GE
Digital Energy

New Era Transformer Fleet Management

Part 1 of a 2 Part Series:
Challenges in Realizing the Condition Monitoring Vision

Dominique Legrand and Austin Byrne
GE's Technical Subject Matter Experts

imagination at work

Executive Summary

Power transformers, regarded as critical grid assets, are presenting an increasing challenge to asset fleet managers due to their large numbers and advancing age. Condition Based Maintenance (CBM) of these assets, based on dissolved gas analysis monitoring, has long been considered the panacea of transformer fleet management. However, while online transformer monitoring systems provide part of the solution, organizations have been struggling to achieve the full benefits of their CBM vision.

Increasingly, organizations are in search of software to perform data interpretation and automatic transformer evaluation. Compared to expensive custom built systems which take years to roll out, the new era of "out of the box" intelligent software, using algorithms combining best practices and recognized industry standards, allows for faster return of their monitoring investment dollars. By adopting new era data analytics software which also facilitates easy customization, organizations can instantly benefit from data validation, amalgamation and cross-correlation. They can oversee their whole fleet and replace data overload with actionable intelligent information, the key to unlocking true condition monitoring value.

Part 1

Challenges in Realizing the Condition Monitoring Vision

Author: Dominique Legrand

Part 2

Solutions Using New Era Asset Fleet Management Software

Author: Austin Byrne

The Power Transformer, a Critical Asset

For many organizations, the power transformer is considered a critical asset due to its key role in the electrical grid, its importance to everyday business as well as its cost and lengthy lead time to replace. Unplanned transformer failures and outages can have severe operational consequences, financial impacts as well as environmental and safety impacts.

The Impact of Failures

For utilities, transformer failures can interrupt the delivery of service to hundreds of thousands of customers, from household consumers who rely on the power provided by the electrical grids to perform everyday tasks to the business consumer who relies on the grid to manufacture products or deliver services to their customers.

Fig 1: Picture of a sub-station fire resulting from a transformer failure

Utilities often compete for business, and there is no worse PR exercise than having to rationalize a blackout, or having to explain images of a burning transformer on the evening news.

Regulators also closely monitor SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) data and may impose hefty fines on utilities if predetermined targets are not met.

Studies have shown that the US progress in terms of SAIDI numbers, after an initial improvement due to significant efforts to modernize the grid, has been slow to continue that trend. The initial positive results achieved are now being offset by the advancing age of the remaining equipment and the SAIDI numbers have struggled to continue to improve significantly.[1]

Delivering power to business consumers is critical to their operations and their ability to contribute to GDP and employ people. Some business consumers even rely on extremely tight tolerances for their power delivery. Manufacturing companies know exactly how much an un-planned production outage costs them per hour in terms of lost revenue and are quick to calculate and communicate the financial consequences (often required for insurance purposes).

For some process industries, an unplanned outage can be disastrous. If a transformer should fail in an aluminium smelting environment, it can lead to the loss of millions of dollars due to the irreversible damage to the production lines. Failure by power utilities to deliver adequate service, or quality of service, can often lead to penalties under a supply contract or even litigation to recover costs and damages.

Ageing Transformer Fleet

As with everything, the older a transformer, the more prone to failure it is, due to component wear and untreated small defects.

Lack of investment in transformer asset replacement over the last decade, partially justified by the good reliability of these assets and their exceptional longevity past their original design life, have now created the perfect storm. Transformer fleets are ageing rapidly and are entering the end of their life-cycle "bathtub" curve, where the probability of failure in service starts to drastically increase.

According to Green Tech Media, the average age of a substation transformer in the US was 42 years in 2013 and the number of transformer failures is expected to peak around the end of the current decade.[2]

The keys to mitigating these risks are monitoring and understanding the condition of the transformers.

Transformer Maintenance

In these days of reduced operating budgets, performing maintenance only when required has become the norm. Regular site visits to check status no longer take place. Transformers often operate with minor faults that slowly erode their design operating life and will bring early failure prior to the planned replacement date.

