15 YEARS OF POWER TRANSFORMER PRESERVATION
A HISTORY OF EXPERIENCE AND SUCCESS

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Foreword

The facts, presented in this papers may be shown in other occasions before. Nevertheless we present here a summary of our long term experience.
We can now serve the transformer users with well proven procedures for evaluation, diagnosis and treatments. Therefore the topic of the aged (or even over aged) transformer is covered by well introduced systems like TPM (Transformer Population Management) with the treatment schedule integrated. This point gains now much more importance, since it starts to be more and more advisable to conserve the stable and mostly tolerant design of older transformers as long as possible, since increasing problems with newer transformer designs are sometimes for customers a even vital (or mortal?) question of survival!

Introduction

Normally, transformers are among the assets with a very long life span. However, as a result of the politically driven change towards deregulation, privatization and liberalization of publicly-owned infrastructures, the necessary investments (and even more so the necessary reinvestments) have been cut to an extreme degree while the necessity of long-term planning has been largely neglected altogether. As a predictable result, the majority of transformer populations are overaged and in dire need of immediate, extensive reinvestments. Under the known circumstances, however, it is hard to imagine how this could be achieved, even if the necessary funds were available, which they are not.
A new problem has come out in the last years. This is a lack of reliability of new transformers. It starts to be an acceptable strategy to conserve aged transformers as long as possible, especially because these older designs are much more tolerant and stable as newer ones. So it will lead not seldom to a improved reliability of the system using these old transformers under conservatory regime as long as possible avoiding the risk with new transformers.

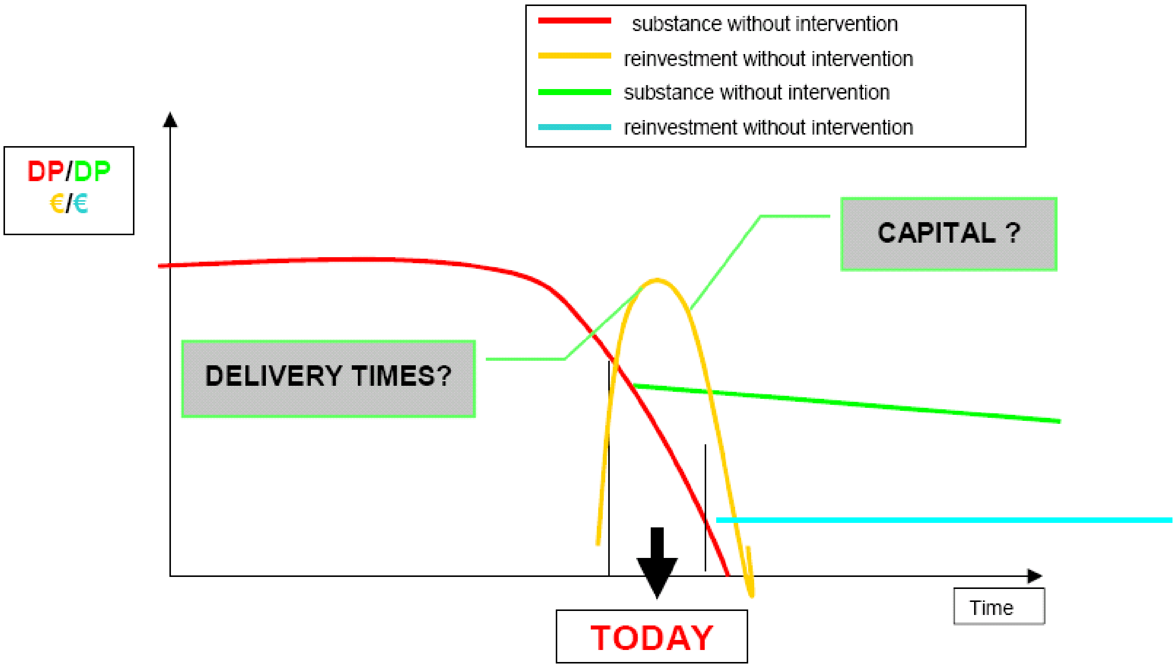


Figure 1
Treatment Goal from A Commercial Point of View, Ageing and reinvestment

Re. Fig. 1 above: The "natural" course of a transformer's substance (remaining life) is exponential. Since the major investments in the power supply industry were made some 50 - 60 years ago, these assets have now reached the "natural" end of their life cycle, and the time has come for reinvestments on a comparable scale. That is not possible, however, due to a combination of the manufacturer's supply situation (i.e. delivery times) and lack of necessary capital. Finding alternative measures to flatten the reinvestment curve is therefore indispensable.

During the past 20 years, investments in the production capacity of transformers were cut back to nearly Zero, and in some cases, e.g. in Germany, virtually cut in half. Moreover, customers' administrative and organizational capacities have also seen dramatic cutbacks. Under today's circumstances, the replacement of a transformer typically takes three years, resulting from a combination of the customer's in-house preparatory phase including budgeting, planning and procurement, and the manufacturer's delivery time.

If we imagine replacing a population of e.g. 120 units under the given circumstances, of which some 60% are more than 40 years old, it is easy to see that this process would take so much time that some of the transformers would have to last for more than a 100 years. Although technically beyond all question, this situation is unfortunately unavoidable under the current circumstances.

What is definitely unavoidable, however, is the fact that a major portion of the transformer population will be expected to reach life spans, which, even under the best of circumstances, simply cannot be achieved without some manner of preservation. Add to that the ongoing necessity of operational and technical safety.

This means that some measures are unavoidable, and that some minimum investments must be made to preserve the transformers' substance (remaining life), at least to an extent ensuring the planned life-spans and the necessary uninterrupted service and supply guarantee. However, it takes a comprehensive understanding of the entire ageing process to achieve the necessary lifetime extension under the above circumstances without breach of the admissible operational and technical safety parameters. Let's remember the 60/6 rule, according to which the admissible substance (remaining life) of a transformer is less than 6 years if no additional measures are taken.

On the other hand it has been shown that, given a comprehensive understanding of the ageing process, it is possible to achieve another 5 – 15 years of admissible and reliable service life even for greatly aged units, provided suitable and methodical measures are taken. This can be demonstrated very impressively through a comparison of differently managed populations. The success thus achieved is therefore not only technically, but even more so economically impressive. But the clock is running, and where there is no substance (remaining life) left, there is nothing left to preserve. It is therefore essential to act immediately and at short notice.

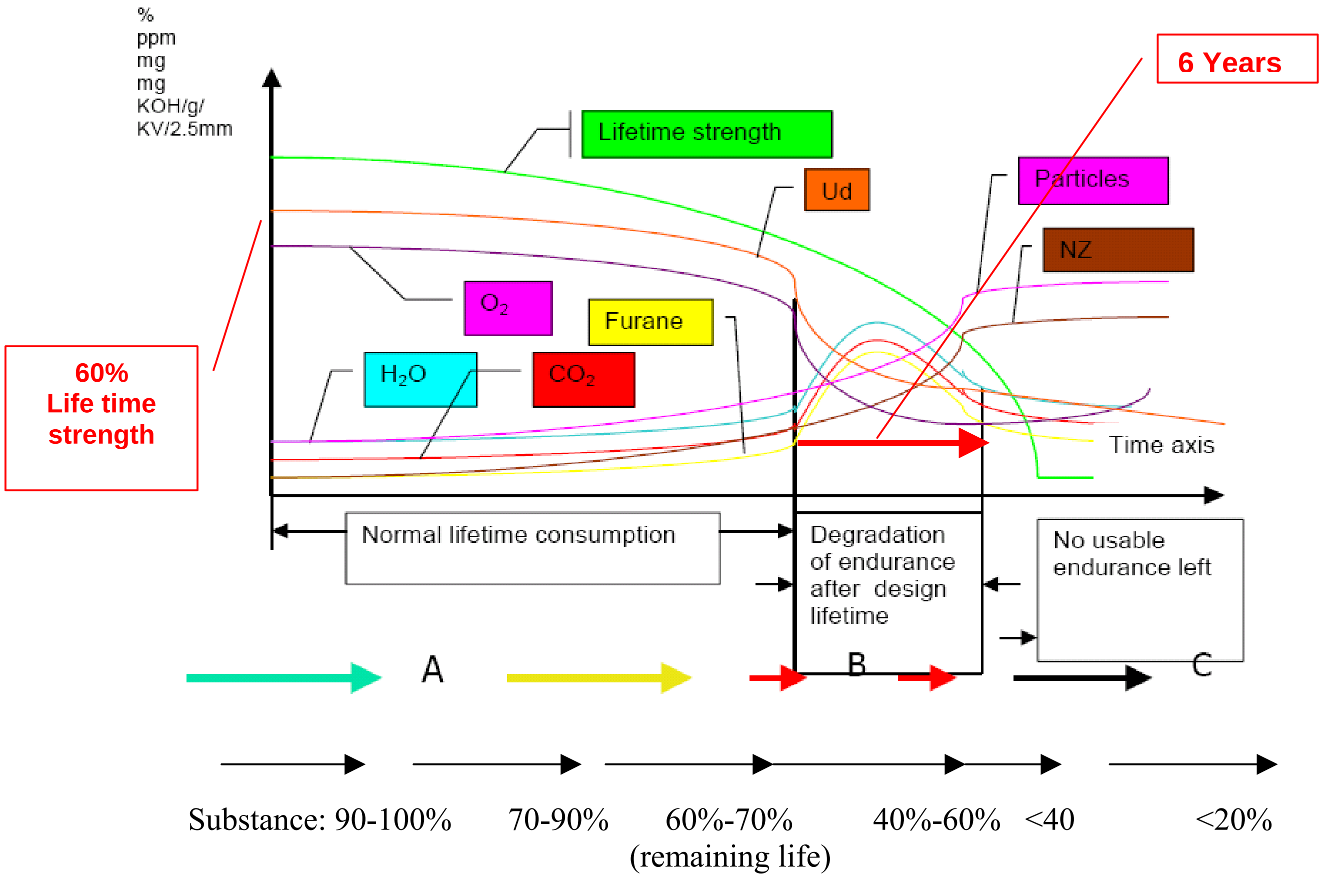


Figure 3 Ageing and Reinvestment

Re. Fig. 2 above: This diagram shows the typical courses of ageing, the ageing accelerators and ageing indicators, with the corresponding residual substance values (remaining life values) indicated underneath. This diagram also explains the 60/6 rule (i.e. less than 60% of substance [remaining life] = less than 6 years of life-span) as the curve projection on the time axis is very short due to its steep course.

auf Katastrophen vorbereitet

SICHERHEIT Neue Studie fällt vernichtendes Urteil: Ein Stromausfall könnte die Republik ins Chaos stürzen.

