"TPM" Transformer population Management

by

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Abstract

Today's transformer population can be characterized as being over-aged with unknown levels of individual residual life. There are many sampling and monitoring systems and conservation methods that deliver large quantities of technical data. However, they are difficult to evaluate and they do not provide the asset manager with the necessary tools for optimizing his assets, not only from a technical point of view, but from an economical perspective as well.

Transformer Population Management or TPM is a integrated system which considers the current age of each transformer in the population (based on the data already existing or to be collected), along with the necessary measures for assuring technically sound and acceptable operating conditions that will assure that the transformer will stay reliable for its remaining life. Information about how the transformer is to be operated in certain parts of the grid or plant must be known. For example, if transformers of a certain voltage level are intended to be phased out, it makes little sense to buy new transformers; the existing ones have to be conserved till the last part of that grid is out of service.

All these parameters have to be observed and set together into a long term schedule of conservation measures, replacing cycles, and investment coordination, and updated regularly with new technical and economical parameters.

Examples of industrial and utility systems will be presented.

General

TPM, Transformer Population Management is at the present stage not a sophisticated computer program providing comprehensive figures and diagrams showing the situation of your transformers at the push of a button, giving advice and making decisions. We are not sure if we will ever get to that stage. The issue of survival with overaged transformer populations remains too complex for an automatic program. Also, very belatedly the users and utilities came to understand that there would be a problem coming up, which was neglected in the stormy times of mergers, deregulation, liberalisation, etc. An economist has calculated that if the actual cycle of replacement of transformers were to remain the same as today, transformers would have to reach a life time of more than 100 years. We technicians know that that is impossible, even if a standard sentence often to be heard is, "we had no transformer problems for the past 30 years, and therefore we think that transformers are not an asset to care for".

This is the same silly thinking as to presume that after driving a car 100 000 km without any maintenance, it will keep going for another 100 000 km or more. The situation is worse than most people seem to be aware of. There are a couple of facts to reckon with:

- The majority of the transformers are over 30 years old, which means that design life time was long exceeded.
- The production capacity in the transformer factories has dropped dramatically.
- Most remaining factories are actually working at the top of their capacity.
- Expertise and know-how has been lost in the past few years on side of the producers and the customers.
- The new transformers are clearly designed for shorter life cycles.
- The actual energy flow in the deregulated market now burden transformers to their full capacity or sometimes even more.

The overall result of that fact is: Only a carefully implemented procedure can deal with limited financial resources, extended delivery times, and the political pressure for sound and secure energy supply. The asset manager, if taking his responsibility seriously, must have a clear picture of the condition of the transformers, the priorities for maintenance and replacement, always with a clear look to optimized cost and investment planning. This also means that he must avoid being driven by unforeseeable isolated incidents while loosing sigh of the complete situation.

At TPM we coordinate evaluation of the actual service life strength of the population members with the different conservation methods, which is useful for maintaining the target of lowering overall reinvestment costs without jeopardizing the sound and secure energy supply. In the following we will show the worksheet for that procedure.

