Condition based (re)investment in transformer populations

ABSTRACT

Slowly but surely, condition-based maintenance is coming to be understood worldwide as the number-one choice for optimising the reliability and cost-effective service of transformers. Up to now, however, it has remained difficult to understand the actual condition of a transformer based only on traditional methods like water-in-oil or dissolved gas analysis (DGA) data. Also, widely used furan analysis for evaluating the paper degradation usually provides less than clear results. Many users try to work with any of the "standard methods" based on IEC or IEEE, or any other generalised method. Considering the problem of significantly different transformer designs and service data, this attempt will rarely be accurate and is usually doomed to fail. To this day, it remains in the realm of long-experienced specialists to truly understand the complete and complex data, and to also understand the defects and weakness of normally available values, and to finally come up with a reliable result which can be validly used as a basis for further maintenance decisions.

KEYWORDS

transformer, condition based maintenance, life-cycle costs

Introduction

Very often in the discussions with users, it is found that the traditional preventive maintenance idea is widely used and is still accepted as a common practice at their organisations. In many cases, the maintenance teams feel under pressure to do any maintenance actions so they can prove that something was done and that the failure could not possibly have occurred due to lack of correct maintenance.

There are vibrant discussions in web forums like on LinkedIn, about quantities which indicate and influence the ageing and

> Identifying quantities which indicate and influence the ageing and show the actual condition is a complex problem due to differences in design, service, ambient conditions, and a number of other factors

show the actual condition. These discussions show clearly the complexity of such procedures. The experience also shows that limit and "typical" values cannot be generalised. Taking into account the differences in design, service, ambient conditions and a number of other factors the same values can tell a completely different story in different cases. Limit values are generally only valid in a certain population.

2. Condition assessment

The biggest challenge remaining is to truly understand the actual condition of a transformer.

Nowadays, a number of measurement systems and processes are being offered with expectations to provide the user with all the necessary data required for evaluating the actual condition of their transformer.

> It is still not easy to understand the actual condition of a transformer based only on traditional methods like water-in-oil, DGA data, and furan analysis

1. The first step is to evaluate the data critically in order to discern the reliable data from unreliable data.
2. Based on reliable data, further decisions can be made whether or not additional measurements are interesting for the final diagnosis purpose.
3. Based on diagnosis, an action plan may be worked out based on the complete technical and financial conditions.

3. Sampling and measurements

Our experience tells us that the following is needed:

- Do we have a comprehensive DGA and oil quality history? This is highly important in order to understand the trending up to now. So the actual condition can be understood as a continuous process and evaluated accordingly.

Making well based-decisions requires the following preliminary processes.

A reference oil sampling should always go with a more thorough discussion with the staff to obtain a valid understanding of the individual condition in the power/industrial plant substation and, naturally, the transformers located in the substation!

Based on these facts, the first condition assessment can be made, and based on that assessment, further investigations may follow; or in cases where the data is sufficient, a final report may be prepared.

Reference oil sampling should be done with reliable state-of-the-art equipment.

4. Report and results

The first report has to contain at least the following:

1. actual health condition
2. actual ageing condition (remaining substance)
3. load capability assessment
4. risk assessment
5. technical risk
6. financial risk

5. The risk assessment

The risk assessment includes technical and financial considerations. Assessment of the technical risks without a view of the financial considerations doesn't provide enough inputs for a reliable decision making.

A highly endangered transformer in a certain application may remain in acceptable condition and in service since the consequences of a possible fault may be controllable and since it might be economically favourable to exploit the remaining substance to the greatest extent.

On the other hand, a transformer in much less technically critical condition in a key application may need to be viewed completely differently because its failure may have tremendous financial implications.

Also, the use of load-tolerant transformers in high-load condition areas, even with higher total losses, is ultimately a more economical solution than using less tolerant units with lower losses because in the latter case, the total lifetime costs would be unacceptably high.

> **Only assessment of the technical and financial risks provides enough input for a reliable decision making**

5.1. Technical considerations include:

- ageing condition
- failure mode
- load capability
- remaining lifetime in the actual condition
- failure probability

5.2. Financial considerations include:

- financial consequences of a failure
- loss of asset
- loss of production
- collateral losses
- failure probability

6. Specification

The first issue to be considered before the transformer is even ordered is its correct specification. Today, such specification must be much more stringent than ever in order to avoid cheap and inadequate design and to obtain genuinely comparable offers.

The required specification must cover:

- correct temperature rise (fully in line with IEC 60067-2 means reduction in case of higher average monthly/yearly even if the maximum ambient temperature is 40 °C)
- correct temperature profile (for example, temperature difference

> **Nowadays specification must be much more stringent than ever in order to avoid cheap and inadequate design and to obtain genuinely comparable offers**

between top cover and entrance in radiators)
- adequate and technically feasible cooling systems
- limits of oxygen consumption (low oxygen content in open breathing types or high CO_2 in closed type means bad internal cooling; if corrosive products are present CuS_2 may be formed)
- correct auxiliaries (for example sampling devices)

7. Monitoring

To understand and control the condition, close monitoring must be implemented. What is close enough? The range varies from regular (i.e. 3–24 month cycle) sampling and controlling to complex online monitoring all the way to online gas monitoring systems.

