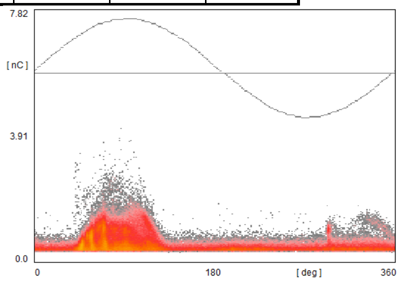


Figure 10, PD Pattern HV-R Phase Figure 11, PD Pattern HV-S Phase

PD measurements combined with acoustic measurements along the entire transformer tank were conducted and it was confirmed PD was present, with its origin emanating from the HV S-phase winding. This internal PD was recorded fluctuating between 3.22nC to 3.70nC and is considered to be at a moderate to high level. Also PD was recorded emanating from the HV R-phase winding, with discharge levels of approximately 1.5nC recorded. The origin of the PD-activity is located deeper in the windings, most probably in the vicinity of the transformer core. As this part is well shielded by the core, due to the shell type transformers construction, no acoustic signals produced by any source would be detectable at the tank. In this particular case, no corrective actions were recommended as the failure location will be most probably inaccessible. Due to this, it was difficult to estimate time to failure and It was advised that an on line partial discharge monitoring system should be installed. However, as this transformer was due to be replaced in the near future, was over 40 years old, it was decided to keep it in service and closely monitor using the online DGA monitor.

CASE STUDY 4 – DGA Monitor Application:

A 220kV Reactor on one of our client's substation sites was showing signs of increased Hydrogen levels. Indications led us to believe there was a possibility of Partial Discharge within the reactor.

Timestamp	H2 [ppm]	CO2 [ppm]	CO [ppm]	Ethylene [ppm]	Ethane [ppm]	C2H2 [ppm]	H2O [ppm]
10/02/2012 02:00	232.1	1743.5	259.5	9.2	29.6	0.2	5
10/02/2012 06:00	228.5	1721	253.3	8.2	23.1	0.2	5.1
09/06/2012 02:00	315.5	2179	311.6	8.2	23.1	0	6.5

This reactor was closely monitored and a specialist company in transformer Partial Discharge (PD) measurements engaged to investigate. Following the investigation for PD a full suite of electrical testing was also carried out. PD and other possible electrical faults were discounted and it was considered that the phenomena of stray gassing in the oil may be the cause. Oil samples were sent to a specialist laboratory and the conclusion was that the cause of the gassing was most probably due to stray gassing. A course of action to regenerate the oil was decided upon. After this process was completed, it was essential the oil was monitored closely to ensure this process was successful in solving the stray gassing issues; subsequently Hydrogen did not begin increasing again. For this purpose on line DGA monitoring proved invaluable.

sampledate	C2H2	C2H4	C2H6	CH4	CO	CO2	H2	H2O
10/01/2014 13:00	0.1	0.4	1.4	6.8	262.9	2002.6	5.1	2.7
10/01/2014 09:00	0.1	0.2	2.6	5.9	262.1	1998.1	4.9	2.7
10/01/2014 05:00	0	0.3	2.7	5.4	261.8	1989.6	4.9	2.6

BIBLIOGRAPHY

[1] “An Overview of Online Oil Monitoring Technologies” Tim Cargol, Weidmann-ACTI, Inc. (Fourth Annual Weidmann-ACTI Conference, San Antonio, 2005)

[2] IEEE C57.104 “IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers” (2008 Revision, Section 6)

[3] IEC 60599 “Mineral oil-impregnated Electrical Equipment in Service-Guide to The Interpretation of Dissolved and Free Gases Analysis2