TMP flow diagram

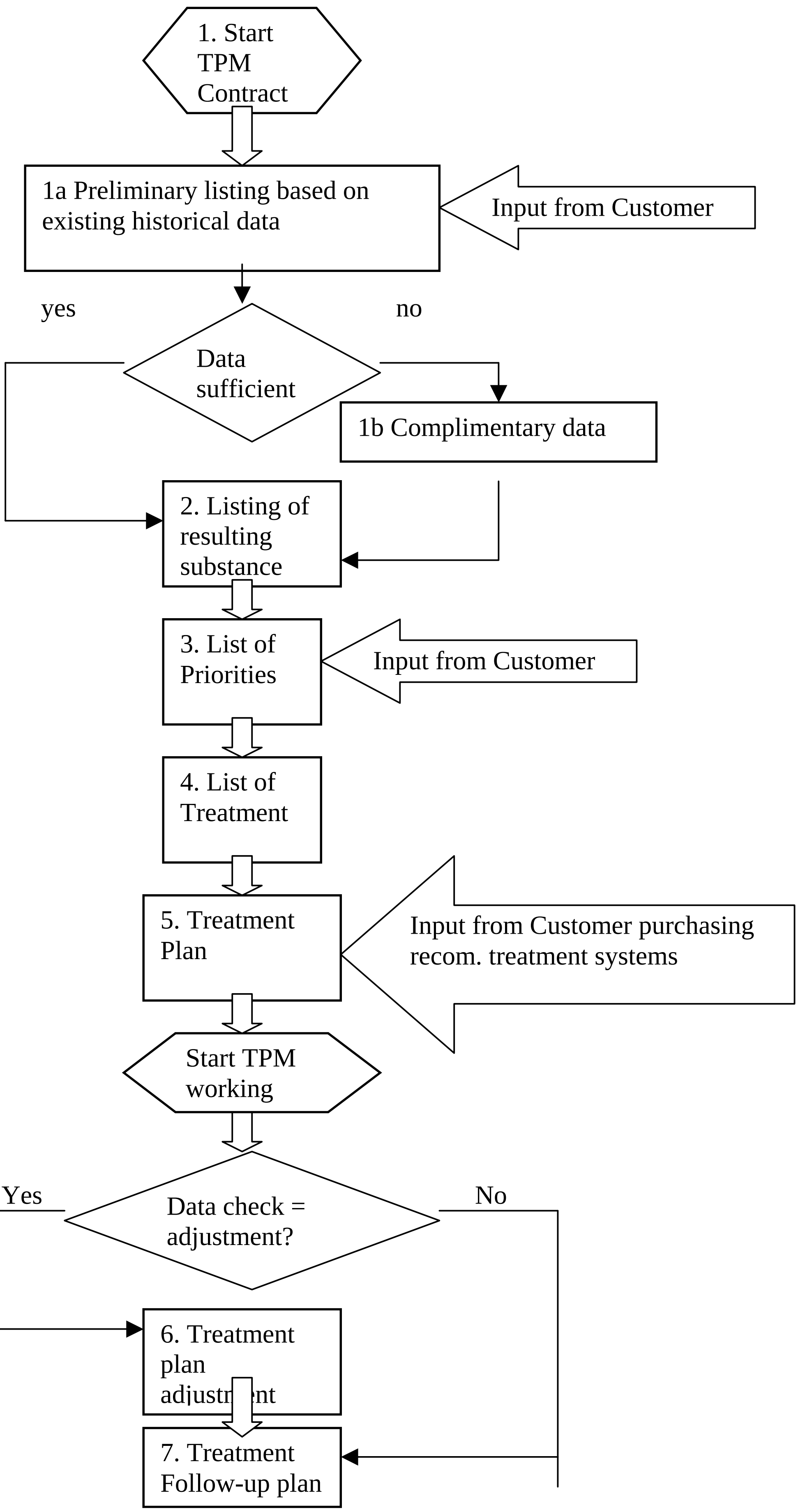

Figure1
Flow diagram for TPM

1. Start TPM Contract

Since the TPM procedure is a long term co-operation between the customer and the consulting entity, a suitable contract should be achieved, in order to have the necessary continuity to meet the target.

1a Preliminary listing based on existing historical data

There normally exists a more or less comprehensive data base of oil test protocols and DGA results, which can be used to make a first survey and evaluation of the population, based on the ageing indicators. Since up to now there are no values available giving a direct and reliable indication of the ageing condition of a transformer, all indicators must be viewed together, and finally concluded into practical results.

The indicators are:

- water content.
- acidity and oil condition.
- oxygen consumption (i.e. CO and CO2).
- furan content.
- particles.
- BDV

By evaluating these data, a first rough condition assessment is possible. Generally it must be said that a more differentiated classification going beyond the following 4 categories make not much sense and seem rather unfeasible, since the above mentioned indicators are just that, indicators and nothing else, and cannot be used as precise data. These categories are:

1. New
2. Reduced
3. highly reduced, but conservable
4. no conservable remaining life strength left.

Similar categories can be found in other publications also. For the customer is important to know whether or not some conservable life remains. In the latter case, only the controlled use until replacement is advisable. If the transformer can and should be conserved, it must be kept in mind that the curve of loss of life strength is exponential, or, in other words, even a 60% evaluation can provide a very short time window for necessary measures, if the transformer needs be kept in service for a longer term.

The following picture illustrates this ageing behaviour. The important point here is obvious, that if the red zone "B" is reached, the percentage of residual life strength is much less, in view of the fact that it will be lost dynamically! If the user has the intention of keeping these transformers in reliable service for more than about 5 years, the necessary measures must be implemented now! Partial or complete loss of life strength cannot be recovered, due to the factor of depolimerization. There is no method or treatment which allows repolimerization!

