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PS 3: Network planning in the context of an ageing transformer fleet
On-line monitoring and diagnostics

Fingerprints for Condition Based Maintenance on Power Transformers

J. FUHR[1], L. EGGIMANN[1], M. ZBINDEN[1], Th. GRAENICHER[1], Th. HEIZMANN[1]
P. FEHLMANN[2], R. BRAEUNLICH[2], M. HAESSIG[3]
[1]BKW Energie AG, Bern
[2]FKH, High Voltage Engineering and Testing Commission, Zurich
[3]Axpo Power AG, Baden,
Switzerland

SUMMARY

Power transformers are expensive and strategically important components of any power generation and transmission system (high voltage and medium voltage). Their reliability is of paramount importance for the availability and profitable operation of such systems. A serious failure of a power transformer can generate not only substantial costs for repair, transport to the factory and financial losses due to power outage, but also consequential damage of other equipment in the substation. Therefore, the major power utilities as BKW Energie AG and Axpo Power AG have a clear incentive to assess the actual condition of all important transformers in their system, with the aim to minimize the risk of failures and to avoid forced outages. In case of a problem during the operation of a new or service-aged transformer (i.e. Buchholz alarm, differential protection, bushing explosion etc.), asset managers are challenged with the following questions: (1) what is the origin of the problem? (2) does the problem affect the reliable operation of the transformer? (3) is it possible to do a repair on-site or to replace with a new transformer? A reliable answer to these questions requires besides the record of the history of the operation and analysis of the alarm, the knowledge about the actual condition of the transformer. In modern systems, alarms and reactions of the protection devices are automatically recorded. Results of the acceptance test at the HV-laboratory of the manufacturer belong to the documentation of each transformer. However, a full set of reliable reference-fingerprints recorded on-site is seldom available for existing transformers. Reference-fingerprints are unique physical or chemical values or patterns which characterize a specific property of the complex HV-system in the original condition. Particular fingerprints of each transformer can be checked at any time on-site under off-line conditions. When deviations in specific fingerprints are detected during an on-site measurement after some incident in the network, a careful analysis must follow to identify the reason for changes in characteristic values to protect the transformer from an unexpected fatal failure in service.

KEYWORDS

Power transformer, life time limiting parameters, fingerprints, condition based maintenance

jitka.fuhraschwanden@bkw.ch

1. INTRODUCTION

The expected life time is 40 years by ordering new transformers. As discussed in the CIGRE Report [1] the failure rates of power transformers depend on the system voltage and are still very low. More than 50% of failures are caused by dielectric problems, i.e. due to increased electrical stress in the insulating system of power transformers. It has been shown in the past by post mortem analysis of failed transformer, that the increased electrical stress in many cases was caused by thermal or mechanical stresses alone or due to the unpredictable combination of several stresses during the operation of the transformer. The discovery of some internal problems in the insulating system of transformers is in many cases recognized by the increasing content of gases dissolved in oil or by spontaneous outage due to the protection devices. Such “problem transformers” were usually sent in the past directly to the manufacturer for further investigation and eventual repair. Presently, it may be difficult to deliver the “problem transformer” to the factory for two typical reasons: 1) the manufacturer of the specific transformer may not exist anymore, 2) transport to the transformer factory becomes expensive due to long distances. Furthermore, it has been shown on several examples, that the results of traditional off-line diagnostic methods like measurement of DC-resistance, voltage ratio etc. as summarized in [2] are not sufficient to assess the actual condition of all critical parts in a “problem transformer”.

Figure 1: Example of a modern transformer in the network (Phase shifting transformer, 400 MVA, 400/130/49 kV)

The main driving forces behind the efforts to develop and apply suitable diagnostic methods and tools for assessing the condition of large power transformers are both, the increasing age of the transformer population (the majority of large power transformers in Switzerland and most other countries in central Europe were installed in the 1960’s) and a competitive environment in the electric power industry which requires a reduction of operating and maintenance costs. The consequent application of advanced diagnostic methods to detect an incipient fault at an early stage will create substantial economic benefit. In particular, condition based maintenance (CBM) concepts look promising in this respect.

Already in the nineties, the Swiss power utilities funded a R&D project of FKH and the Swiss universities for the development of practice-suitable on-site diagnostics of transformers. These methods have evolved steadily over the past 20 years. The great success of the diagnostic activity in

Switzerland is attributed to the acquired experience, the efficiency of execution and the modern measurement systems available today.