VON UNSEREN KORRESPONDENTEN

BERLIN. „Wo warst du, als das Licht ausging?“ heißt eine romantische Komödie mit Doris Day, die während eines Stromausfalls im New York der 60er Jahre spielt. Doch Stoff für eine Komödie bietet das Krisenszenario nicht, das 18 Experten eines überfraktionellen Bündnisses für den Fall eines solchen „Blackouts“ entworfen haben: Ihrer Ansicht nach droht Deutschland im Chaos zu versinken, wenn in weiten Teilen der Republik für mehrere Tage der Strom ausfällt.

„Ohne Strom geht nichts“, heißt es in dem gestern vorgestellten „Grünbuch“, das Sicherheits- und Rettungskräfte gemeinsam mit anderen Praktikern erarbeitet haben. „Sicherheit und Grundversorgung der Bürger könnten von staatlichen Einrichtungen und privaten Hilfsorganisationen nicht mehr aufrechterhalten werden.“ Die Arbeit von Polizei und Rettungskräften wäre ebenso betroffen wie die Versorgung der Menschen mit Lebensmitteln und frischem Wasser. Doch trotzdem ist der Studie zufolge derzeit „kein einheitliches Risiko- und Krisenmanagement“ erkennbar.

Ohne Strom keine Kommunikation

Dass ein Stromausfall ganz Deutschland lahmlegt, scheint nur auf den ersten Blick weit hergeholt. Denn obwohl die deutschen Stromnetze als die zuverlässigsten in Europa gelten, gehen die Autoren des „Grünbuchs“ von einer hohen „Eintrittswahrscheinlichkeit“ aus – und können sich da auf mehrere Beispiele berufen.

Nach einem Wintereinbruch im November 2005 knickten im Münsterland unter der Last der Schneemassen mehr als 80 Strommasten um. Bis zu 250 000 Menschen mussten daraufhin tagelang ohne Elektrizität auskommen. Nur ein Jahr später gingen in weiten Teilen Westeuropas für 90 Minuten die Lichter aus, weil die geplante Abschaltung einer Hochspannungsleitung zu einer unerwarteten Kettenreaktion geführt hatte. Polizei, Feuerwehr und Hilfskräfte sind aber mittlerweile auf Computer angewiesen – und damit auf Strom.

Die Autoren warnen zudem, dass die Debatte um die öffentliche Sicherheit seit den Anschlägen 2001 von der Terrorgefahr bestimmt wird. Für flächendeckende zivile Risiken gebe kaum ein Bewusstsein.

Der Abgeordnete Hartfrid Wolff (FDP) sagte, „angesichts der Herausforderungen haben wir bewusst vermieden, einfache Lösungen anzubieten.“ Neben möglichen Strom-„Blackouts“ müsse auch über die Folgen drohender Pandemien wie der Vogelgrippe nachgedacht werden. Deshalb sei ein „nachhaltiges Sicherheitskonzept“ gefragt, das jeden Einzelnen anspreche, forderte der Liberalen-Politiker. Er warnte zugleich davor, dass sich der Bund beim Katastrophenschutz nicht aus der Fläche zurückziehen darf.

Figure 3

Cutting from my local newspaper!

If they are already reporting about it, the situation must be very critical indeed! They tell us about the catastrophic consequences of black outs which start to be a more and more frequent issue.

The Development of Data Collection

Where as 15 years ago only the traditional methods of oil sampling and gas-in-oil analysis were available, and all on-line procedures where considered rather exotic (and naturally unaffordable), it is nowadays possible to verify nearly all important values by a vast range of - even physically different- procedures. As a result, it is now also possible to perform logically significant check measurements if there is reason to believe that a measuring result is flawed.

We now have access to numerous tried and proven methods and countercheck measures to facilitate the decision-making process. The task of today is to find the right kinds of methods and to use them correctly.

In those days the word of an expert, who would issue his opinions in a manner often difficult to follow for outsiders, was still universally considered „the law“. The users had no choice other than to believe what they were told, even if the process was sometimes more reminiscent of crystal ball gazing than technical analysis. However, while we are not trying to doubt the competence and experience of these experts, the methods available at the time were usually the only way to obtain any results at all.

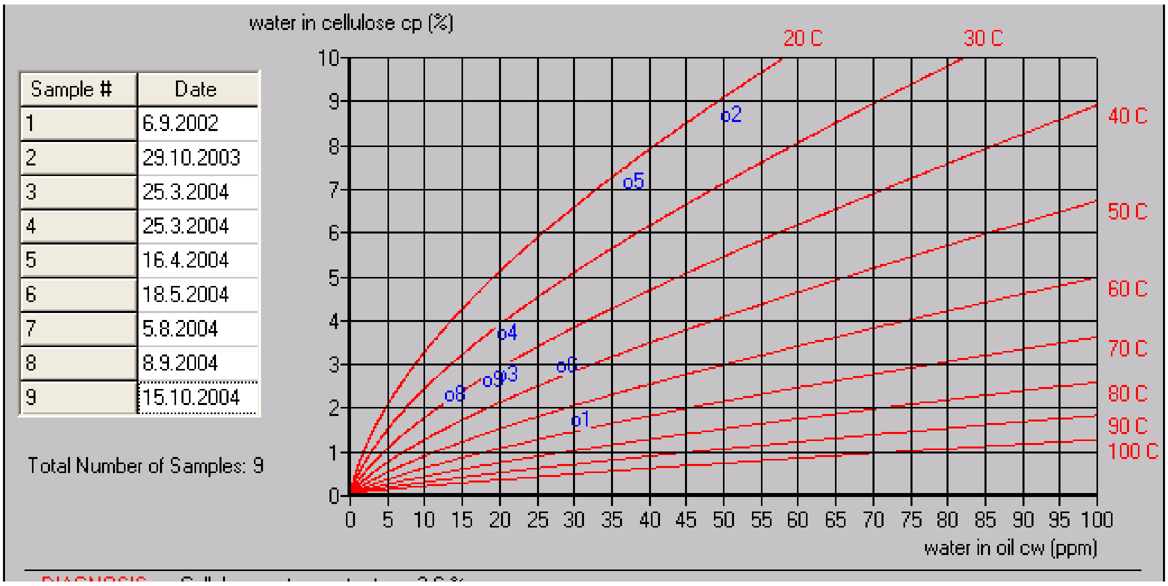
The only way available in those days was to take relative measurements, i.e. to try an understand changes and trends and to draw conclusions on the basis thereof. To this day the opinion seems to prevail that in order to ensure comparability it is necessary to have e.g. the DGA performed always by the same lab and the same people. However, given today’s very different circumstances, necessities, and available technical options, it should be expected that measurements yield true values congruent with other measured values, subject to the usual tolerances. And here is where the users should start being wary of uncritically accepting values which are not logical! If even verifiable values are obviously wrong, then how true or reliable are non-verifiable values?

One of the main differences between then and now is that, rather than searching primarily for current faults, a transformer’s actual condition and ageing behaviour are assessed. The main issue nowadays is whether or not preservation is still possible and under what conditions a transformer can continue to operate. A flawed condition may easily translate into a death indicator.

Back then, hardly anyone was aware of the interaction between the various ageing accelerators, and the water problem, oil overageing, and oxygen consumption were treated as completely separate issues. Add to that the different views and approaches prevalent at the time, and the total obliviousness to the fact that some methods and processes were simply leading to the wrong conclusions. A typical example is the measurement of the water content in overaged oil, which nearly inevitably leads to the wrong conclusions about the water content in the transformer, if measured by traditional means, e.g. Karl Fischer. On the other hand, the significance of high oxygen consumption is still not given the attention it deserves, nor is the measurement of the atmospheric gases considered necessary to this day.

Even other methods, like e.g. the furan analysis, were still in their infancy at that time. Test reports would generally conclude with the laconic phrase that „no thermal or electric faults were found“, while high water contents with high breakdown voltage values were accepted in the same manner as moderate water contents with bad breakdown voltage values. In both cases, some drying method or other was tried as a remedy, not least traditional oil processing or even oil changes, which at times even seemed to improve things.
Many times, however, cause and effect were very different than presumed. In fact, critical examination for logical significance of the data obtained is still far from standard procedure. Many times the values presented are not congruent, and hence either the sampling/measurement and/or the evaluation flawed.
If even verifiable data are either illogical or clearly flawed, wouldn’t it seem the advisable to discard the entire measurement and definitely refrain from cost-intensive measures? In that case the measurement would have to be repeated, and, at least in critical cases, counterchecked by a physically or chemically different process.