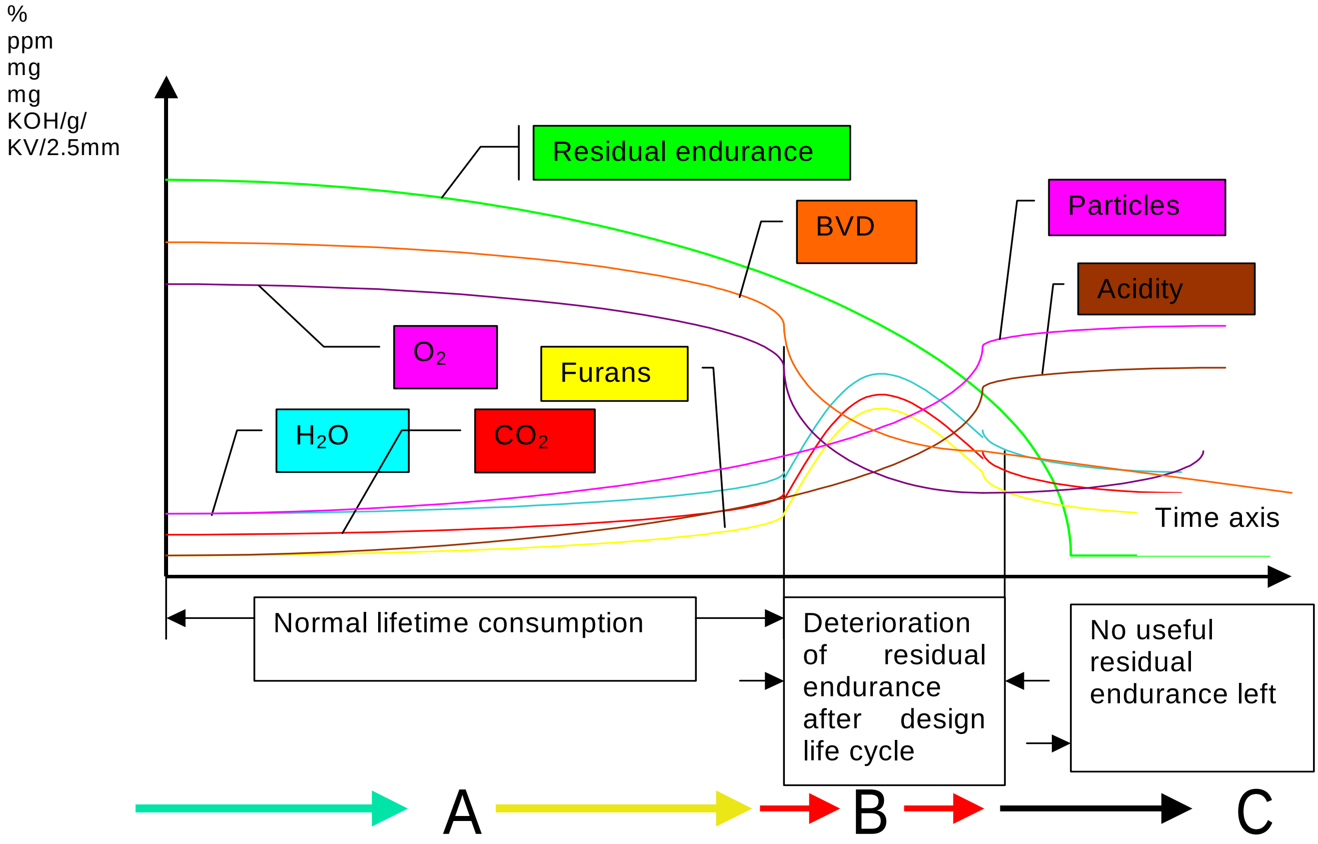

Figure 2
Ageing behaviour of power transformers

Based on the above evaluation the following first table can be made:

Transformer	Result	DP	O2 consume	Cp	Acidity	DGA	Particles	Remarks
MTR1*								
MTR2*								
MTR3Nord								Data incomplete
MTR3Süd								Data incomplete
EigB3								
MTR4**								Nearly no substance
EigB4								
Anfahr4								
Erreg.4								Fast deterioration
10 MVA1								Fast deterioration
10 MVA2								Fast deterioration
20MVA TR3								
Colour code	Substance		Evaluation of data					
	High		Good					
	Reduced		first problems					
	strongly reduced		Treatment necessary					
	Substance left		Treatment urgent					
	Low substance		Controlled use until replacement					

Figure 3
Table of ageing condition

1b Complementary data

As obvious from Figure 3, it is mostly the initial data which must be regarded as incomplete, and typically it is indispensable to get more reliable and complete data. In this paper, we won't go into too much detail on how to obtain these data, because that would take a separate presentation. Here, we will only give some brief indications on how to proceed:

- water content. Via On-line, FDS or PDC
- acidity and oil condition. Oil test
- oxygen consumption (i.e. CO and CO2). On-line gas monitoring (resaturation curves)
- furan content. Oil test
- particles. Oil test
- BDV Oil test

It must be remembered that all data gained by traditional oil sampling are highly doubtful and must be evaluated very critically.

3. List of Priority

Once acceptable and reliable data are available, the "non-technical" aspects must be determined. These aspects must be communicated by the customer and cover mainly the lifetime expectancy for the whole plant where the transformer is installed.