The extent to which the monitoring should be done depends on the individual case. Monitoring is not to be confused with maintenance.

8. Treatments

Based on the monitoring data, certain actions should be implemented. To keep the transformer working, a number of maintenance procedures are available on the market:

- oil purification (treatment); (only physical degassing, filtering, drying)
- oil regeneration is a chemical treatment by molecular sieves (Fullers earth) retaining polar products, acids and sludge
- online conditioning

Oil purification does not fix the real problems like excess water or gas.

Oil regeneration addresses oil ageing problems.

Online conditioning is the process of addressing the ageing accelerators water and oxygen and keeping the particle content low, thus maintaining the breakdown voltage.

> **The extent to which the monitoring should be done depends on the individual case, but it is not to be confused with maintenance**

9. Examples

The following examples illustrate certain typical cases for investment or against it, depending on the overall technical and financial conditions:

- In one industrial plant, the loss of 1 unit is tolerable because of sufficient redundancy and spares availability.
- The case is similar in a power plant for the start-up transformer but NOT for the substation's auxiliary supply.
- Use the load-tolerant older transformers with higher losses in the high load centres and the less tolerant low-loss transformers in low load conditions.

Example 1: Aluminum smelter plant in Germany

Background

The plant is over 40 years old and affected by high energy costs, and the decision to keep it running or to shut it down is always valid.

The whole plant is very old, including its transformer population, which was also badly maintained until about the 1990s.

On the other hand, overly high investments under the above mentioned conditions were not acceptable.

Solution

- starting the correct monitoring programme with regular oil and DGA tests
- based on those results, developing a maintenance plan for the population
- investing in the necessary equipment for improving and preserving the transformers

Next step

After achieving an overall technically correct condition of the transformer population by using adequate technologies, i.e. online conditioners, regeneration, etc., the aim was to develop a long-term re-investment plan for that population. This population contains 6 feeder transformers 150 MVA 220/33/6 kV and 32 rectifier transformers 17-35 MVA 33/0,8 kV.

Long term re-investment considerations

The population consists of three generations:

- The first generation is about 40 years old.
- The second generation is about 30 years old.
- The generation of re-invested units was installed in 2000.

The condition assessment shows that all three generations will converge on present criteria of end of life forecast at about the same time, i.e. sometime during the next 5-10 years (including the "new" generation). The new 17 MVA transformers installed in 2000 showed the typical indications of bad internal cooling (Premature Ageing Syndrome "PAS" extrapolating

> **In some cases condition assessment of transformers of very different ages shows that units will achieve the end of life at about the same time**

the ageing indicators, a lifetime of maximum 15 years could be estimated.

The delivery of two new units, a 35 MVA and a 20 MVA took place in 2008, while two of the old units were sent to the factory for refurbishment.

At least the 35 MVA type has proven to have a very stable and long-term tolerant design. For this reason, a refurbishment seemed justified even though the costs would not be much lower than or even equal to a new unit.

The assessment of the dismantled unit supported this point of view.

In the case of the 20 MVA unit, the condition of the core sheets was so bad that a refurbishment for this type would have not made much economical sense.

Long-term aspect and planning

In order to minimise the re-investment without reducing the reliability of production, the following policy was determined:

- Since there is a 3-of-4 unit arrangement, meaning that 4 units supply the load which can be supplied by only 3 of those units, it is tolerable if one of the four units fails because a replacement is available. The already established preservation programmes to keep transformers in a good condition (keeping ageing accelerators at low levels) are continued.
- For every transformer type, a spare is available so that a fast replacement of a failed unit is possible.

It is, therefore, possible to use all units throughout their full lifetime cycle until the end of life "EOL" condition is reached.

Example 2: Transformer population of a rural utility

Background

This utility located in a rural area has a transformer population with transformers aged up to 35 years. In total, the utility has about 40 units 35/40 MVA 120/20 kV.

Result

The first batch of older transformers showed the somewhat surprising result of being in nearly "new condition". The reasons for that are:

> ❞ **In some cases young transformers of “modern” design were much weaker than older units and showed signs of ageing like increased oxygen consumption, some furans, increased tendency of acidity, and oil ageing under the same load and temperature conditions**

- The transformers are under low loads and the temperature seldom exceeds 50°C, which means that the thermal ageing of the cellulose is negligible.
- These transformers have a good old, highly tolerant design.

The second batch also showed that the younger transformers of “modern” design were much weaker and showed signs of ageing, like increased oxygen consumption, some furans, increased tendency of acidity, and oil ageing under the same load and temperature conditions.

Final recommendations and new challenge

In this case, given the actual conditions, no replacement or re-investment is necessary.

The new challenge now is load increase at certain remote places due to new renewable energy systems, mainly wind turbine parks (parcs eòlics).

To address this issue, **a load capability study** for transformers was developed to select the most tolerant units for these increased loads as it became obvious that different transformers of different designs will not react in the same way to the increased loads.

This approach offers a way to get maximum use out of the invested assets.