The State of Affairs of Data Collection



Sample #	Date
1	6.9.2002
2	29.10.2003
3	25.3.2004
4	25.3.2004
5	16.4.2004
6	18.5.2004
7	5.8.2004
8	8.9.2004
9	15.10.2004

Total Number of Samples: 9

Figure 4

Different results obtained from the determination of water

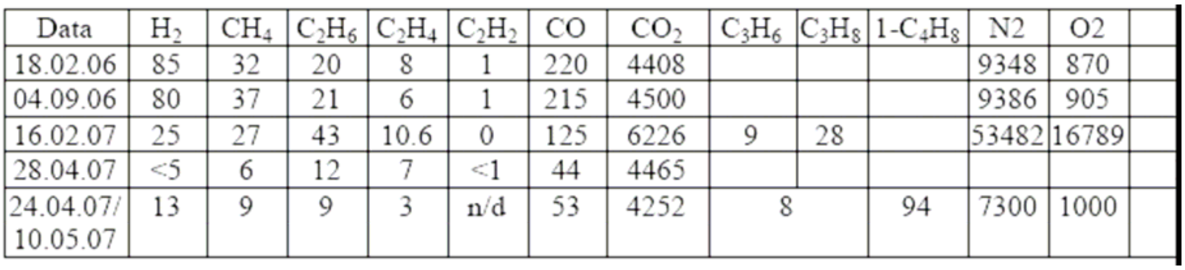
The resulting diagram is completely chaotic and the information value of the data thus obtained is worth Zero. This degree of fluctuation of the water content in a transformer is obviously impossible. As a matter of fact, only the measurements approaching 3% are correct, which was consistently proven with different physical methods (FDS, water separation rate, RH).

Sampling

Classic sampling now offers markedly improved methods (e.g. Gatron EGS system or ABB sampling device) whereby the sampling probe is hermetically connected to the sampling valve while temperature monitoring ensures that the oil is really taken from the life circuit within the transformer. The air pressure is also documented, and the oil forwarded into the sample container in a manner safely ruling out atmospheric contamination.

The filled container is then sealed with a defined quantity of residual air. The accompanying temperature and air pressure data give the laboratory a clue of the original conditions and permit compensation of the residual air. If, in addition, the oil is moved through a sampling system where the necessary advance flow (normally 10-20 litres) is pumped internally through the transformer and the relative moisture content and temperatures of the transformer (top/bottom) are measured and documented during sampling, it is possible to rule out oil loss and to ensure the comparability of the samples through establishment of clearly-defined conditions (e.g. TransDiag by DIDEE).

And if, moreover, the samples are correctly processed at the laboratory (e.g. through application of the appropriate reference standards), it is virtually inevitable that all results will be comparable, within the scope of the usual tolerances, regardless of who took the samples and who evaluated them.



Data	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2	C_3H_6	C_3H_8	$1\text{-}C_4H_8$	N2	O2	
18.02.06	85	32	20	8	1	220	4408				9348	870	
04.09.06	80	37	21	6	1	215	4500				9386	905	
16.02.07	25	27	43	10.6	0	125	6226	9	28		53482	16789	
28.04.07	<5	6	12	7	<1	44	4465						
24.04.07/ 10.05.07	13	9	9	3	n/d	53	4252	8		94	7300	1000	

Lab/Proc
Lab1
Lab1
Lab2
Proced1
Lab3

Figure 5

DGA carried out by different laboratories and using different processes

The above illustration: Here, the same transformer was sampled within a relatively short period of time by different laboratories, using different methods. No gas-influencing treatments were administered during that time. It is impossible to state which of the values are correct as the method used is not verifiable. The differences between the values obtained for the atmospheric gases are entirely inconclusive. It is impossible to state the true value of these gases one of the methods used, cannot even measure it. Naturally it is impossible to evaluate them. These data were presented without comment in a report, and here wasn't even an outcry for truly reliable data. So what are these data trying to tell us?

On-line/On-site Method

Nowadays it is ever easier to obtain data directly on site, which applies both to oil data and DGA. Even if some of the methods used give rise to technical issues and if the consistency of these methods is dubitable, they still yield values which are much more reliable than those obtained by dubious samples which, in extreme cases, may not even be evaluated until months later. It is also a way for dealing with distribution transformer issues in an economically justifiable manner.

These methods definitely include some very good and future-oriented approaches. There are a number of different on-line DGA technologies on the market, from sensor technology all the way to mobile gas-phase chromatographs. The technology to be used for any one case depends on the specific facts of that case and needs to be chosen accordingly. At any rate, it is important to make sure that the technology used will in fact yield verifiably correct results and reproducible values. One of the major advantages of on-line technologies is that they allow resaturation tests and thus a determination of absolute gas production. At the end of the day, gas production is the only conclusive value. This is a very new aspect allowing a whole new range of options for truly sharp diagnostics.

It is now possible, at reasonable cost, to determine partial discharge behaviour, to measure the tan delta of the processes, to directly measure the water content in the cellulose (FDS), and to check the mechanical integrity (FRA).

Another interesting approach is the low-frequency measurement of tanδ to determine the relative ageing status.

In summary it can be stated that reliable and authoritative data can nowadays be obtained at reasonable cost. Let's remember, however, that measuring is just that, i.e. it is neither a diagnostic tool nor a solution of the problem.

If measuring is not used for proper diagnostics and followed up by suitable improvement actions, it is likely a waste of time and money.

Data to be Measured and the Related Diagnostics

Since ageing diagnosis is our principal issue, the issue of failure detection will be ignored.

Oil data, or, to be more precise, the data obtainable through oil analysis

- Acid
- Interface surface tension
- Tanδ
- Breakdown voltage
- Water content. (via relative moisture content, e.g. Vaisala probe)
- Colour
- Sludge

DGA data

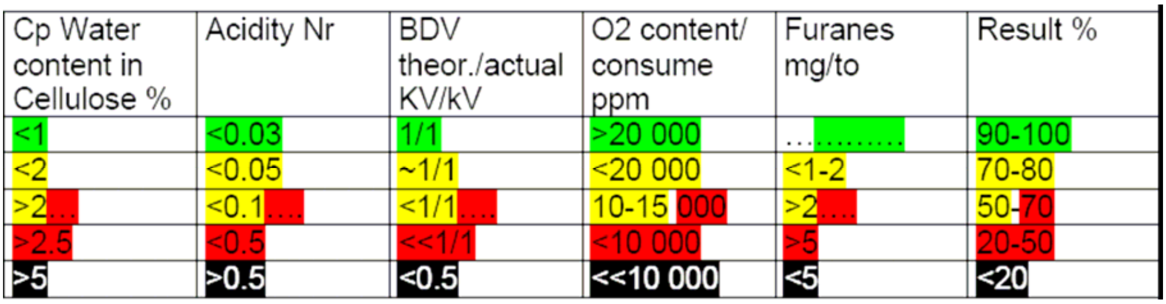
- Oxygen
- Nitrogen
- CO
- CO_2
- Hydrogen
- The other fault gases
- Furans

Other data obtainable from FDS, FRA etc. as needed

Typically, overaged and moisture-logged transformers also have a relatively high partial-discharge level which is made very evident by the DGA.

The O_2, CO, and CO_2 contents are an indicator of ageing speed, i.e. a low O_2 content combined with a high CO_2 and CO content is an indicator of accelerated decay, and, usually, of a relatively high acid presence.

Mostly, but not necessarily, this condition also goes hand in hand with high water content. Although in some cases it has been possible to remove the water by a variety of drying methods, water removal alone will not effectively stop a transformer's decay.
If a low BDV value is noted in relation to the water content, that also is an indicator of beginning cellulose decomposition, i.e. quick action is needed although things may already be too late!
The presence of sludge and high acid values usually goes hand in hand with high furan values.



Cp Water content in Cellulose %	Acidity Nr	BDV theor./actual KV/kV	O2 content/ consume ppm	Furanes mg/to	Result %
<1	<0.03	1/1	>20 000	…………	90-100
<2	<0.05	~1/1	<20 000	<1-2	70-80
>2…	<0.1…	<1/1…	10-15 000	>2…	50-70
>2.5	<0.5	<<1/1	<10 000	>5	20-50
>5	>0.5	<0.5	<<10 000	<5	<20

Figure 6

Chart: Typical values

This chart contains guide values which can be obtained from the measurements and used as reference values. It is very important to always consider all of the values. It is inadmissible to consider only one value by itself as it may have been measured incorrectly or may be subject to other influencing factors, etc. Only an overall evaluation allows an authoritative assessment of the situation, on the basis of which cost-intensive decisions may be taken, or worse, not taken, which usually turns out to be even more costly.
Based on the data thus obtained, the transformer can now be classified in six (6) categories, anywhere between ”in mint condition“ and ”dead“.

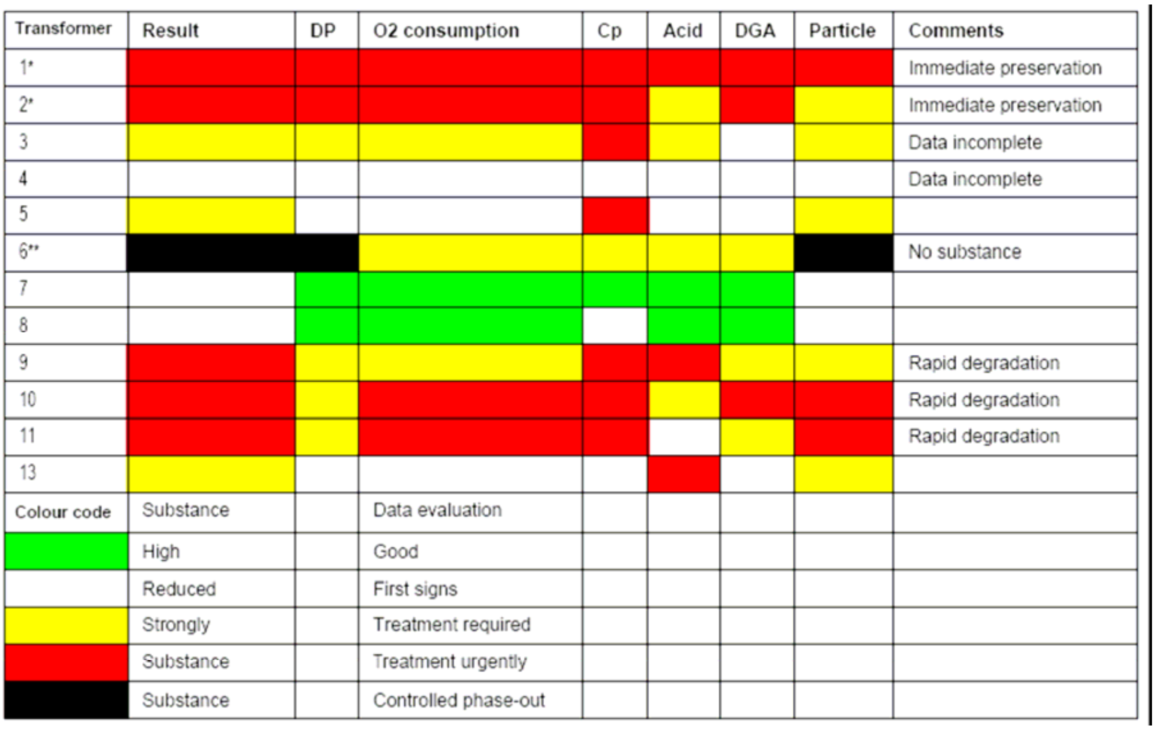
As long as preservable substance is found, that substance can be preserved, i.e. kept in operating condition, in accordance with the user’s investment planning.