Alternatives are:

- **A**. the plant/substation should work indefinitely,
- **B**. there is a fixed date when the plant/substation will be shut down
- **C.** it is uncertain whether the plant/substation will be shut down in the near future, later on, or even not at all
- **D**. there is no truly definite time window for shutdown

A. For all transformers with indefinite lifetimes in use in plants/substations, a condition-based planning of coordinated replacement with investment optimization should be implemented.
A typical example is a population of 100 transformers, all of them in a condition and at an age where replacement will be indispensable within the next 5 years at the latest. That means a replacement cycle of 20 transformers per year. Apart from the delivery situation of the industry, this means that a heavy short term investment.

If it were possible, due to conserving measures, to extend the useful lifetime of the last transformers to be replaced up to 15 years, the yearly replacement would come down to 5-7 units per year, without the need to respond immediately to unforeseen situations. Instead it would be possible to react flexibly to changes in delivery or financial situation without the pressure of having transformers in unacceptable condition.

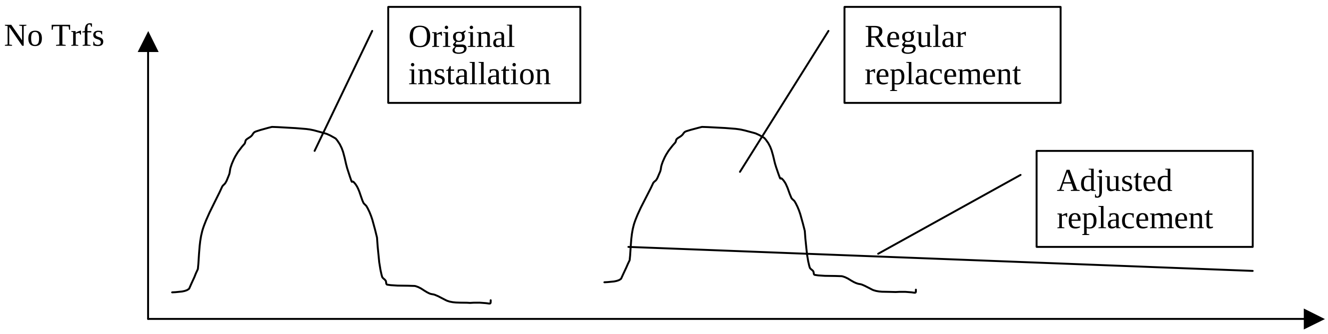

Figure 4
Reduced need of replacement after 30-40 years

B. If there is a fixed date for shut-down, the measures would be limited to maintenance for that time while the necessary reliability and security data and the applied measures could be implemented at a lower level.

Tr.	Type	Cp [%]	Treatment	Assessment*	Comments
1	Regl 33kV	approx. 2.5-3	F,G,W	6	Measure Cp
2	Regl33 kV	<2	F,G	3	
3	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
4	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
5	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
6	GL 33kV	approx. 2.5	F,G,W	7	Maintain condition
7	GL 33kV	approx. 2.5	F,G,W	3	Maintain condition
8	GL 33kV	approx. 2.5-3	F,G,W	6	Measure Cp
9	GL 33kV	approx. 2.5-3	F,G,W	7	Continue treatment
10	GL 33kV	approx. 2	F,G	4	Maintain condition
11	GL 33kV	approx. 2	F,G	4	Maintain condition
12	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
13	GL 33kV	approx. 2	F,G	4	Maintain condition
14	GL 33kV	03.05.04	F,G,W	9	55°C max see App.
15	GL 33kV	approx. 2.5-3	F,G,W	7	Measure Cp
16	GL 33kV	approx. 2.5-3	F,G,W	8	Measure Cp
18	GL 33kV	approx. 2	F,G	7	Slow down deterioration
Tr.	Type	Cp [%]	Treatment	Assessment*	Comments
19	Regl 33kV	approx. 2.5-3	F,G,W	6	Measure Cp
20	Regl33 kV	<2	F,G	3	
21	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
22	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
23	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
24	GL 33kV	approx. 2.5	F,G,W	7	Maintain condition
25	GL 33kV	approx. 2.5	F,G,W	3	Maintain condition
26	GL 33kV	approx. 2.5-3	F,G,W	6	Measure Cp
27	GL 33kV	approx. 2.5-3	F,G,W	7	Continue treatment
28	GL 33kV	approx. 2	F,G	4	Maintain condition
29	GL 33kV	approx. 2	F,G	4	Maintain condition
30	GL 33kV	approx. 2.5	F,G,W	4	Maintain condition
31	GL 33kV	approx. 2	F,G	4	Maintain condition
32	GL 33kV	03.05.04	F,G,W	9	55°C max see App.
33	GL 33kV	approx. 2.5-3	F,G,W	7	Measure Cp
34	GL 33kV	approx. 2.5-3	F,G,W	8	Measure Cp

Figure5
Schedule of priority and treatments

Colour coding:

Red: These transformers should, in their current condition, be operated only while under treatment, in order to maintain operational safety and/or to safely control any further deterioration caused by the ongoing ageing process.