Issues detected early can turn a possible catastrophic failure into a controlled and planned outage. Even a costly planned repair is less expensive than replacing the whole asset. A replacement spare is often not available and transformer manufacturers offer long lead times for new products. Finally, as you would expect, a planned outage is both shorter and less costly than an unplanned one and therefore has positive consequences on the utilities SAIDI index, let alone their customers.

Utilities clearly understand the need for regular assessment of their transformers and yet many only use yearly oil sampling as their standard method of assessment.

Monitoring & Diagnostics

Dissolved Gas Analysis (DGA) is now accepted as the most effective method of transformer health assessment as the oil contains 70-80% of transformer health information. When a thermal or electrical fault occurs in a transformer, the oil and paper insulation will break down generating gases that dissolve back into the insulating oil. DGA is the extraction and analysis of those gases for monitoring and diagnostic purposes. The types of gases present in the oil indicate the nature of the fault; the rate of increase of these gases over time indicates the developing severity of the fault.

Manual DGA

An oil sample is taken manually by an operator from the transformer and then sent to a specialist oil laboratory for DGA analysis. The cycle time from "sample collection" to "results of analysis" can range from several days to weeks, depending on transportation time and proximity of laboratory. Oil sampling is typically performed every 12 months and possibly more frequently when a problem is detected or already known.

Fig 2: Manual oil sample being taken from a transformer using a gas-tight glass syringe

There are a few key issues with this manual sampling method:

- Human intervention in the process (methodology, transport) frequently introduces errors in the results.
- Lab to lab results variation (15% to 30%) for the same oil sample.
- Transformer faults can develop quickly and cause failure between the spaced out sampling intervals.
- Spaced samples cannot provide rate of change information and therefore no measure of fault severity.

Today, asset managers are switching to online DGA monitoring because it offers the following benefits:

- Constant detection of incipient faults, with no blind spot between samples.
- No delay on results back from the laboratory.
- Earliest possible detection and real time analysis of the issue.
- Consistent, repeatable results so trends can be monitored.
- Remote access to the data without the need for a visit.
- Availability of modern software tools to store, monitor and analyze the data.

Monitoring vs Diagnostic

There is an important difference between these two concepts and it drives a different class of monitoring devices, so it is important to grasp the nuance.

Monitoring: by comparing the concentration of gases in oil with previous measurements, we can detect small changes and developing trends to indicate a possible impending issue before it becomes a problem.

Diagnostic: by identifying which gas is increasing or looking at ratios of gases, we can determine the likely nature of the anomaly and begin to make decisions based on this information, without having to remove the transformer from service to determine what is happening through a costly forensic examination.

Single Gas DGA Monitoring

These were the first types of online DGA monitors on the market. They were developed around 15-20 years ago. They are single or composite gas devices, tracking mainly Hydrogen (H_2) gas, which is generated across all fault types.

An eponymous example is GE's Hydran™ range of DGA monitors, nearly 50,000 units of which have so far been sold to utilities around the world.

Fig 3: GE's Hydran M2 monitor mounted on a transformer

These devices can detect a rising gas level, indicative of a fault condition, and raise an alarm. They measure both the gas level (in ppm) but also the gas rate of change (in ppm per day).

But while asset managers may know that a fault is developing in their transformer, they still need to get a manual oil sample analyzed by a lab (or use a portable multigas DGA analyzer) to be able to diagnose the type of fault present before taking an operational decision.

Multigas DGA Monitoring and Diagnostic

For years, different international working groups have been focusing on understanding and quantifying the information obtained from DGA values, to the point where standards are now published and trusted around the world to diagnose transformer faults from this DGA data.

The "IEEE C57.104 – Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers" is one of the best known standards but other reference documents exist from other groups like IEC® and Cigré®.

There are 7 additional fault gases identified in addition to Hydrogen, and being able to record the level of each of these fault gases enables a proper diagnostic evaluation of the transformer's performance.