Preservation

The following measures are used to conserve a transformer’s active components:

Oil regeneration (Fullering).

Appropriate state-of-the-art equipment is used to remove the ageing products not only from the oil, but from the transformer as well. As a result, oxygen consumption, which is an indicator of the rate of decay, will slow down dramatically.



Transformer	Result	DP	O2 consumption	Cp	Acid	DGA	Particle	Comments
1*	🟥	🟥	🟥	🟥	🟥	🟥	🟥	Immediate preservation
2*	🟥	🟥	🟥	🟥	🟨	🟥	🟨	Immediate preservation
3	🟨	🟨	🟨	🟥	🟨	⬜	🟨	Data incomplete
4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	Data incomplete
5	🟨	⬜	⬜	🟥	⬜	⬜	🟨	
6**	⬛	⬛	🟨	🟨	🟨	🟨	⬛	No substance
7	⬜	🟩	🟩	🟩	🟩	🟩	⬜	
8	⬜	🟩	🟩	⬜	🟩	🟩	⬜	
9	🟥	🟨	🟨	🟥	🟥	🟨	🟨	Rapid degradation
10	🟥	🟨	🟥	🟥	🟨	🟥	🟥	Rapid degradation
11	🟥	🟨	🟥	🟥	⬜	🟨	🟥	Rapid degradation
13	🟨	⬜	⬜	⬜	🟥	⬜	🟨	
Colour code	Substance		Data evaluation					
🟩	High		Good					
⬜	Reduced		First signs					
🟨	Strongly		Treatment required					
🟥	Substance		Treatment urgently					
⬛	Substance		Controlled phase-out					

Figure 7

Typical evaluation matrix and categories of proposals for action

Active gas conditioning.

Permanent (or semi-permanent) gas conditioning, i.e. reduction of the saturated value to 20-30%, is used to homogenize the dielectric and to reduce the oxygen to extent where all oxidation processes are virtually stopped. Nonetheless, a rateable gas residue will remain, which, via the nitrogen reference, will allow a seamless comparison with the history (to the extent that historical data were gathered in a substantiated manner).

Dehydration.

Dehydration can be performed continuously, usually in combination with gas conditioning, although other methods are conceivable as well.

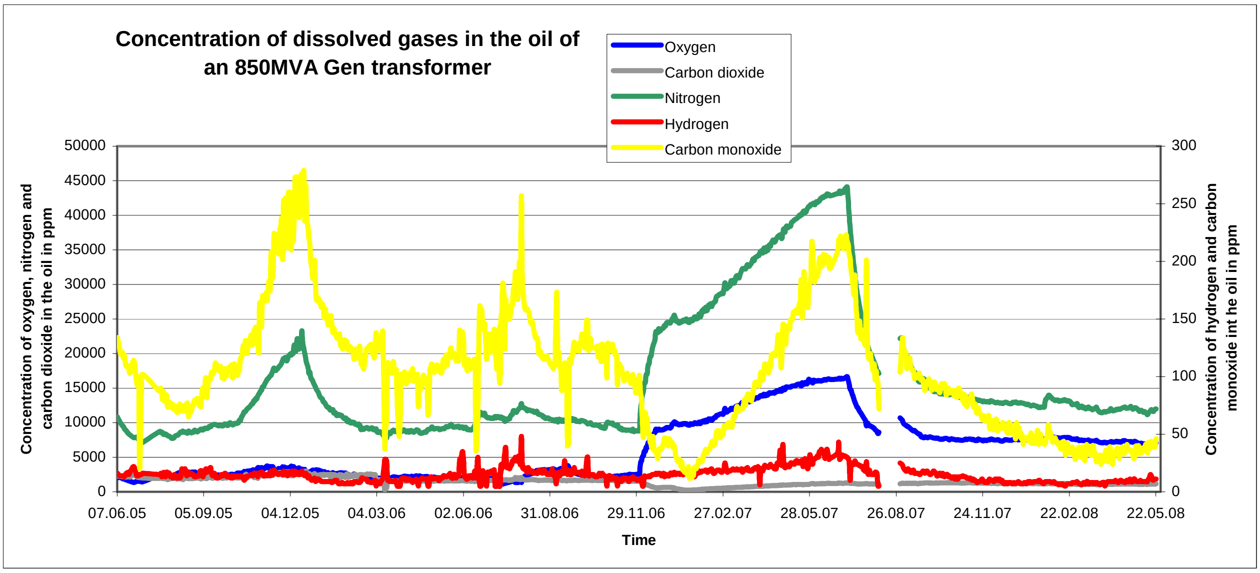


Figure 8

Gas Conditioning and Regeneration

The above diagram illustrates the effects of the various different measures available. Until late 2006, the equipment was treated by gas conditioning. The resaturation values measured between 9/05 and 4/06 show an intense level of oxygen consumption (no increase of O_2, huge increase of CO). Following the regeneration measure in 06/07, the oxygen consumption is reduced markedly. After reactivation of the gas conditioning process, H_2 and CO fall markedly below the previous level, whereas O_2 remains higher than before. I.e. the degradation processes have been reduced dramatically. Under these circumstances, the remaining substance (i.e. remaining life) of this transformer will remain stable for a very long period (more than 10 years).

Particle filtering.

Particle filtering is normally done in combination with 4.2, or even 4.3.

Figure 9

TransCond

This figure shows a machine performing these tasks. TransCond's easy and uncomplicated installation, even during transformer operation, and the avoidance of any direct actions to the transformer allow fast and effective interventions with minimum time and effort.

Other options.

It is also possible to use passive processes, e.g. hermetical sealing of the oil conservator when using gas conditioning, or appropriate modification of the oil or air paths between tank and oil conservator.

Examples

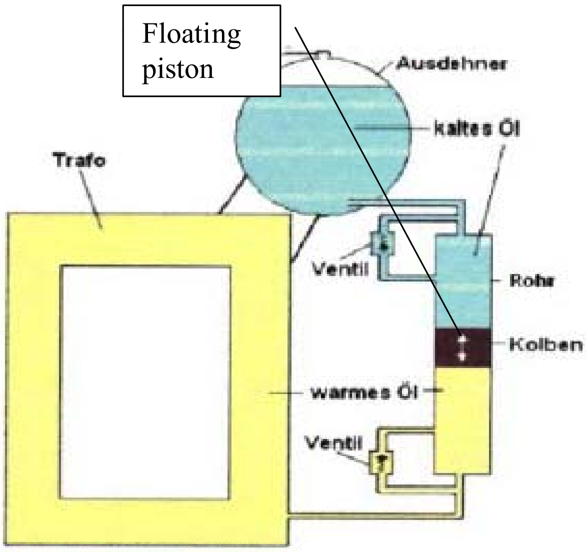


Figure 10

OxyBan

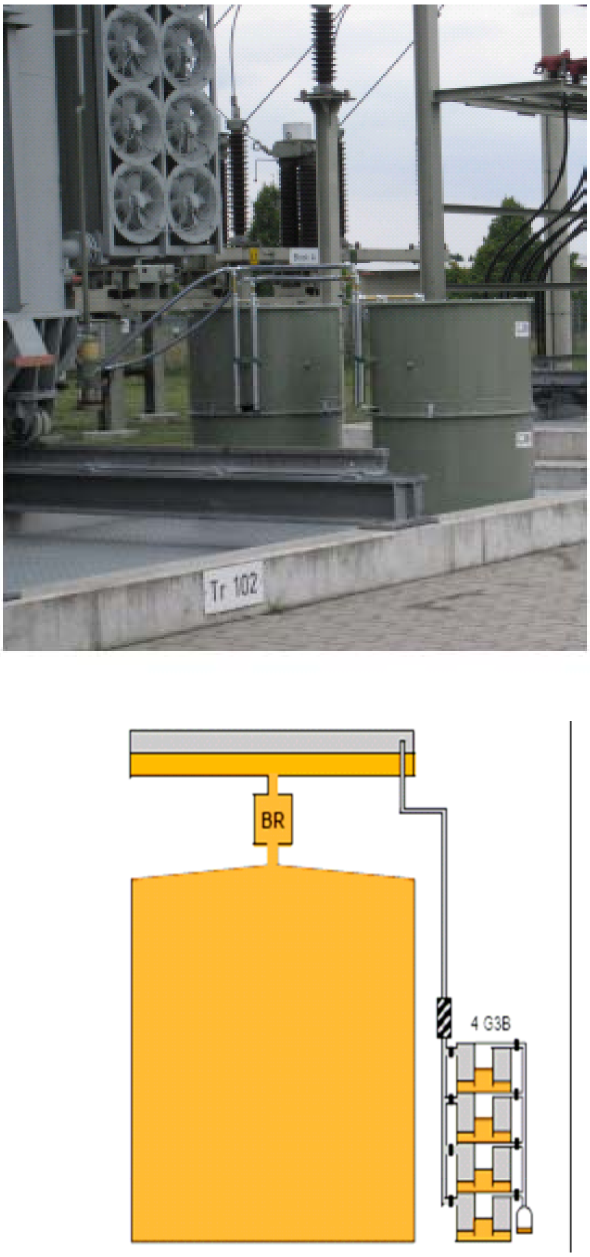


Figure 11

Gatron G3B - Prototype

Explanations to the above pictures:
There are currently three different methods available for achieving post hermetic sealing while avoiding the use of hydrocompensators which are both expensive in the medium term and very susceptible to failures.