Yellow: Regular operation if given treatment for a period of 3-6 months per year, while alternating with other transformers during these treatment intervals, which will be required to keep these transformers in their current condition.

White: Preventive treatment for a period of 3-6 months per year in order to keep these transformers in their current condition is highly advisable or has to be initiated once the values begin to deteriorate.

Green: These transformers require no immediate action, although interventions will become necessary as soon as the values start to deteriorate. If all transformers were marked green, a preventive circulation of the treated units at cycles of 3-4 months would be a sensible conservation measure.

C. This is typically the case in plants where, due to factors like energy prices, raw materials /sales prices or similar, the survival at a certain place is insecure and depends on the decision of management in a 2-4 year period. Under these conditions, consistent conservation is indispensable, because for as long as the assets are expected to continue working, they must be in serviceable condition. Otherwise the necessary investments will be a reason for reverting that the decision, or for shutting down the plant due to the fact that the equipment not in workable technical condition. This situation differs completely from that outlined under "A" and "B". In a case like that, all possible means of conserving the units must be implemented.

D. Basically it is the same situation as under "C", with very similar consequences. A typical case is the German 220 kV grid, which is intended to be deleted. This may be a time frame of 10 years or more, but it makes no sense to invest in new transformers or in costly repairs. In that case, all conserving measures will be highly cost effective!

Taking into account all of the above mentioned factors, the list of priorities can be finalized and taken to the next step, i.e. the list of treatments.

4. List of Treatments

Before we talk about the various treatments available it must first be clarified which treatment is necessary and why. The main target of any treatment is to get rid of the ageing accelerators, i.e.:

- water
- acidity (polar products)
- particles
- oxygen

Treatment against water is always a long term process, oxygen treatment is at least a semi-permanent process, and treatment against particles is the same. Treatment against acidity and polar products is a short term process which is normally done once in the entire lifetime of a transformer.

The following systems are available:

1. Short term off-line systems

For water treatment, short term systems like oil spray or/and low frequency are available, lately even on-site vapour phase plants. All these systems are not recommended for aged transformers for several reasons. Since such treatments will necessarily have an impact on the remaining polymerization factor, it is unacceptable to lose even more of the already reduced life strength. Additionally, these systems are very costly and require shutdown for a certain period of time. Oil treatment plants are in no way a solution, since it is impossible to reduce the water content at short term with such plants.

2. Passive driers based on cellulose or molecular sieves

Passive driers on cellulose base are normally not effective, with the exception of systems with special temperature and flow control. MS-systems work as dryers, but there may be some side effects compromising oil quality. For maintaining the BDV and water content data, they may in fact be a workable solution, provided no long term conservation is required.

3. Combined active degassing and drying

There are different systems on the market, mostly high vacuum plants based on traditional oil treatment plants. These systems are not acceptable for several reasons: Applying high vacuum on a long term basis will be destructive on the oil and is dangerous, due to non-settled oil going back to the transformer. Heat for emulsion separation is another deterioration factor for the oil.

An acceptable, even ideal solution for long term conservation are plants with moderate vacuum, without vacuum pumps, as they have no influence on oil quality while leaving 20-30% of total gas content for secure DGA evaluation.

Since these systems automatically keep the oxygen and nitrogen content low, the necessary gas conditioning is included.

Acidity and polar products

Up until today, some people keep recommending oil changes for that purpose, even claiming that this would help against water also. The latter statement is simply wrong, and certainly only the second best solution for conservation of transformers with regard to acidity and ageing products.

The use of a modern regeneration plant with molecular sieves and final reinhibition of the regenerated oil is currently the best solution for that part of conservation. Sometimes are recommended ion exchangers for dealing with acidity. This can be only a partly solution, because the cleaning effect of the reiterated passes of the clean oil base will be missed.

Passive gas conditioning

It is possible to seal open conservator transformers against atmospheric ingress using classic diaphragm or bag systems, which would solve at least the oxygen problem. Newly available are "virtual" systems which can be easily implemented without high costs or changes to transformer design. For aged transformers, this is the solution typically adopted.

5. Treatment plan

The above-listed technical possibilities must now be viewed in relationship to the non-technical conditions in order to determine the scope of measures needed. I.e. the range of measures will go from a simple passive drier for short-term improvement of BDV and water content, all the way to keeping a transformer in service to the extent of regeneration, and keeping it under permanent gas conditioning, if the required task is to keep a weak, highly aged transformer in service for as long as possible.