This contribution presents the actual maintenance concept applied to all power transformers at BKW Energie AG, a major Swiss utility. The possibility to identify and to localize the origin of an alarm or of a spontaneous outage of a transformer is demonstrated applying consequently all available diagnostic methods (standard and advanced). An in-depth analysis of the diagnostic results delivers a reliable basis for an efficient asset strategy.

2. PARAMETRS INFLUENCING THE LIFETIME OF TRANSFORMERS

A reliable operation of a power transformer can only be ensured when the original characteristic properties, defined by the design, remain unchanged during the lifetime. Based on physics and on the design of a transformer, four main characteristic values can be defined. **Figure 2** summarizes both the characteristic values and the consequences when design limits are exceeded during operation.

Permissible stress	Consequences
1. Electrical field	Electrical breakdown
2. Magnetic field	Eddy currents-> hot spots
3. Mechanical forces	Noise, Deformation of windings
4. Thermal stress	Hot spots, accelerated aging of Insulation
First control during delivery tests in the factory	

Figure 2: Characteristic values of the transformer

2.1 Design, manufacturing, final assembly on-site

Design values may be affected and modified by poor quality of materials used in the manufacturing process. The complex system of a transformer requires a variety of conducting materials (core, windings and tank) and high quality insulating materials (oil and cellulose). Finally, the manufacturing and assembly process itself (including drying the active part, filling the oil etc.) can affect the final quality of the transformer. During the commissioning test in the HV-laboratory of the transformer factory, insufficient safety margins of the design, material problems or a poor manufacturing process will be recognize in most cases. It is therefore important, to specify all necessary tests in the tendering phase of a project.

Most large power transformers (> 100 MVA) units must be transported without oil due to weight limitations of the complete unit. Also high voltage bushings and external cooling units are normally dismounted for transport. In order to avoid uncontrolled outage during the start of operation of the new or repaired transformer on site, both the possible damage during the transport or poor final assembly work of bushings and oil filling can be recognized with suitable on-site diagnostic methods. In order to confirm an error free quality of the insulating system the partial discharge measurement during transformer excitation by an external voltage source is most meaningful, though it requires a considerable effort.

2.2 Operation of the transformer

The reliability of all HV-apparatus is strongly dependent on the ability of the insulating system to withstand the permanent electrical stress without any damage during the expected lifetime, of typically more than 40 years. During the service the HV insulating system is continuously aged, primarily through a combination of electrical, mechanical, thermal and chemical stresses. In power transformers, as a result of such "normal" aging process, mainly two types of weak regions are generated and randomly distributed in the insulating system: (1) weak regions with decreased dielectric strength normally causing PD-sources; (2) weak regions with permanent increased temperature normally causing hot spots.

Due to the sufficient safety factor used by the design of transformers, the complete electrical breakdown originated by different aging processes develops slowly and can in most cases be recognized by the analysis of the insulating oil including the examination of dielectric-chemical properties and the analysis of dissolved gases in oil (DGA) [3]. In case of increasing amount of fault gases the composition is analyzed and the risk of the defect is judged by specialists. The analysis of DGA may indicate hot spots, bad contacts, arcing and partial discharge activity. The DGA procedure is well established and the interpretation of results and recommended “limiting values” for maximum admissible decomposition of gas are described in IEC publications. Despite of existing international standards and extensive use of DGA since more than 50 years, the correct judgment of the severity of a fault is not always possible. Due to the fact, that DGA is an integral method, the localization of the fault inside the transformer is not possible. Therefore additional diagnostic methods must be used (conventional and advanced) to identify and localize the source of the fault gases dissolved in the insulating oil.

3. DEFINITION OF FINGERPRINTS

Reference fingerprints are unique physical or chemical values or patterns which characterize a specific property of the complex HV-system in the original new condition. Particular fingerprints of each transformer can be checked at any time on-site under off-line conditions. On-site measurements should be performed using exactly the same measuring method which was used for the reference fingerprint of the new transformer. When changes and deviations from the specific fingerprints are detected during on-site diagnosis, they must be analyzed carefully and differences must be explained to judge possible changes in the condition of the transformer and to protect the unit from an unexpected fatal failure in service.

3.1 Standard fingerprints

A survey of conventional diagnostic methods and their application to transformers and to other equipment for more than 50 years is given in [2]. In the past the common diagnostic practice for assessing the condition of power transformers showing some irregularities in DGA-results or causing an outage due to the alarm or protection system, was mainly based on the following procedures:

- Physical/chemical analysis of the oil delivers information about the general quality of insulating oil (for example low breakdown voltage due to the moisture or other aging products).
- Confirmation of DGA results by analysis of additional oil-samples with the aim to find the origin of gas development (hot spot, partial discharge).