GAS	NAME	CONDITION RESULTING IS GAS PRODUCTION
H_2	Hydrogen	Nearly **all fault conditions**, low energy PD
CH_4	Methane	**Oil** overheating between 200 and 500°C
C_2H_6	Ethane	**Oil** overheating between 300 and 500°C
C_2H_4	Ethylene	**Oil** overheating over 500°C, possible formation of carbon particles
C_2H_2	Acetylene	Electrical **arcing**, Oil > 800°C, strong formation of carbon particles, **metal** melting
CO	Carbon Monoxide	**Paper** insulation overheating
CO_2	Carbon Dioxide	Severe oil oxidation, **paper** degradation
O_2	Oxygen	Oxidation, **leak**

Fig 4: Key transformer fault gases and their signification

By adding the diagnostic capability of multigas analysis to the monitoring capability of Hydrogen detection, the more recent multigas online DGA monitors have allowed remote automated monitoring and diagnostics to take place. By adding communication links to these devices, operational decisions without going to site can now be routinely undertaken, saving both time and money for asset managers.

Incremental Transformer Monitoring

A comprehensive analysis of insurance claims performed by the Hartford Steam Boiler Inspection and Insurance Company[3] have shown that the single biggest source of transformer failures is insulation failure in the main tank (which therefore can be detected by main tank DGA analysis) but that other root causes need to be addressed.

High voltage bushings for example often fail due to age, oil leak or moisture ingress. When they do fail, they sometimes fail catastrophically leading to the total loss of the transformer to which they are attached. More than 10% of failures can be attributed to them based on a Doble survey cited by Sokolov[4]. Online bushing monitoring devices are available and being installed on more and more critical generation transformers.

Something as simple as cooling fans not switching on when needed can lead to oil overheating, paper degrading faster and as a result, a reduction in the transformer life expectancy.

The presence of moisture in the oil not only accelerates the paper ageing process, but can reduce the ability of the transformer to be loaded to its normal capacity, sometimes resulting in unexpected failure. Various IEEE models using moisture and oil temperature information can be used to calculate, in real time, the safe loading limits of transformers.