Taking into account all of these factors, the necessary treatment systems and services must be purchased and applied according to a long term scheduled treatment plan, in order to maintain the transformer’s entire condition as required by the customer. Apart of short term treatments like regeneration, the necessary long term treatment systems must be distributed over the population. For example, combined drying and gas conditioners will be needed at a ratio of 1/1 to ¼, this means one system for between 1 and 4 transformers max., depending of condition and size of the transformers.

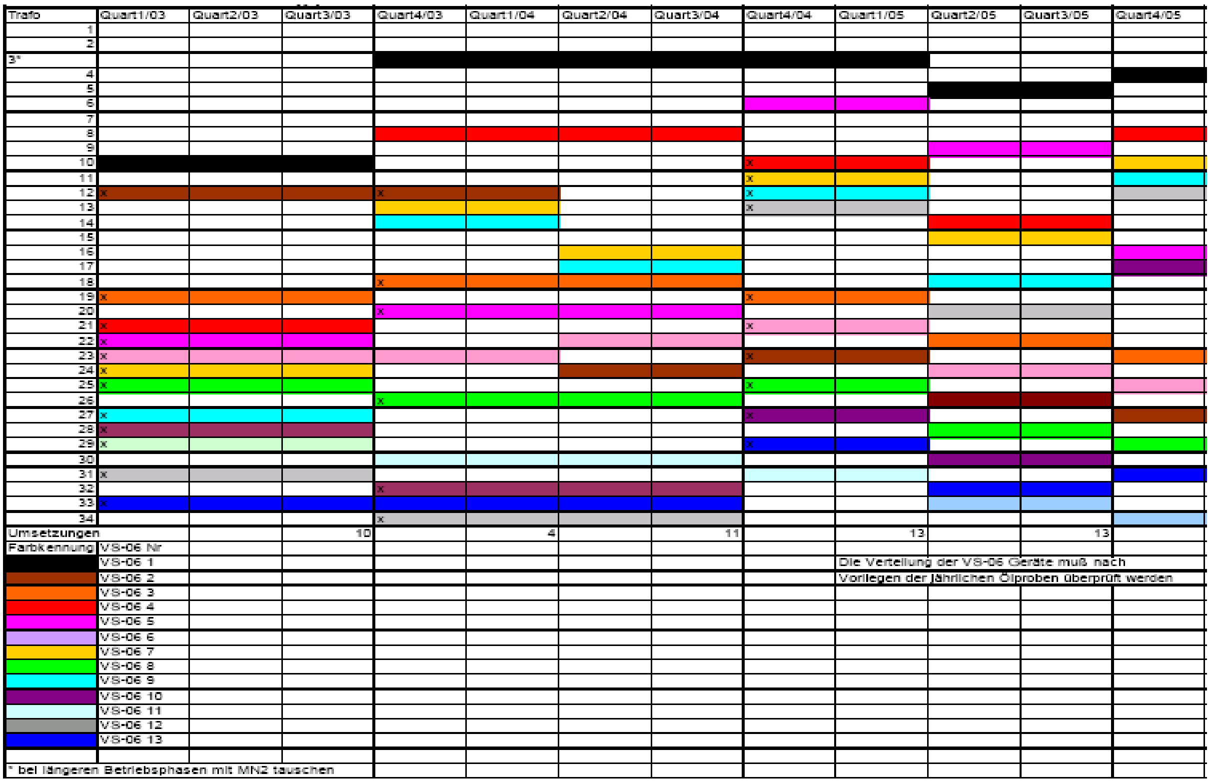

Figure6
Treatment plan

6. Treatment plan adjustment

Once the plan is fixed, regular control and adjustment of the systems purchased and installed is required. We recommend a six-month cycle for taking oil test and DGA samples to control data development. Complementary on-line monitoring systems are recommended, especially in critical cases, where e.g. transformers must be kept in service until replacement even with low life strength, or were conditions must be observed to note any deterioration of problematic conditions.

7. Examples

7.1 Aluminium smelter

- Start of procedure:	1999
- No. of transformers:	34
- Size of transformers	20-150 MVA
- Age	6-35 years
- Overall condition:	see Figure 7
- Task	Recovery and maintenance of acceptable data, followed by long term conservation, avoiding replacement even of the oldest units

History:
- 1999 starting with 10 combined gas conditioners and on-line dryer (ratio 1/3)
- 2001 all transformers have reached acceptable BDV and water content data
- 2002 start of long-term conservation management
- 2004/5 improvement of the conservation system at a ratio of ½ and upgrading of some younger transformers to closed design
- 2006 scheduling of regeneration for transformers with an acidity content above 0.1 and scheduling of an increased number of conservation systems. It is obvious from the oil tests and from a paper sample test that the depolimerization situation could have been kept at a highly stable level. The transformers not in acceptable situation in 1999 can be run at a highly satisfactory level of BDV and other key data. The evaluation of the data shows that apart from one or two transformers, the major part of the transformers can be kept in service for the next 5-6 years without restrictions.