Example 3: Condition and planning of auxiliary transformers in several power plants

The auxiliary transformers in a power plant must be assessed and a health care plan proposed.

In this case it was found that the startup transformers Y 3BCT70 and Y 3BCT80 showed relatively low technical risk assessed at (2), initially assessed priority at (5) (low priority), and initially assessed low financial risk assessed at (2).

Table I: Risk assessment

Plant	Condition	Measure	Priority	Tec. risk	Fin. risk	Invest 2013 in T€	Invest 2013 in T€	Invest 2013 in T€	Invest 2013 in T€	Invest 2013 in T€
N 0BBT01	normal*	O	5	6	2			20		
N 0BBT02	normal*	O	5	6	2			20		
P 0BBT01	reduced	O; W	1	4	2	20				
P 0BBT02	normal*	O	5	6	2			20		
Y 3BCT70	partially warm reduced	O; W; R	1	2	5	32.5; 25		20		
Y 3BCT80	partially warm reduced	O; W; R	1	2	5	32.5; 25		20		
Invest/ Year						135		60	40	

O = Oxygen reduction; W-Water reduction; R= Regeneration

On the other hand, the substation supply which is situated in the generator bus bar must be considered far more risky since its failure would mean a shutdown of the power plant for about a week. So to this type must be given the highest priority (1) even if the technical risk is low (2) and the financial risk is actually high (5).

This case showed the complexity of such an assessment in an exemplary way. There were two different transformer types to assess:

1. the "start-up" units needed to feed the plant when it is shut down or to deliver the power for starting it after a shutdown. These transformers are feeding some auxiliary bus bars where it is not a big deal to change over from one source to another.

2. the substation auxiliaries which form a typical part of the generator bus bar system so any failure of these transformers means an unplanned shut down with important financial consequences. Therefore the risk priority of these transformers is much higher than for the "start-ups".

Since it is planned to shut down these power plants which should be replaced in about 15-20 years by a new high efficiency plant, it is also essential to reach the target with that population on one hand, but on the other to avoid to invest in new units as much as possible. Naturally it must be avoided that the loss of any key asset causes interruption in the last years of the plant's planned life time.

So much about the economical background.

What was the technical background?

Evaluating the DGA and oil test history of these transformers it could be found that the start-up units had a "hot running area" from the beginning which had surely been caused by the design. It is especially typical in newer transformers whose temperature profile is not homogenous due to the non-uniformly working internal cooling, so that parts and areas in the winding block run hotter than the rest. This is not really a "hot spot" but only some parts running at such higher temperature that typically increased O_2 consumption coupled with an increased production of CO_2 can be observed. In addition, certain production of C_2H_4 and C_2H_6 as well as the correlating C_3… gases can be found. Wrongly, this is often interpreted as a real hot spot from 150 °C to 300 °C. The gas production is mostly moderate and indicates that at least the winding temperature in these zones is above the official maximum temperature value of 115 °C in line with IEC. Since such zones may be even smaller and only some discs or turns of a winding may be affected, the gas production remains small. Nevertheless, the Montsinger rule remains valid - that the temperature increase by 6-10 K results in cutting the life time of the cellulose in half! In case of "corrosive oil", the failure can occur much earlier, in a time frame of less than 5 years. In the actual case here, the transformers survived a long time and therefore the risk may be

> **Position of the transformer in the grid plays significant role in assessing financial risks and its priority**

> **In cases when a transformer has an insulation area with temperature above 115 °C and that it is filled with "corrosive oil" a failure can happen early, in a time frame of less than 5 years**

limited. Nevertheless it is much higher than in the station auxiliaries where this design problem is not given to the same extent.

The table above summarises the results and also includes the recommended investment plan for the upcoming years regarding the necessary treatments and improvements aimed at minimising the risks as well as costs.

Conclusion

Making a comprehensive condition assessment needs a well-founded database with a clear understanding of the complete ambient conditions including the technical conditions. The expert needs to understand these conditions, fill the gaps in the documentation with his expertise and must be able to set all the data in correlation to that "ambient". Under these conditions it is finally possible to give the end user the necessary planning base for an improved purchase, the mid and long term budget planning together with assuring a reliable service respecting all needs for economical and sustainable operation.

Saving money means spending it in an intelligent and fact based way through a reliable data collection, translating data into facts (expertise), and finally decision making, well-founded on true facts to implement the necessary processes and invest the necessary money for the most technically reliable and economically optimised solution.

Author

Georg Daemisch obtained his M.Sc. (EE) Electrical Power Engineering in Karlsruhe, Germany. He was a sales engineer for small- and medium-sized transformers for TRAFO UNION (Siemens/AEG) and large power transformers for BBC Mannheim (ABB) for Latin America, the Near East and other areas. In 1985 Georg was MR (Maschinenfabrik Reinhausen) sales engineer for OLTC's for Southern Europe for in Regensburg/Germany. Since 1991, Georg has been self-employed and since 1992 has been the owner and managing director of DIDEE GmbH (Daemisch Industriedienstleistungen GmbH). Since 2005, DTC (Daemisch Transformer Consult) has been specialising in consulting for transformers and executing online treatments of transformers and life time assessments.