A Typical "High-End" Transformer Management System

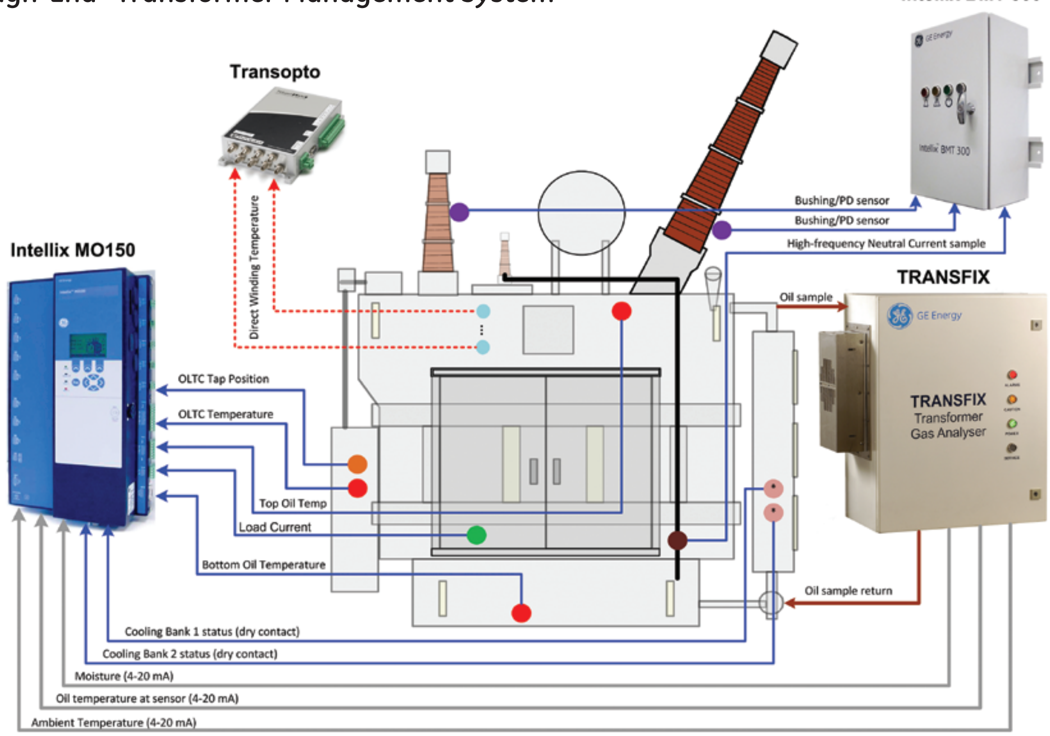

Fig 5: Sensors in a typical Transformer Management System. A variety of sensors and monitors are collecting a vast amount of data in order to analyse all parts of the transformer. They must share information and communicate altogether on the same data highway.

On-load tap changers (OLTC), because of their mechanical action, account for a high proportion of faults when they are present. Contacts coking or overheating due to wear, timing issues creating excessive arcing, reversing switch failure due to inactivity, contact filming, bandwidth problems, etc... Tracking the activity and performance of OLTCs is quite useful to increase mechanical maintenance intervals.

The presence of partial discharge in solid insulation is now being monitored as an early sign of impending insulation failure. Technical papers on PD monitoring are presented at most transformer conferences now.

Transformer Management Solution

Recently, there has been a trend for new critical transformers, usually in generation plants, to be equipped with every possible monitoring device so as to provide extended coverage of the likely failure modes. This increased awareness of transformer condition is aimed at further reducing the chance of unplanned outages or catastrophic failure.

These "Transformer Management Systems" use a collection of monitors and sensors and integrate their data streams into a homogeneous collection of information in order to enable improved real-time diagnostics. A typical architecture is shown in Figure 5.

While this wealth of data is invaluable in the right hands and comes a long way towards providing the perfect basis on which to build condition based asset management, in practice the implementation has encountered a few challenges that have prevented utilities form reaching their stated operational goal.

The Challenge of CBM

Modern day utilities and industries face a unique challenge brought on by their ageing transformer fleet. Advances in monitoring and sensing technologies have allowed the capture of more in-depth information regarding the condition of power transformers. The root of the challenge lies in transforming the vast amount of data gathered into coherent and actionable information which can be used not only to manage their fleet, but more pressingly to realize the expected savings in operating expenses stemming from having transitioned from time based to condition based maintenance (CBM).

Resources for Deployment

On-line monitoring devices, no matter how simple, require resources to install and deploy. They need a power source connection and need to be attached to the transformer. The larger multigas units need to be mounted on a concrete plinth and oil cabling attached to them. So work needs to be planned, an outage may even need to be scheduled and crews need to be assembled to prepare the site, install the unit and set it up.

These crews are always in high demand and are the crews responsible for responding to more pressing emergency restoration work. Faced with this choice, the deployment of a monitor often gets pushed back until a more suitable time can be found. This is one of the reasons why some monitors that have been purchased at great expense still languish in warehouses years later.

Bringing the Data Back

A monitor is only as good as the information it reliably provides and transmits. Substations are nearly always connected through a SCADA system (Supervisory Control And Data Acquisition) and the monitor's alarm contacts can be connected to the SCADA system. Trenching and cabling work is however required. Getting the actual live information of the various gas ppm levels so that these can be graphed is where the challenge lies.

A multitude of communication hardware and protocols is in use and this represents a setup challenge to make sure that everything communicates correctly. Then there is the configuration issue to map the data fields in the database and the ever present concern of cyber security. So in the end, many sophisticated monitors are only sending out generic alarms with no way to visualize the raw data that caused the alarm to be triggered.