The most long-standing of these is the TrafoSeal made by Altmann which, unfortunately, does not work correctly for pump-cooled transformers due to the ill-defined separation of the media.

OyxBan, on the other hand, avoids this problem in that the floating piston achieves a well-defined separation of the media and creates a diffusion barrier.

The new G3B recently launched by Gatron is a breathing buffer. However, it can be used only after complete saturation of the system as the diffusion to the atmosphere continues. This new system must prove its behaviour in planned control measurements. A comparison of the three methods will be presented after some further measuring.

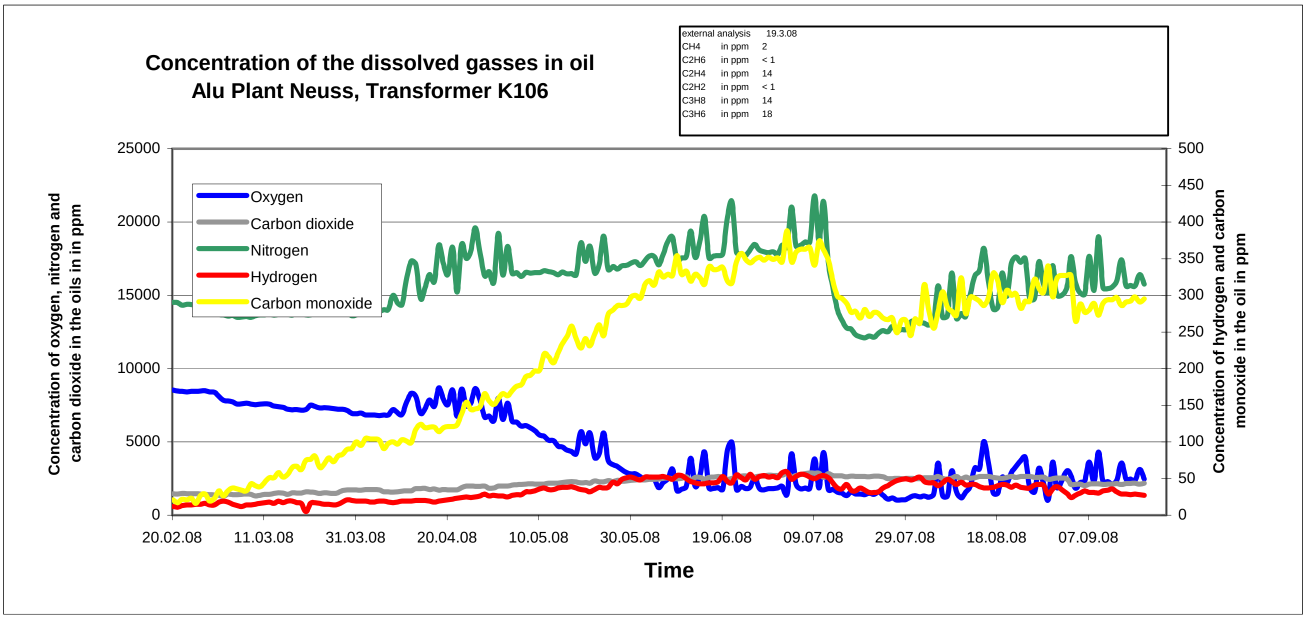


Figure 11

Online gas control Oxyban.

After connection of the Oxyban in late 04/08, the oxygen content goes down by internally consume as the effective diffusion barrier allows very little oxygen from entering together with the fresh oil coming from the oil compensator in case of load fluctuations. Resaturation is only marginally faster than with a hydrocompensator. As a result, the system can be considered adequately sealed.

Caution!

Methods which do not lead to the desired results or are even counterproductive:

- Regular treatments with oil treatment plants (as sometimes recommended for maintenance purposes). The effects are cosmetic at best while every treatment causes the loss of lighter oil fractions and diminishes the oil quality due to the overheating necessarily occurring during the process.
- The use of oil regeneration for drying of the active part. This method, if offered by service providers, is nothing short of fraudulent.

In summary it can be said that different situations, conditions and circumstances demand different methods and approaches of preservation, and that proper analysis and preparation are an indispensable first step (see DTC TPM) to choose the best possible solution for every case at hand. Naturally, the only way to achieve this in a sensible and reasonable manner is to use a reliable and reproducible measuring technology. Unfortunately, in many cases the "trial-and-error method" is used, including e.g. the use of passive dryers, regardless of whether a transformer is actually water-logged or not. That course of action, however, will never achieve recognizable results, and may even bring discredit to the entire process, leading to the conclusion that the preservation did not yield any quantifiable results.

Examples

Population of an aluminium plant 36 transformers

Age structure	over 30 years	17 transformers
	over 20	10
	under 10	7

Rating MVA /voltage KV 18/30, 36/30, 150/220/30/6
Summary of results:

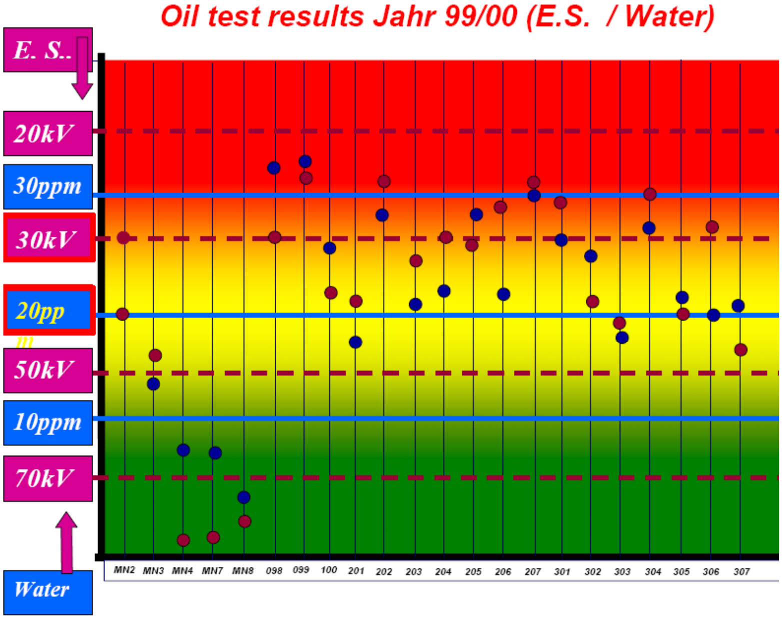
Although the intervention to this population came quite late in many cases, it was not altogether too late. Some of the oldest and even some of the 20-year old transformers had aged so dramatically by 1999 that they were identified as no longer fit for use. While the replacement of the transformers was not an option, the presence of preservable remaining substance was presumed.

Initially, several trials were made using passive drying, oil changes, and similar traditional methods. However, none of these methods led to a genuine improvement of the situation. Only the use of combined drying and gas conditioning eventually made it possible to stabilize the remaining substance to a degree allowing the restoration of safe and admissible conditions while preventing further decay to the greatest possible extent.

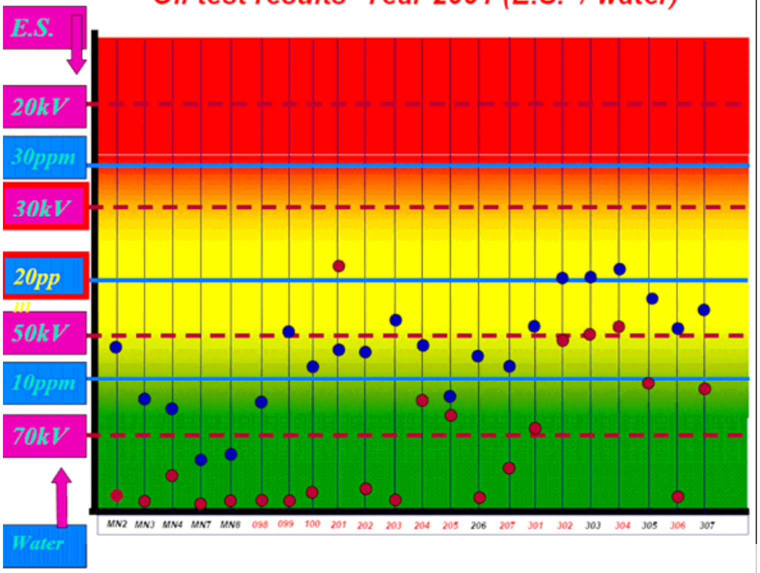
Not until 2008 were two of the most run-down transformers finally replaced. The others would remain in operation for an unforeseeable period of time. As a result, some of the transformers would have to run for another 10 years even after it was found that they are no longer permissibly operable under normal circumstances, and that continuation of operation was no longer possible without short-term replacement of the transformers. It was possible, however, to preserve the actual typical 40% of the remaining substance for another 10 years without discernible decay, and to preserve the balance for at least another 5 years, and, following further measures, at least for another 10 years and more.

Measures taken: Drying combined with partial degassing (including the <10-year old transformers) at an initial ratio of 1 machine/3 transformers and a current ratio of 1 machine/1.8 transformers. The oldest transformers are now subject to permanent conditioning whereas the transformers reaching 0.1 mgKOH/kg are subject to regeneration.