- Chromatographic oil analysis (HPLC) to confirm a thermal problem in the paper insulation.
- Measurement of DC-resistance of windings to check the galvanic connections (comparison with design data).
- Measurement of voltage ratio to approve the conformity of windings (comparison with design data).
- Measurement of capacitance and dissipation factor of the main insulation at power frequency to detect changes in the main gap between windings (comparison with design data).
- Measurement of short circuit impedance to detect a deformation of windings after short circuit.
- Capacitance and dissipation factor of insulation of bushings to detect a seriously aged units (comparison with the first measurement on-site).

It has been shown on several examples, that the results of these traditional off-line diagnostic methods are not sufficient to assess the actual condition of all critical parts in a “problem transformer”. As already mentioned in chapter 2.2, the slowly developing internal defects in the insulating system of transformers are recognized by results of DGA [3, 4]. Spontaneous failures in the transformer or in the network lead in the most cases to a shutdown by the protection system like a Buchholz relay or differential protection. In both cases, the following questions are for the asset managers and maintenance engineers in the foreground: (1) what is the origin of the identified problem (increasing gas content or outage of the unit)? (2) is it a serious problem which will affect the reliable operation of the transformer? (3) is it possible to repair on-site or do we need to replace the transformer? To answer these questions in complete satisfaction, additional off line diagnostic methods defined as a “new fingerprints” have been developed and successfully applied since more than 20 years.

3.2 Advanced fingerprints

New advanced diagnostic techniques (new fingerprints) concentrate on measurable quantities for both: check-up of characteristic values (see **Figure 2**) which are directly related to the main stress parameters and on comparison with typical failure identifications which were recognized in the past. An overview of new fingerprints is presented in **Figure 3**. A detailed description of advanced diagnostic methods is given in several publications [5, 6].