Financial aspect:

In other words, a total re-investment of about 15 million Euros was postponed for more than 7 years for the time being, with an investment for conservation measures of less than 1 million Euros. Assuming an internal interest rate of 5%, 750 000€/year, the complete procedure was “in the pink” after less than 1.5 years, and this is for the capital costs saved only! Even if only the mid-term vision of plant life can be realized at that point, it will be possible to maintain an acceptable reinvestment cycle of one or two units per year.

Remark: In this case it is difficult to evaluate the long-term vision of that plant’s life. On the one hand, location together with the biggest roller plant in Europe and the excellent quality produced provide valid arguments for keeping the plant running. On the other hand, incalculable energy costs may force a shut down for that reason. The issue will keep coming up for decision at a 2-year cycle.

The conclusion is that investments must be kept to the lowest level possible, while the assets must be kept in a serviceable condition without technical or legal restrictions in order to avoid the risk of shutdown for technical reasons, even if management decides to keep on going. Consistent conservational management is the most cost effective way to solve that task.

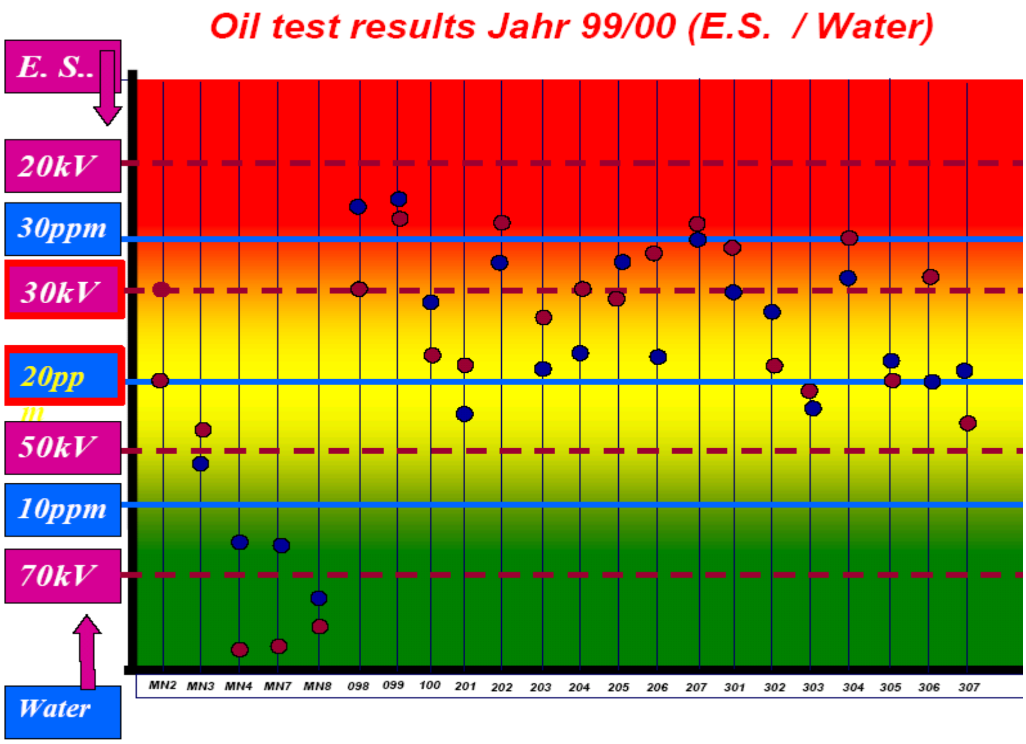

Figure 7
Condition of the BDV population and water in 1999

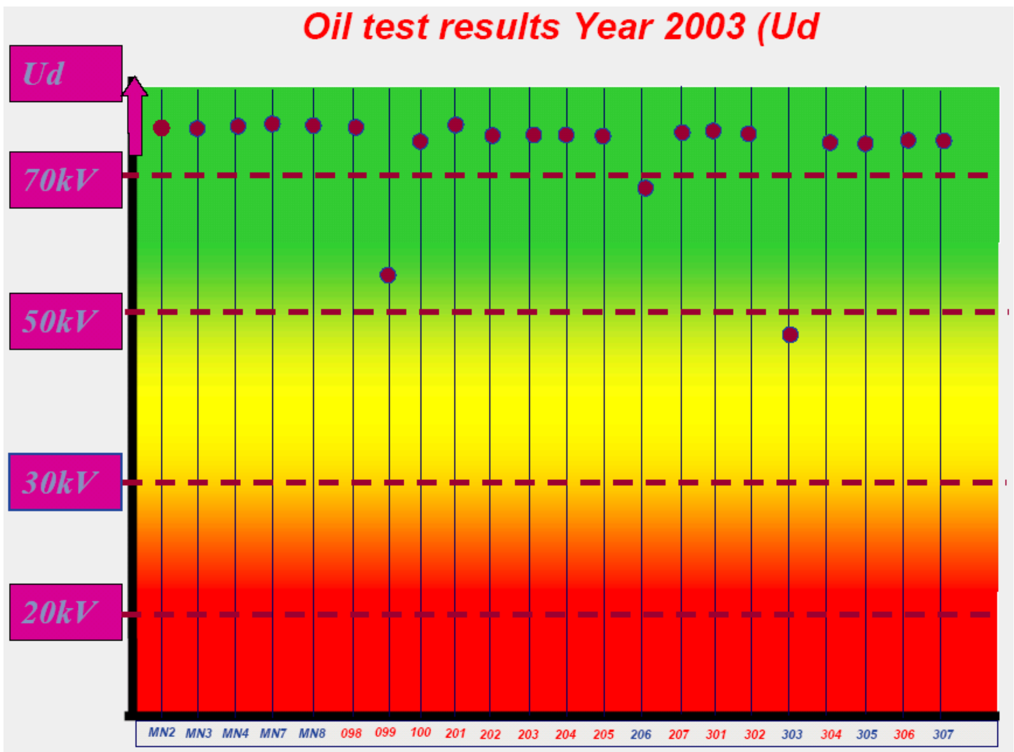

Figure 8
Condition of the BDV population for 2003

7.2. Industrial power plant

The initial condition is shown in Figure 3. The result is that one transformer has to be replaced as no life strength is left. For the two first transformers, which have low life strength, reliable service had to be ensured up to 2009, after which the units would have had to be shut down due to the boiler license running out. The first schedule was based on a shutdown of this unit in 2005.

The solution was for conservation of the units, with in the sequence as shown in Figure No. 8

Conservation plan						
Trafo	Sonst. Behan	Quart4/04	Quart1/05	Quart2/05	Quart3/05	Quart4/05
MTR1*						
MTR2*						
MTR3Nord	Regeneration				x	
MTR3Süd						
EigB3						
MTR4**						
EigB4						
Anfahr4						
Erreg.4						
10 MVA1		x				
10 MVA2						
20MVA TR3	Regeneration	x			x	
					x	
Umsetzungen				2		1
Farbkennung		Con Nr				
		unit1 1				