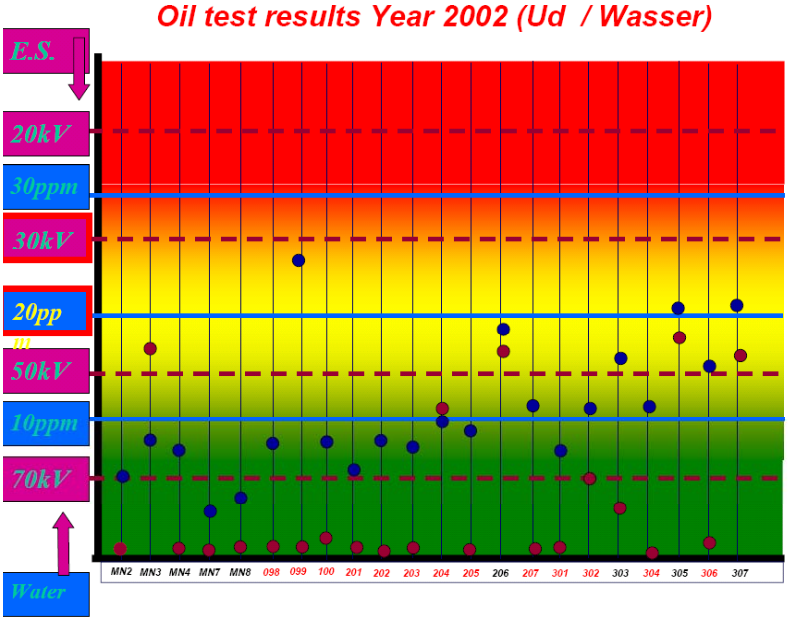
Oil test results Jahr 99/00 (E.S. / Water)

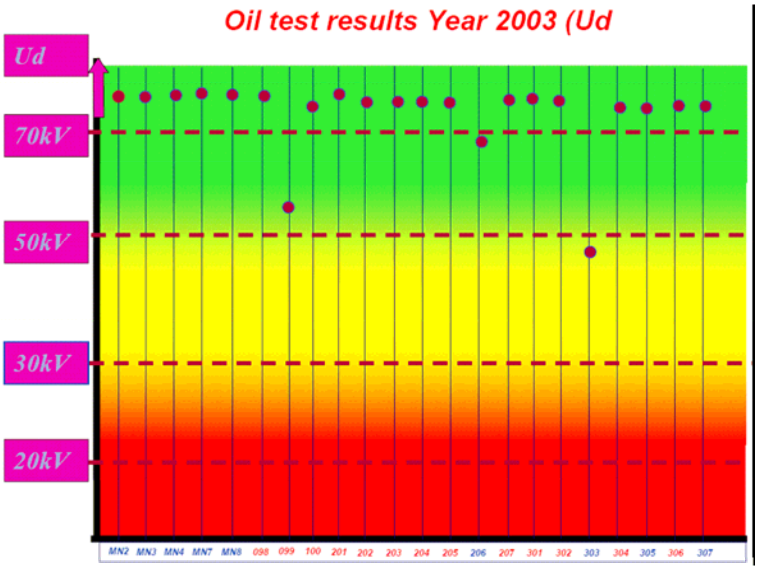


Oil test results Year 2001 (E.S. / water)



Oil test results Year 2002 (Ud / Wasser)





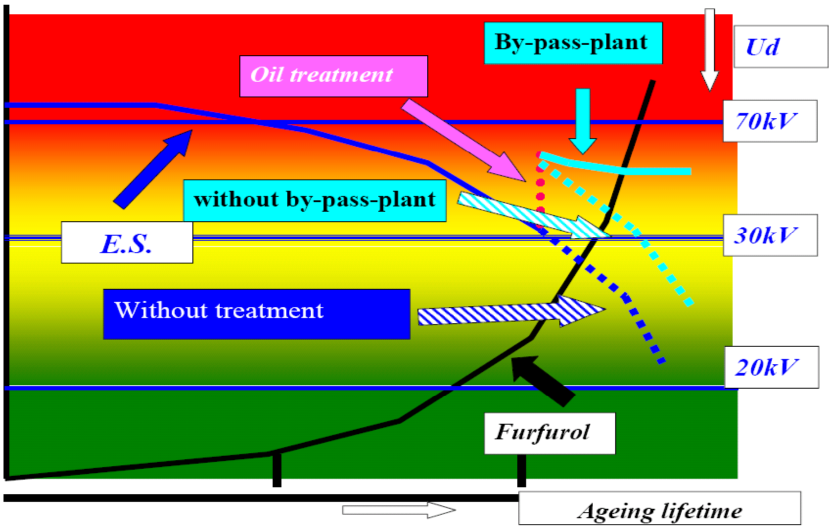


Figure 12 - 16

Results

The remaining substance of the transformers has remained to this date at the "bypass plant" line.

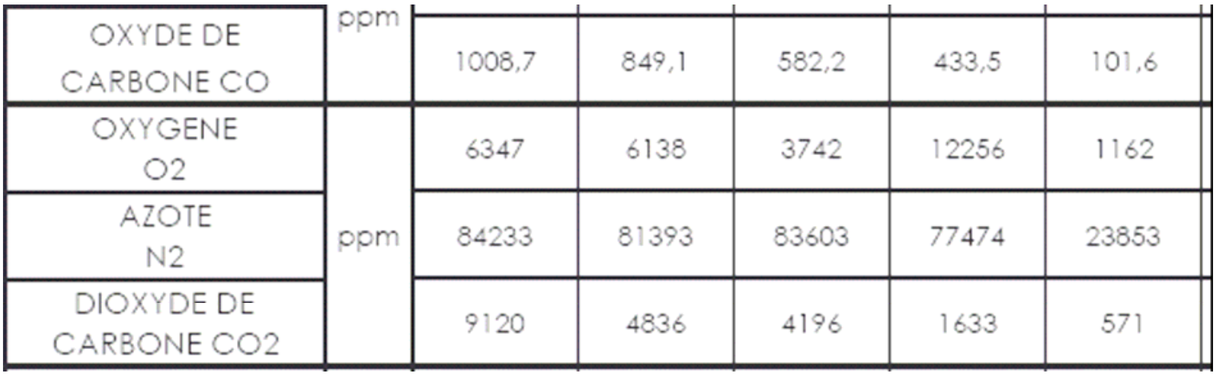
Aluminium plant in France

Age pattern: uniform, with average transformer age of 14 years in 2004
Layout pattern: the plant is equipped with 8 sets of regulation transformers with a rating of 78 MVA/220/55kv and one rectifier transformer each with a rating of 78MVA 55/0,8 kV.

Even during our first visit on 2000 we were told that all transformers were experiencing problems with excessive temperatures and water contents. However, since the problem was being viewed as the transformer manufacturer’s responsibility, the plant was trying to solve the problems via the court system. Unfortunately, the remedies suggested by us were rejected by the transformer manufacturer. The transformers were subjected to a number of different measures, presumably including long-term vacuum & heat treatment, with the result that, even though the water contents were markedly lowered from 4% to approx. 2.5%, the transformers’ substance was damaged to such an extent that by 2004, when we were consulted again, no truly salvageable substance was left. In 2005, a replacement of the entire population was started.

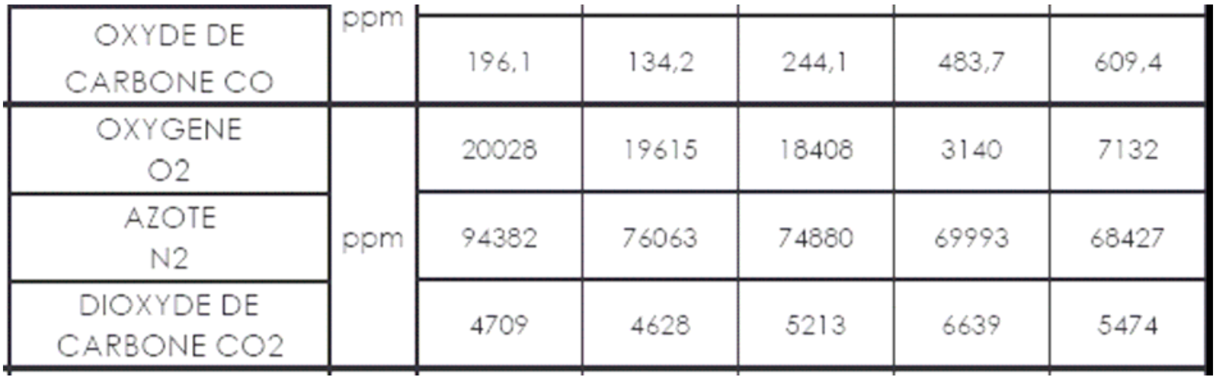
Let’s look at an excerpt from the DGA to shed some light on this issue: Extremely low O2 values, except during the last measurement, which is without a doubt flawed, and high CO_2 values. Rapidly rising furan values in spite of repeated interventions through degassing drying and tough treatments.

TG12



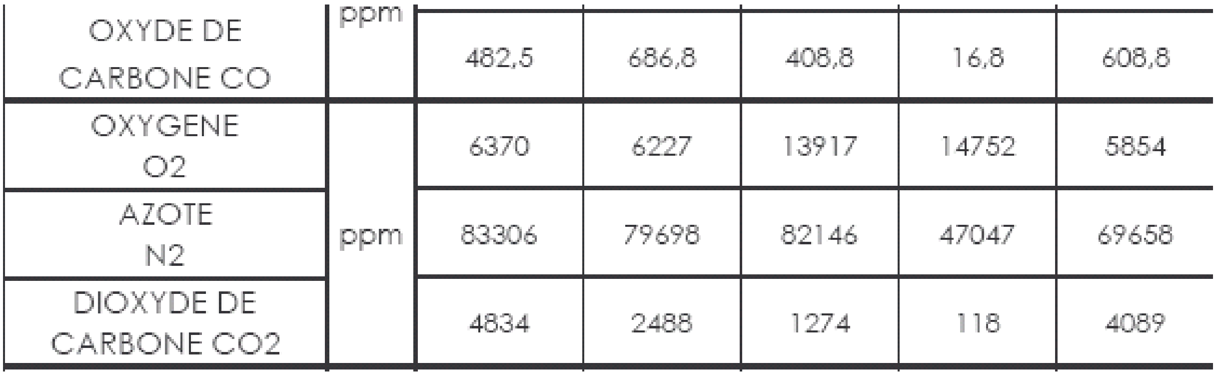
OXYDE DE CARBONE CO	ppm	1008,7	849,1	582,2	433,5	101,6
OXYGENE O2	ppm	6347	6138	3742	12256	1162
AZOTE N2		84233	81393	83603	77474	23853
DIOXYDE DE CARBONE CO2		9120	4836	4196	1633	571