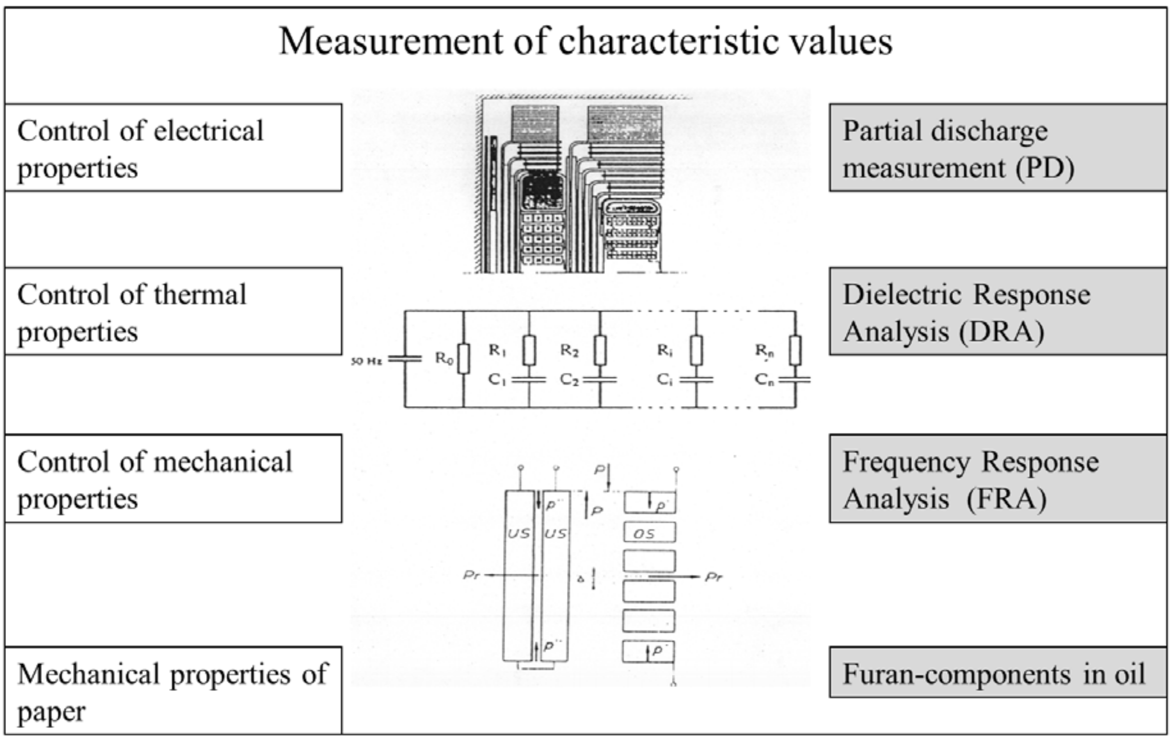


Figure 3: Definition of new fingerprints

3.2.1 Electrical assessment of insulation condition by PD-measurements

Defects caused by electrical stress, i.e. weak regions in the insulating system, are theoretically detectable by sensitive on-site partial discharge (PD) measurement. In Switzerland on-site partial discharge (PD) measurements has been applied on more than 300 transformer units in the power range of 10 to 500 MVA and voltage range of 110 kV to 380 kV during the last 20 years.

High sensitivity (< 50 pC) is reached by using an external voltage source and an advanced PD-measuring system, which allows an efficient discrimination between PD-signals and background noise in the substation (mainly due to corona discharges synchronized to 50/60 Hz) [6, 7]. Induced voltage is generated by electronic frequency converters or diesel generators and step-up transformers. In power station the excitation voltage may be delivered by the power station generator in isolated operation. Beside the delivery of the excitation voltage, a special attention must be given to the capacitive current which may exceed the inductive magnetisation current considerably (especially valid for new transformers which are equipped with high permeability cores). In these cases inductive compensation is advisable in order to reduce the capacitive current of the power supply. An overview about available voltage sources for on-site PD-measurements is shown in **Figure 4**.

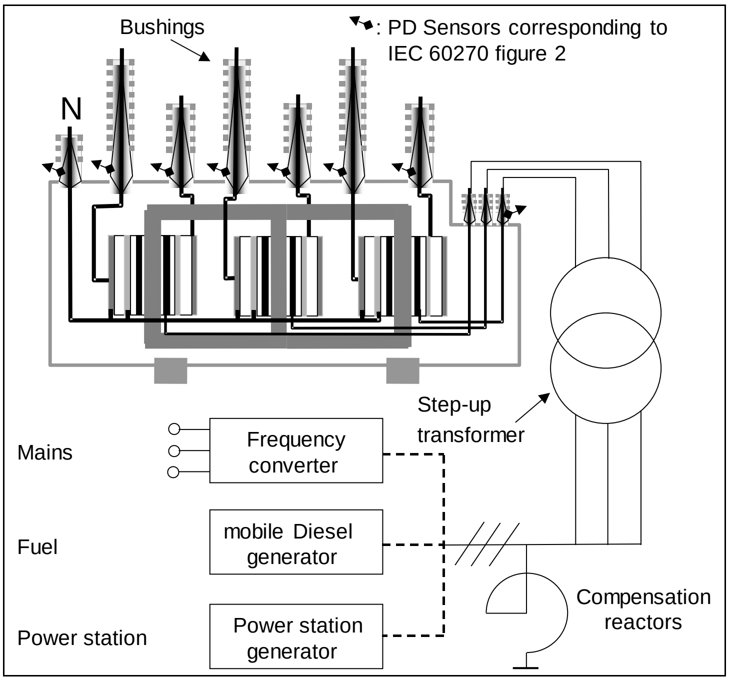
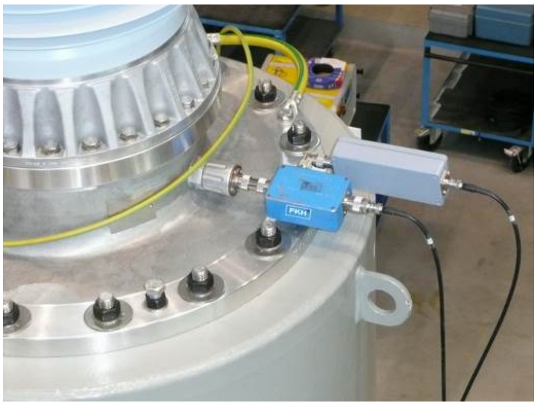


Figure 4: Example of different external voltage sources for on-site PD-measurements

The PD signal coupling is achieved be passive high frequency current transformers (HF-CT) connected to bushing taps. If bushing tap-off connectors are not available, coupling capacitors are placed next to the bushing. A compact disposition of the PD measuring circuit is mandatory, in order to prevent a disadvantageous increase of background noise due to the loop formed by the bushing and the coupling capacitor (see **Figure 5**).