Homogeneous Solution

Many companies have developed good monitoring solutions for various sub-systems of a transformer. The challenge for the user has been an integration challenge: making different vendor's equipment co-exist and transmit data alongside each other on the same communication highway. This has unfortunately resulted in many disparate systems only providing a fraction of the benefits originally planned.

To get around these issues, users have been asking for a complete transformer management solution from a single equipment vendor, but few have the technological breadth in terms of sensors to be able to deliver such a solution and many have relied on transformer OEMs and EPC to perform the integration task on their behalf, with varying degrees of success.

Monitor Cost of Ownership

One of the aims of condition based maintenance was to reduce the number of visits to the transformer site and thus reduce operating costs. Yet the initial generations of online monitors proved to be less reliable than anticipated and necessitated service calls to fix or upgrade, negating the gained site visit advantage. This has become more apparent as monitor fleet numbers have increased and this has exposed both the manufacturer's product quality as well as their ability to quickly service the products in the field.

Some monitors use consumable gas bottles (carrier and calibration gases) and the management of these has proven to be a lot more complex than anticipated. As an example: a fleet of 150 monitors using consumables could, depending on the accuracy setting, possibly mean a gas bottle to replace every working day. These storage and logistical issues have sometimes resulted in monitors simply stopping operation.

While these issues could be considered "minor" with a few monitoring units deployed, they became much worse with a large installed base of monitors, creating another asset to manage and slowing the continued adoption of transformer monitoring.

Data Management

With more and more monitors being deployed, users have become inundated with a huge amount of data, available in various formats and protocols that first need to be stored before it can be deciphered. The challenge has been to build an expert system to act as a repository for this data but also to enable access to this data by the user who needs to analyze it.

Often IT priorities have not been aligned with that of asset managers and the timetable of projects have gone out of synchronization. Either the corporate database has not been ready or the mapping of the data fields has been lagging behind or simply all the data is there but the access for the users is not or is so cumbersome that it is not used.

This latter issue often stems from differences in user requirements depending on the type of user: operational user only needing to know statuses vs asset management or maintenance users requiring to delve into the details and perform diagnostics.

The complexity of these data ownership and management issues, often ignored until too late, has caused the actual proper "usage" of transformer monitors to lag well behind their actual installation on site.

Required Expertise

An online transformer monitoring system provides a lot of good data continuously to enable the remote detection and diagnostic of an impending fault. This however requires the presence of an "expert," someone with transformer management experience and well versed into DGA diagnostics and the applicable standards so that they can make sense of the data presented and combine it with their experience to decide a course of action.

The data gathered on the health and condition of transformers is invaluable, in the right hands. However, in the hands of inexperienced personnel, such data can be confusing, daunting and can lead to a lack of accountability as employees shy away from the responsibility of interpreting the data.

These transformer experts are a limited resource these days. Many of them are near or at retirement age and there is a very large experience gap with new graduates trying to fill their shoes.

Analysis Burden

Organizations that lack transformer expert resources often rely heavily on the alarm information provided by monitors and sensors. Focusing on alarm breaches rather than the analysis of trends and interpretation of continuous data flow can result in faults being caught and reported too late.

Not only do utilities have fewer resources than in the past but these same experts are faced with more and more data requiring their attention. They are "swamped" and need help to prioritize and focus on the more important and pressing problems.

The newer experts need help trying to make sense of the raw data and are used to and prefer pre-analyzed information being presented to them. In view of this situation, the current "expert analysing raw data" model is simply not scalable as the number of monitored transformers expands rapidly.

The root of the challenge lies in transforming the vast amount of data gathered into coherent and actionable information which can then be used to continually monitor the condition of transformers, detect faults and take action at a much earlier stage, thus pre-empting failures, preventing unplanned outages and halting premature aging caused by untreated defects.

New Approach Needed

The Realization

From the overview above, it has become clear that utilities have not yet been able to achieve the perfect transformer "condition monitoring" vision that they had embarked upon. Many monitoring equipment vendors, by focusing on the monitoring product and not the whole environment in which it performs, have probably not done enough to help their customers achieve their vision.