TG16



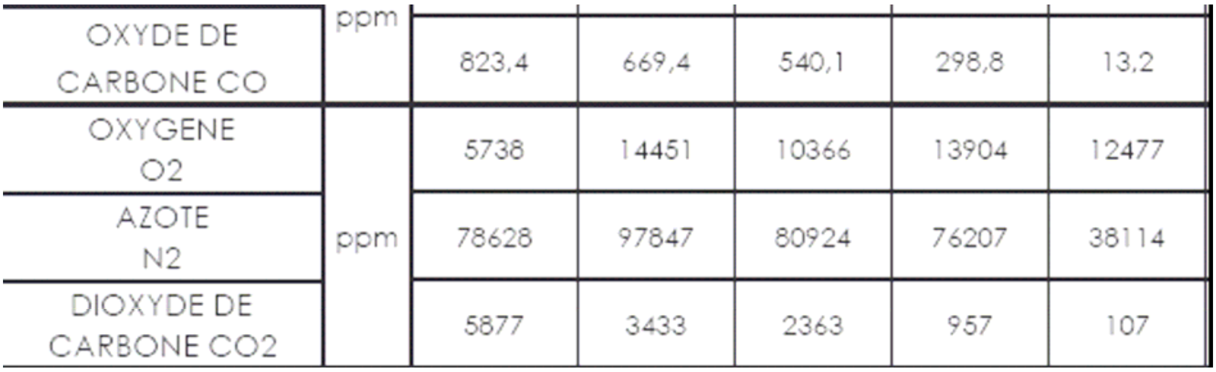
OXYDE DE CARBONE CO	ppm	196,1	134,2	244,1	483,7	609,4
OXYGENE O2	ppm	20028	19615	18408	3140	7132
AZOTE N2		94382	76063	74880	69993	68427
DIOXYDE DE CARBONE CO2		4709	4628	5213	6639	5474

TG11



OXYDE DE CARBONE CO	ppm	482,5	686,8	408,8	16,8	608,8
OXYGENE O2	ppm	6370	6227	13917	14752	5854
AZOTE N2		83306	79698	82146	47047	69658
DIOXYDE DE CARBONE CO2		4834	2488	1274	118	4089

TG13



OXYDE DE CARBONE CO	ppm	823,4	669,4	540,1	298,8	13,2
OXYGENE O2	ppm	5738	14451	10366	13904	12477
AZOTE N2		78628	97847	80924	76207	38114
DIOXYDE DE CARBONE CO2		5877	3433	2363	957	107

Figures 17- 20

The documents on the regulating components were not made available to us although these were replaced as well.

The results: Naturally, the preliminary conditions were much worse than those of the German plant as the transformers were obviously afflicted by design errors. Time and again, temperatures inside the oil would rise up to 90°C, in spite of moderate ambient temperatures. A consistent and systematic approach involving an improvement of the external cooling system, combined with the early use of genuine preservation measures and other measures, would definitely have prolonged the transformer's use for at least another 5 or even 10 years.

In 2004, 12 million Euros were invested for new transformers, whereas thorough preservation of the existing transformers in the entire plant could have been had for less than 10% of that sum. Based on a 5% interest rate, not spending these 12 million Euros would have paid off in two years. After the third year, the plant would have earned 600,000 Euros per year! Conservatively calculated, this would have translated into 3 x 0.6 million Euros = 1.8 million Euros!

Also, it might be noted that one of the new transformers blew up right after commissioning – another risk which needs to be taken into account in transformer replacement!

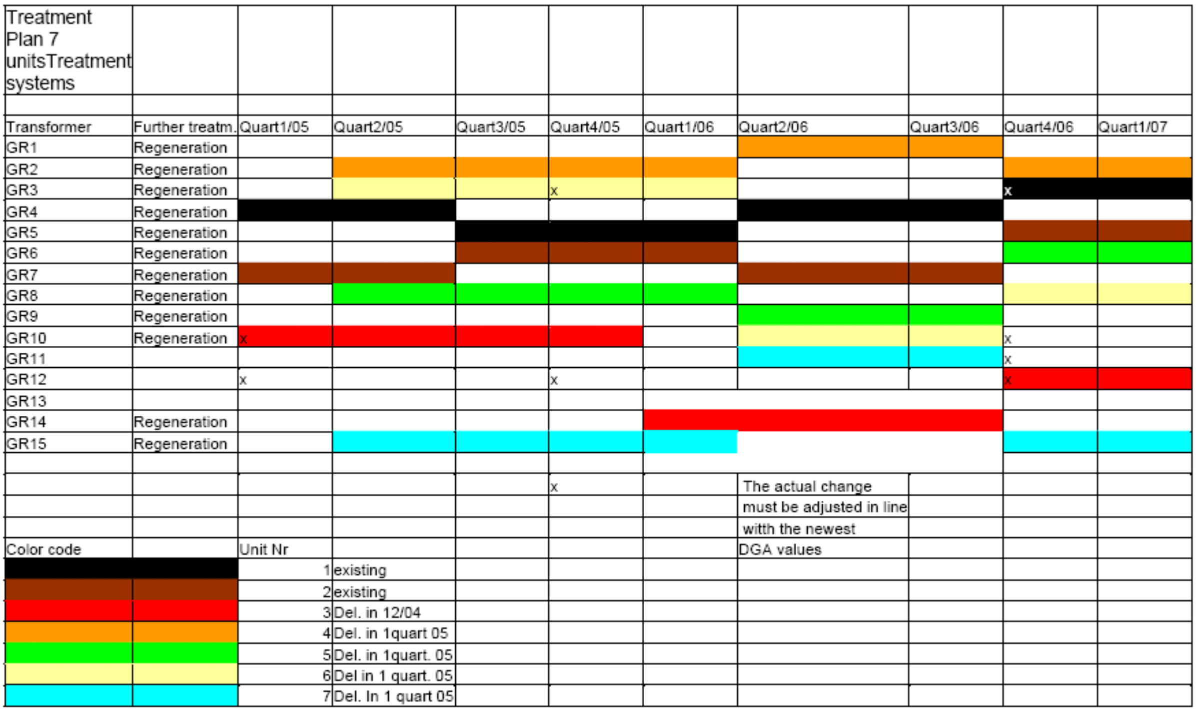
Aluminium plant in Greece

15 sets of regulating transformers/rectifier transformers with a primary level of 15 kV

Previous history: The operator had been advised, as part of a regular maintenance routine, to treat each transformer once a year with oil processing.

The results: Water contents of up to 5% in the cellulose and dramatically reduced substance. One set of transformers (unit13) were beyond salvation.
The following treatment plant involving regeneration and 7 conditioning systems was prepared for the treatment of the remaining substance:

Table 1
Treatment plan Alu Plant Greece



Treatment Plan 7 unitsTreatment systems										
Transformer	Further treatm.	Quart1/05	Quart2/05	Quart3/05	Quart4/05	Quart1/06	Quart2/06	Quart3/06	Quart4/06	Quart1/07
GR1	Regeneration						🟧	🟧		
GR2	Regeneration		🟧	🟧	🟧	🟧			🟧	🟧
GR3	Regeneration		🟨	🟨	x 🟨	🟨			x ⬛	⬛
GR4	Regeneration	⬛	⬛				⬛	⬛		
GR5	Regeneration			⬛	⬛	⬛			🟫	🟫
GR6	Regeneration			🟫	🟫	🟫			🟩	🟩
GR7	Regeneration	🟫	🟫				🟫	🟫		
GR8	Regeneration		🟩	🟩	🟩	🟩			🟨	🟨
GR9	Regeneration						🟩	🟩		
GR10	Regeneration	x 🟥	🟥	🟥	🟥		🟨	🟨	x	
GR11							🟦	🟦	x	
GR12		x			x				x 🟥	🟥
GR13										
GR14	Regeneration					🟥	🟥	🟥		
GR15	Regeneration		🟦	🟦	🟦	🟦			🟦	🟦
					x		The actual change			
							must be adjusted in line			
							witth the newest			
Color code		Unit Nr					DGA values			
⬛	⬛	1	existing							
🟫	🟫	2	existing							
🟥	🟥	3	Del. in 12/04							
🟧	🟧	4	Del. in 1quart 05							
🟩	🟩	5	Del. in 1quart. 05							
🟨	🟨	6	Del in 1 quart. 05							
🟦	🟦	7	Del. In 1 quart 05							

Combined Heat and Power Plant (CHP)

The task at hand was to ensure operation of the plant until at least 2012 while preserving sufficient substance to keep the plant functional beyond that time, if needed.