PD signals are measured with oscilloscope, spectrum analyser and as well with a computer based phase-resolved PD-acquisition system (**see Figure 6**). Before each measurement a sensitivity check i.e. calibration of all transformer bushings and a cross-sensitivity analysis between bushings is performed. The Calibrating signal is applied at the high voltage terminal and responses are taken at measuring taps of all bushing. In extension to the evaluation of apparent charge values an analysis of frequency and time domain characteristics of the calibrating signal is performed. This knowledge is important for later localization of the detected partial discharge impulses during the test. An example of calibrating matrix is given in **Table 1.** The measuring centre frequency and bandwidth were 1.2 MHz / 0.3 MHz for all phases and 3.4 MHz / 0.3 MHz for the primary neutral terminal. The listed values in PC show the displayed charge when 1000 pC were injected into the terminals 1W or 2U respectively.



Installation of high frequency transformers and divider secondary capacitor on a bushing with measuring tap.

Example for the use of coupling capacitors where bushing connectors without measuring taps were installed at the low voltage terminals.

Figure 5: Example of connections of coupling units for PD-measurements

	1U	1V	1W	1N	2U	2V	2W
1W	44 pC	65 pC	1000 pC	332 pC	99 pC	120 pC	104 pC
2U	158 pC	230 pC	140 pC	42 pC	1000 pC	668 pC	619 pC

Table 1: Extract of a calibrating matrix (for charge injection on two terminals 1W and 2U) for a three phase substation transformer: 60 MVA, 220 kV / 10 kV, connection scheme YNd5.

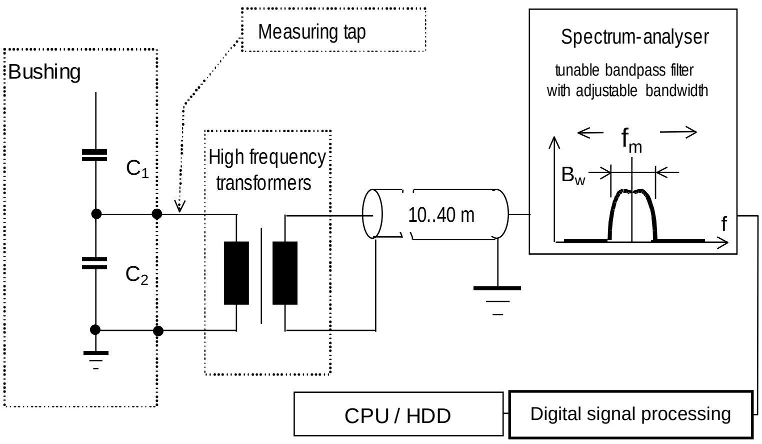
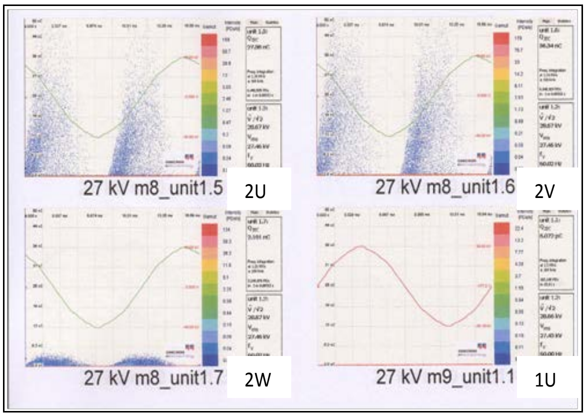


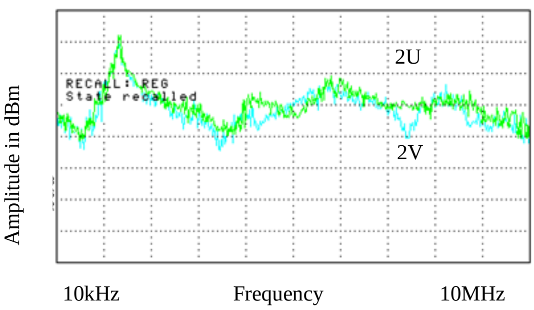
Figure 6a: Schema of measuring circuit for the PD measurement on a transformer bushing tap

