Eurotechcon 2018 by DTC Georg Daemisch

Monitoring versus Maintenance
If it ain't broke, don't fix it?

1. Abstract

Nowadays, there is a huge range of different monitoring facilities for power transformers available on the market.

That is why we are increasingly faced with the dilemma of how best to improve the reliability of transformer service and how best to use the data for that purpose.

A typical marketing ruse used by manufactures of monitoring systems is to lead the users to believe that now all their problems are solved. But is it really a solution if your doctor tells you that you are ill and that there is no therapy for your illness?

Also, in many cases of transformer failure the finger of blame is pointed at the staff, who typically get accused of "lack of maintenance".

While this is a very typical scenario, nobody ever told these poor people what they should have done. In most cases, somebody will tell them to go ahead and install more monitoring devices. But will more monitoring devices safely rule out future failures? What do we get from monitoring? At first glance: "Data"! BUT what to do with the data? Which data ought to trigger a reaction, and what kind of reaction? Is it safe to put our trust in the limit values? Which data ought to trigger which action, and at which priority? What should we do if any of the values is reached or even exceeded?

Have any contingency plans been established, what should be done or what procedure should be observed if a certain condition is reached?

To really get the most out of the data, it helps to rely on long-term experience and to think outside the box: it is the unconventional solutions which allow us to classify the data, to work with them, and to use reliable reference data as a diagnostic tool to design an adequate therapy.

2. Monitoring:

2.1 Formulating and defining the goals:

What good are measurements and monitoring activities if the operator does not know what to do with the measurement results? In that case, the whole monitoring effort will be a waste of money, time, and material.

Since every time a transformer fails, the finger of blame is first pointed at the operator, who gets accused of either not enough or faulty maintenance. Then what happens is that monitoring measures are suggested as a solution to the problem, which are typically sold to the client as "maintenance".

As a general rule, however, monitoring is not the same thing as maintenance, and it certainly does not solve any problems!

Here is where the system first starts to look illogical. As a general rule, monitoring is (or should be) the basis of a condition-based maintenance system. What this means, of course, that the goal of condition-based maintenance should be kept in mind even when first selecting a monitoring system. When selecting a system, it is therefore a good idea to set a specific goal as to what should be monitored, and for what purposes.

It is also crucial, when selecting a monitoring system, to plan for the appropriate measures to be taken if the monitoring system outputs certain critical data. Indiscriminately collecting and storing data really won't do much good as even critical developments are not necessarily recognized.

2.2. Available systems:

What kinds of measurements are generally possible?

As a general rule, a distinction must be made between on-line and off-line measuring.

2.2.1 On-line measuring:

- Gas in oil, to a varying extent
- Water, either together with the gas values or on its own.
- Temperatures
- Partial discharges
- Additional data

2.2.2 Off-line measuring

- Winding resistances
- Impedance
- Various dielectric measurements such as SFRA, FDS, tan Delta, etc.
- Tap-changer data such as transition behavior, drive torque behavior, etc.
- Partial discharges

2.2.3. What is available on the market?

a. There are basically four technical solutions available on the market for gas-in-oil measuring:

- Sensor-based systems
- Electroluminescence technologies
- Photo-acoustic systems
- Classic gas chromatography

Without a doubt, each of these various technologies comes with its own set of advantages and drawbacks. But there is one thing they all have to deliver: comparable (within the tolerances), reproducible and correct results, regardless of the technology used. The usual reasoning that different technologies will inevitably lead to different results is simply unacceptable.

To put it bluntly: whichever way the measuring is done, it has to yield correct results, even if it is done with a hammer. Instead of the results revealing the type of the measuring method used, the measuring method has to yield correct measured values, every time. In other words: all measuring methods, provided they are technically correct, have to yield the same results!

b. For measuring water in oil, we have tried and proven sensor technology. But please bear in mind that these sensors work by measuring relative humidity, which means that they may achieve results which are different from those achieved by KF laboratory systems. Provided the ppm values for the water dissolved in oil are converted correctly, probe measuring is definitely the way to go for transformer operators because it allows them to also deduce the moisture content of the cellulose, which at the end of the day is what the operator really wants to know.

c. The measured temperature value, particularly of the active part, is of particular interest. It's about time to throw classic thermal imaging on the scrap heap of obsolete technology. Every expert knows that even in the best-case scenario, this instrument never measures more than the oil temperature, and that the result displayed is usually absurd if the value displayed for the winding is lower than the oil temperature.

Fiber optics have increasingly proven their worth for measuring the winding temperature. Fiber optics have one major advantage: you can distribute the sensors along the coil windings so as to obtain the value for the "presumed" hotspot, and, by properly distributing them, to also monitor the temperature profile. Whenever a series of transformers is ordered, at least one of them should be equipped with fiber optics, to make it possible to double-check even the results of the heat run test.