Table 2

The following initial evaluation was prepared based on the data received

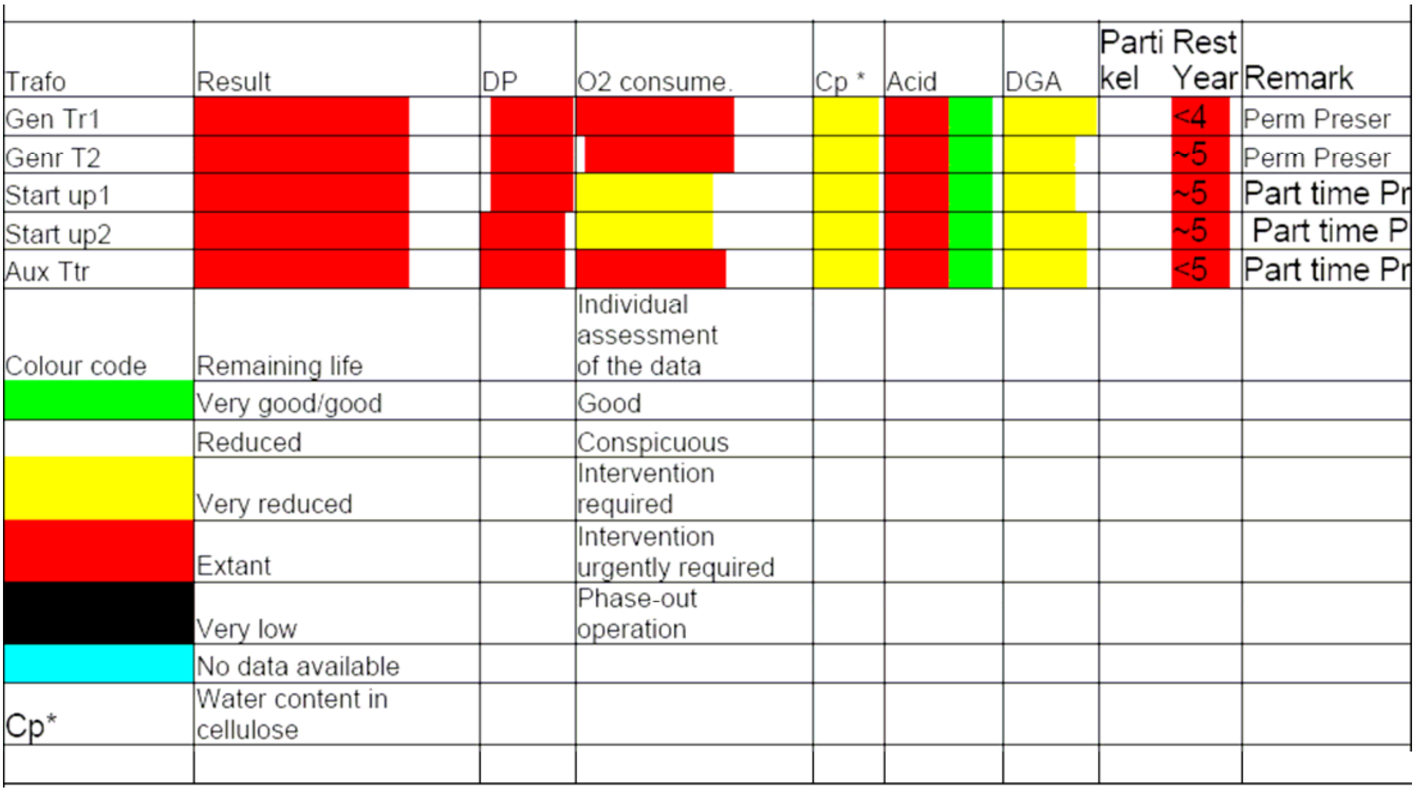
Transformer	Result	DP	O2 consumption	Cp *	NZ	DGA	Particles	Remarks
1	🟥	🟦	🟥	🟥	🟥			Sustainable preservation
2	🟨	🟦	🟦	🟨	🟥	🟦		
3	🟥	🟦	🟦	🟥	🟥	🟦		
4	🟨	🟦	🟦	🟥		🟦	🟥	CP/Ud conspicuous
5	🟨	🟦	🟦	🟥		🟦		
E filter	🟥	🟦	🟦	🟥	🟥	🟦	🟥	CP/Ud conspicuous
6	🟥	🟦	🟦	🟨		🟦	🟥	CP/Ud conspicuous
Colour ID	Remaining life		Individual assessment of the data					
🟩	Very good/good		Good					
	Reduced		Conspicuous					
🟨	Very reduced		Intervention required					
🟥	Extant		Intervention urgently required					
⬛	Very low		Phase-out operation					
🟦	No data available							
Cp*	Water content in cellulose							

Table 3

Based upon these data, the following operation chart was prepared:

Treatment plan CHP						
Transformer	Other treatm.	Quart2/06	Quart3/06	Quart4/06	Quart1/07	Quart2/07
1	Regeneration	■	■	■	■	
2	Regeneration	🟫				■
3	Regeneration			🟫		
4						🟫
5						
E filter			🟫			
6	Regeneration					
	Technical attendance	to take place				
					x	
Transfers			2	2		1
Colour ID		System				
■	■	System 1				
🟫	🟫	system 2				

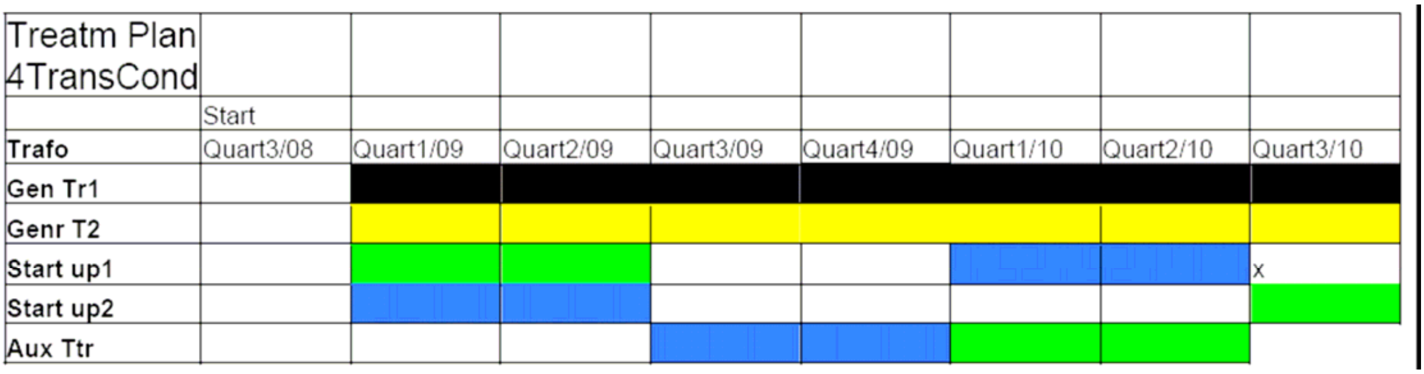
Quart3/07	Quart4/07	Quart1/08	Quart2/08	Quart3/08	Quart4/08	Quart1/09
	■	■			■	■
■				■		
	🟫	x			🟫	
		🟫				🟫
🟫			🟫			
			■			
		x				
		x				
		x				
	1	2	2	2	1	



Trafo	Result	DP	O2 consume.	Cp *	Acid	DGA	Parti kel	Rest Year	Remark
Gen Tr1	🟥	🟥	🟥	🟨	🟥🟩	🟨		🟥 <4	Perm Preser
Genr T2	🟥	🟥	🟥	🟨	🟥🟩	🟨		🟥 ~5	Perm Preser
Start up1	🟥	🟥	🟨	🟨	🟥🟩	🟨		🟥 ~5	Part time Pr
Start up2	🟥	🟥	🟨	🟨	🟥🟩	🟨		🟥 ~5	Part time P
Aux Ttr	🟥	🟥	🟥	🟨	🟥🟩	🟨		🟥 <5	Part time Pr
Colour code	Remaining life		Individual assessment of the data						
🟩	Very good/good		Good						
⬜	Reduced		Conspicuous						
🟨	Very reduced		Intervention required						
🟥	Extant		Intervention urgently required						
⬛	Very low		Phase-out operation						
🟦	No data available								
Cp*	Water content in cellulose								

Year 2008

Actual evaluation with estimation of remaining life time under present conditions. By using more intensive preservation, the remain. Life time can extended to about 15 years. This is a decision of the customer, reaching only the planned date or have reserve of lifetime.



Treatm Plan 4TransCond								
	Start							
Trafo	Quart3/08	Quart1/09	Quart2/09	Quart3/09	Quart4/09	Quart1/10	Quart2/10	Quart3/10
Gen Tr1		⬛	⬛	⬛	⬛	⬛	⬛	⬛
Genr T2		🟨	🟨	🟨	🟨	🟨	🟨	🟨
Start up1		🟩	🟩			🟦	🟦	x
Start up2		🟦	🟦					🟩
Aux Ttr				🟦	🟦	🟩	🟩	

Treatment for 6 transformers in a CHP actual version, when 15 years remaining life time required

The above measure is currently still ongoing and will be continued. It is already evident that the targets set can be achieved. A paper sample taken from one of the transformers suggests the presence of sufficient preservable substance. In addition to the regeneration measures, two conditioning systems are also in use.

There are many more examples available for information. Interested parties are invited to either contact DTC directly or view the reference list.

Summary

We deliberately included negative examples to show that consistent asset management will lead to financially positive results even with little effort, whereas an inappropriate course of action will lead to corresponding losses.

Looking back at the limited options and knowledge available 15 years ago, we can now say that there are now options available for reliable data collection and can be put to sensible use through application of the technologies which have in the meantime developed to the point that they can be used. It is therefore now possible to meet the requirements of today through use of the state-of-the-art technologies now available. It is even possible to preserve and manage extremely overaged

populations through an optimized combination of investment funds, delivery times and economic behaviour and to ensure a reasonable security of supply and operation (uninterrupted service) without need of having to put up with unacceptable processes and conditions. And there are now instruments available for getting the idea across, even to non-technically inclined people, that reliable operation requires only modest investments and that it is possible to master both the financial and the political risks involved in an orderly and reproducible fashion. Spectacular failures can be avoided to a large extent, and solved both technically and politically through appropriate anticipatory actions.

DTC has been at the forefront in development of cutting-edge know-how for the past 15 years and has left the well-trodden paths of the past millennium early on to provide the users with viable solutions for mastering the tasks of the 21st Century.

We are looking forward to hearing your questions.

September 08

Georg Daemisch

Biography

*M.Sc.(Eng.) Georg Daemisch
Owner and managing director of DTC specialized in consulting for transformers
Majority Owner and managing director of DIDEE GmbH(Daemisch Industriedienstleistungen GmbH) specialized implementing On-Line treatment and monitoring systems for transformers.

Sales Engineer for southern Europe in MR (Maschinenfabrik Reinhausen) in Regensburg/Germany for OLTC's

Sales Engineer for big power transformers in BBC Mannheim (ABB) for Latin America, Near East and other areas.

Sales Engineer for small and middle sized transformers in TRAFO UNION (Siemens/AEG)

Studies performed in Karlsruhe/Germany as Dipl. Ing. (Electrical power engineering)