		unit2				
		unit 3				
		unit 4				
* Außer Betriebnahme 5/05						
**Ersatz geplant Nach Ersatz dieses Trafos ist die freiwerdende VS-06 je nach lage der DGA Result						

Quart1/06	Quart2/06	Quart3/06	Quart4/06	Quart1/07	Quart2/07	Quart3/07
		x				
		x				
		x				
	2		2		13	

Figure Nr.9
First conservation plan

The schedule now requires adoption since the transformers MTR1 and MTR2 will be kept in service till 2009.

7.3 Combined heating and generating plant

The overall plant is 30 years old and a shutdown was planned. In the meantime it was decided to keep the two blocks in service for at least ten more years.

Transformer	Result	DP	O2 consumption	Cp *	NZ	DGA	Particles
T01							
02							
01							
201							
101							
E-filter							
01							
Colour coding	LTSTR		Individual data evaluation				
	High		good				
	Reduced		fair				
	Strongly reduced		measures necessary				
	Already existing		urgent measures needed				
	To low		controlled shutdown				
	No data						

Figure 10
Table of transformer condition

Treatment plan						
Trafo	Sonst. Behan	Quart2/06	Quart3/06	Quart4/06	Quart1/07	Quart2/07
1.T01	Regeneration					
0T02	Regeneration					
2T01	Regeneration					
2T01						
1BT01						
E-Filter						
0BT01	Regeneration					
Anmerkung: der vorläufige E						
unter Berücksichtigung der vom Kunden erhobenen Daten Ölprüfungen etc. sollte halbjährlich im Ra						
der TPM	Betreuung	erfolgen				
					x	
Umsetzungen			2	2		1
Farbkennung		System				
		System 1				
		system 2				

Figure 11
Treatment plan

Conclusion

The above examples show how different solutions can be found for different circumstances to achieve the goals demanded by the customer.

In each case it is necessary to have precise knowledge of the useful life extension goal in order to work out technically and financially optimized results.

More than 12 years of experience in the field have given us wealth of know-how to support our customers in all aspects of the matter. The following issues need to be clearly understood:

- condition-based maintenance is possible only if there is reliable knowledge of the condition
- the maintenance targets must be defined prior to deciding about any measures
- there is an established procedure showing how best to adjust investment capital to meet the required targets
- TPM procedure is always a long term process.
- **spending money is not spoiling money!**