This means that as a minimum, all windings on the center leg of a three-phase transformer should be equipped with sensors at the top, at 2/3 of the winding length, at 1/3 of the winding length, and at the bottom. This is the only way to check the internal cooling to any reliable degree.

d. Some vendors have also introduced systems for monitoring at least the bushings for partial discharges. However, I am not personally familiar with the extent to which these systems are being commercially used. It is probably a better idea to switch from the OIP to RIP version of the bushings.

e. Additional data that can be monitored on-line are the data of cooling systems, fans, pumps, etc.

To determine the condition of a transformer, whether after a DGA message or based on any other value, it is always a good idea to use off-line measuring as back up. Along with temperature measuring, this allows you for example to estimate the moisture in the cellulose, which can then be compared to the FDS measurement. In our experience, PDC measurements are rarely correct and typically yield unrealistically high values.

Monitoring will provide useful up to that point, and you will want to use the monitoring results to decide on the best course of maintenance action.

3. Maintenance:

What constitutes sensible transformer maintenance, and what therapeutic course of action due the monitoring results suggest?

Maintenance actually concerns three areas.

- Externally accessible items, such as coatings, cooling systems, fans, etc.

a. Coating: Inappropriate, non-UV resistant coatings are often the norm, especially in countries along the equator. Especially the highly popular Light Grey coating, which is particularly favored in the U.S., has inadequate low pigment content and is destroyed by UV radiation. It is a better idea to use high-pigment paints, especially for new coatings.

b. Cooling systems must be cleaned regularly, especially oil-air coolers, which are often comprised by environmental influences such as sand, plant seeds, etc., which reduces the cooling capacity to the point that the oil temperature rises by up to 8 K.

c. Fans must also be checked regularly.

d. Checking the bushings for tan Delta and capacity changes.

The inner workings of transformers:

a. Oil: Unfortunately, IEC 60422 confounds internal transformer problems with oil quality problems. The oil quality is essentially defined by two (2) measured values:

- Total Acid Number (TAN) = above 0.1 mgKOH/g means insufficient oil quality

- Interfacial tension < 20mNm is considered insufficient.

Both dates should be congruent

All other data collected under this standard are transformer data.

b. Condition of the transformer:

- Moisture-logging = more than 2% water content in the cellulose

- Mechanical condition of the cellulose = depolymerization in the DP value

- Low breakdown voltage (relative to the water content) is indicative of fiber content in the oil and hence the deterioration of mechanical strength.

- Condition of the off-circuit tap-changers and tap selectors of tap changers.

- Problems with internal cooling, indicated by the production of thermally generated gases such as C_2H_4, C_2H_6 and the corresponding C_3.... gases.

- Problems with the dielectric, as indicated by gases indicating PD (partial discharge) ($H_2 + CH_4$) and arc formation (C_2H_2).

4. The solution:

a. The external problems can normally be solved on site as part of the regular maintenance work. Defects in the external cooling are often detected by monitoring the temperatures.

b. The condition of the oil is most easily corrected by regeneration, only in rare cases is a new oil refill required.

c. In case of increased water content, bypass drying systems are the simplest and most economical solution.

d. If a rapid deterioration of the cellulose quality can be detected, typically due to increased oxygen consumption, the rate of ageing can be reduced by removing the ageing accelerators (temperature, acid, oxygen, water, particles). E.g. by using partially degassing bypass systems with fine filtration. It is also conceivable to switch from open breathing systems to closed systems hermetically sealed against the atmosphere by air bags or other methods.

If the breakdown voltage cannot be improved even by these systems, this shows that an EOL (End Of Life) criterion has been reached.

There is no remedy for obvious problems with the internal cooling; in that case, the transformer should be operated at the lowest possible load. These problems are typically indicated by the generation of heat-generated gases such as C_2H_4 or C_2H_6. In such cases it is reasonable to assume that individual areas of the transformer are stressed beyond the permissible temperatures. In this case, the results of the furan analysis should also be viewed with a critical eye. Since this method shows an average value at best, it is safe to expect accelerated deterioration in the presence of higher thermal stress on winding parts. A failure of these overly stressed winding parts can typically be expected in between 15 years. If the oil is corrosive, the transformer will fail within 5 years. The oil should be checked for corrosive behavior, and if it tests positive, it should be treated accordingly.

In the case of dielectric problems, it might be a good idea to locate the weak points and to repair the transformer.

Repair is likewise indispensable in case of problems with off-circuit tap-changers and selectors of on-load tap-changers in the tank oil.

In all cases, it should always be considered whether a repair makes sense at all. If there are any indications that the cellulose is already in the limit range of the DP value, even if only partially, it might be worth considering a new winding with a higher-quality insulation material. But this makes sense only if the design is reasonably rugged. If the design is weak, new procurement makes more sense, but you need to give clear specifications and monitor the design and, of course, production.