Complete Transformer Fleet Management Solution

Analysis

Perception Fleet transformer fleet management software

Communication

Secure industrial wireless/radio communications, Ethernet switches and Fibre Optic converters

Monitoring

Complete range of monitors: from single gas to multigas DGA , including portable units, mathematical models and bushing monitoring

Fig 6: GE's new multilayered approach – A total integrated solution aimed at building on a solid base of monitoring device, adding communication and delivering a useable transformer fleet management outcome to asset managers.

As a market leader, GE's Monitoring & Diagnostics (M&D) business has realized that fact and is now facing into the challenge. The new strategy uses a layered approach to help customers achieve an end goal of data analysis through the use of monitors and sensors connected using a communication solution.

Monitors and Sensors

Gathering data from assets while they are operational offers insight as to the health of these assets that offline testing simply cannot match.

GE's range of online monitoring devices covers all aspects of transformer operational failure modes. Not only with a large range of online DGA monitors but also a wide range of sensors for measuring non-DGA parameters such as load, oil temperature, winding temperature, ambient temperature, and cooling fan status. Bushing monitoring is the latest addition to the range, as well as Partial Discharge measurement for the main tank.

These monitors and sensors form the foundation of a successful condition based maintenance strategy, but they are not the complete "stand alone" solution. They must be complemented by both communication devices and analysis software in order to provide a truly useable solution and realize the complete vision.

Communication

The ability to reliably and securely transfer data is vital, yet this was always left to the customer to sort out, almost as an afterthought. As part of a solution offering, GE is now providing a variety of communication options developed and tested to solve complex communication challenges.

Proprietary protocols have been replaced by worldwide standards like Modbus®, DNP3 or IEC 61850. Hardware connectivity options have been increased on the product catalogues to enable to interface to a wider range of existing data infrastructure.

Partnering with GE's Industrial Communications business has enabled M&D to offer an array of both wired and wireless communication solutions to transfer signal or data back to where they can be used.

Analysis

Data interpretation and analysis is critical to successful asset management. Data overload and lack of experts' time have combined to dictate the need for intelligent analytic algorithms. Their role is to automatically evaluate the data coming from each asset to determine their risk of failure and highlight the asset requiring attention so as to prioritize the need for a human expert to delve into the data.

Using a wartime analogy, in effect we need to perform a sort of "triage" of the incoming wounded in order to prioritize the surgeon's time and make sure he or she addresses the most urgent cases.

Conclusion

This concludes part I of this paper on New Era Transformer Fleet Management focusing on the "Challenges in realizing the condition monitoring vision." As discussed, power transformers, regarded as critical grid assets, are presenting an increasing challenge to asset fleet managers due to their large numbers and advancing age. Condition Based Maintenance (CBM) of these assets, based on dissolved gas analysis, has long been thought to be the panacea but while online transformer monitoring systems provide part of the solution, utilities have been struggling to achieve the foreseen benefits of their CBM vision.

In part II of this paper, "Solutions using new era asset fleet management software", we will explore how next generation software tools, focused on providing transformer fleet managers with actionable intelligence, are key to unlocking true condition monitoring value.

References

1. IEEE Distribution Reliability Working Group, Benchmark Results for 2012 Data, presented at July 23, 2013 General Meeting in Vancouver, BC
2. Transformer Monitoring Markets 2013-2020: Technologies, Forecasts, and Leading Vendors. Ben Kellison, February 2013, GTM Research, A Greentech Media Company.
3. An analysis of international transformer failures, part 1. William H. Bartley, 1996-2013, the Hartford Steam Boiler Inspection and Insurance Company
4. Evaluation and identification of typical defects and failure modes of 110-750 KV bushings. Victor Sokolov, Boris Vanin, 2006

GE Digital Energy

Lissue Industrial Estate East
Lissue Road
Lisburn BT28 2LU
United Kingdom
Tel: +44 2892 622 915

GEDigitalEnergy.com

imagination at work

GEA-12828(E)
English
141104