5. Examples

5.1

Oil data of a 40 MVA 110/20 kV transformer

Loc	TRF	Date Manufact	Rp	date sample	date LAB	oil temp	vis	cond		colour	acidity	BDV	H2O	meas 20°	IFT	tan δ	t
NHOF	T13	01.01.55	40	03.01.01	03.01.01	20,0	klar	nn	nn	2	0,02	67		0,0		72,00	0,21
NHOF	T13	01.01.55	40	21.01.03	21.01.03	25,0	klar	nn	nn	2	0,04	66		0,0		80,00	0,21
NHOF	T13	01.01.55	40	06.01.05	10.01.05	8,5	klar	nn	nn	2	0,01	54	17,2	17,2		98,00	0,21
NHOF	T13	01.01.55	40	26.03.07	26.03.07	21,0	klar	nn	nn	2-3	0,02	42	17,5	16,9		94,20	0,20
NHOF	T13	01.01.55	40	01.11.07	01.11.07	16,0	klar	nn	nn	2	0,03	42	17,0	17,0		116,20	0,20
NHOF	T13	01.01.55	40	21.02.08	21.02.08	12,0	klar	nn	nn	2	0,03	61	13,0	13,0	27,56	104,00	0,20
NHOF	T13	01.01.55	40	20.11.09	24.11.09	10,0	klar	nn	nn	2	0,03	65	15,0	15,0	27,91	107,10	0,19
NHOF	T13	01.01.55	40	11.09.12	11.09.12	25,0	klar			2	0,03	24	25,0	20,6	27,91	113,00	0,19
NHOF	T13	01.01.55	40	20.09.12	20.09.12	18,0	klar			2	0,03	39	19,0	19,0	27,61	114,40	0,19
NHOF	T13	01.01.55	40											0,0			
NHOF	T13	01.01.55	40											0,0			
NHOF	T13	01.01.55	40											0,0			

This transformer needs only Drying, Oil data are ok.

5.2

Example 600MVA 400/220kV

Lab.-Nr.				
Date of sample	year 2001	Year 2002	year 2004	year 2005
Sampl. location				
total gas cont.	59900	65610	17633	17138
N2 Nitrogen	49500	52804	11660	9634
O2 Oxygen	4010	782	4531	4150
CO2 Carbondioxid	5630	10083	1389	3291
CO carbonmonoxid	756	1771	49	46
H2 Hydrogen	17	43	1	1
CH4 Methane	6	52	<1	<1
C2 H2 Ethin Acetylene	0	1	<1	<1
C2 H4 Ethan Ethylene	4	11	<1	4
C2 H6 Ethan Ethan	3	17	<1	<1
C3 H6 Propen Propylene	8	34	3	11
C3 H8 Propane	1	12	<1	<1
Solution pressure	568	621	135	158
Oil Data				
El. strength (kV/2,5mm)	83	83	>80	>80
Watercontent	17	17	<15	<15
Acidity	0,16	0.16	<0.05	<0.05
Furfural detection				
Mass content w	0.761	0.761		

This Example shows till 2002 the need for reclamation and By-pass plant. Acidity 0.16 mgKOH/g and Oxygen 782 ppm and CO_2 10083 ppm, increased Furans (Mass content) Against our recommendation was made an oil change (Acidity 0.05 with reclamation a value of typical 0,01 would have been achieved.

The By-Pass plant was attached keeping mainly O_2 consume low.

5.3

Example Industrial transformer

SAMPLE DATE	10.05.2000	02.08.2001	24.09.2002	03.06.2003	23.04.2008
O2 OXYGEN ppm	20572	3023	715	6175	6050
C3 H8 Propan	1	96	327	509	190
CO2	2674	4642	4817	5137	2780
CO	253	258	266	265	201
Water content	11	14	12	17	15
Acidity No.	0,01	0,01	0,02	0,03	0,09
Tan δ	0,004	0,037	0,0952	0,1039	0,0898

Fig.2 Fast increasing ageing indicators in 8 years in service of a 17 KA rectifier transformer

In this case also both procedures are needed in order to control all accelerators: Acidity (Reclamation), water and O_2 consume (By Pass conditioning)

6. Conclusion:

A clear distinction must be made between monitoring and maintenance, for all interventions performed on transformers. You should plan all monitoring measures from the outset with the aim of obtaining meaningful data for condition-based maintenance, and implement these measures in a target-oriented way.

For all data obtained from monitoring, you must specify which measures should be taken for which values of these data. It is simply unnecessary to collect data which do not lead to any consequences for maintenance purposes.

Of course, all these data must be collected in such a way as to make any trends visible. Individual data are usually meaningless, which is why the popular signaling systems are usually also not really helpful. Of course, certain values can also serve as a clear guideline for action, e.g. acetylene in the tank oil or Tan delta, or capacity values at bushings which indicate a defect. This is particularly important for OIP bushings as they usually destroy the transformer in the event of a failure.

Before planning any monitoring measures, you should first set a goal for what you want to achieve with a certain transformer or even a population. You should also do a risk assessment including any economic aspects.

After all, this assessment will influence your decision on how much money to spend on maintenance. This means that you may also want to adjust any monitoring expenses accordingly.

There will always be cases where a decision is difficult to make, BUT:

If it ain't broke don't fix it.

And

Fix it before it is broke!

These decisions can only be made in the individual case!