Figure 6b: Example of measuring equipment for on-site PD measurements

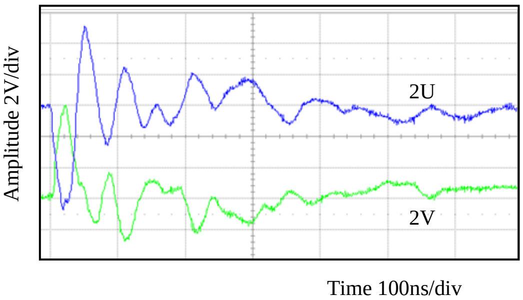
The result of a PD-measurement using a phase resolving PD-acquisition system is a three-dimensional pattern (phase angle, discharge magnitude and number of events), which can be considered as a fingerprint of the PD-activity of a specific defect in any HV-insulation system. Each specific PD-defect, such as a tip electrode or voids in solid material, has their specific PD-pattern describing the physical processes of the discharge [8]. Recording of real PD-signals in frequency and time domain and comparison with the responses of the transformer network to the calibrating impulse injected at bushings delivers first indication about the possible location of the PD-source. For the detailed localisation of the detected PD-sources additional methods like measurement of acoustical and UHF-signals must be applied. Typical results obtained during on-site PD-measurements are shown in **Figure 7**.



PD-Pattern



Frequency spectra of two PD-current impulses



PD-current impulses in time domain

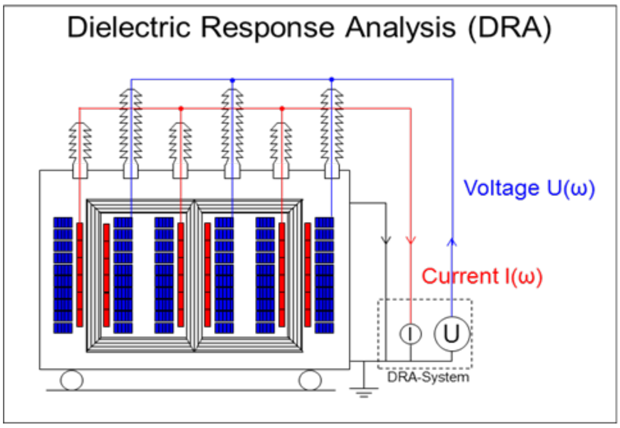
Figure 7: Typical results of PD-measurements

Beside the information obtained from results as shown in **Figure 7**, the following additional parameters and tests can improve the reliability of the PD diagnosis significantly:

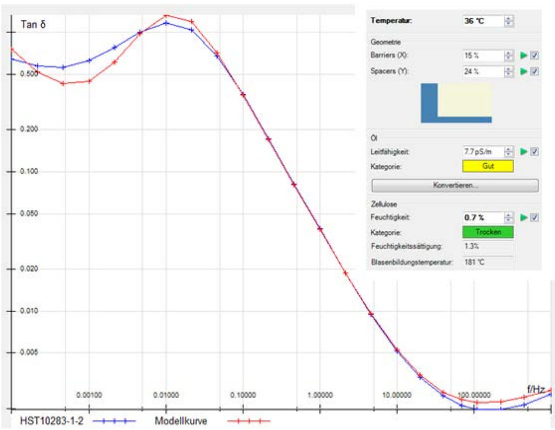
- comparison of impulse shape in time domain
- comparison of shape of frequency spectra
- repetition rate of PD-impulses
- phase and amplitude distribution of PD-impulses
- inception and extinction of the PD-activity
- variations of PD-pattern with changes in the test voltage
- variations PD-pattern during a extended test period
- comparizon of the apparant charge intensity distribution over all bushing taps

3.2.2 Check of thermal properties by Dielectric Response Analysis (DRA)

Decomposition of cellulose insulation caused by thermal stress and leading to water generation, is detectable by measurement of polarization effects in the insulating system using dielectric response analysis (DRA). DRA can be performed either in time domain by measurement of polarization and depolarization currents (PDC) or in frequency domain by judgment of dielectric response from the complex impedance using frequency domain spectroscopy (FDS) [9]. When the geometry of the transformer insulating system is known, the measured values in the time domain (PDC) or in the frequency domain (FDS) can be calculated from the dielectric properties (the frequency dependant permittivity and conductivity) of the oil and cellulose parts. For the determination of the humidity or polar aging products in the transformer insulating system, the dielectric response of the specific transformer is simulated with well defined dielectric properties of oil impregnated pressboard (different moisture content). From the comparison of measured and simulated dielectric responses (curve fitting), the amount of polar components can be estimated [7]. The schema of measuring circuit for DRA-measurements and typical results are shown in **Figure 8**.



Schema of the DRA-measuring circuit

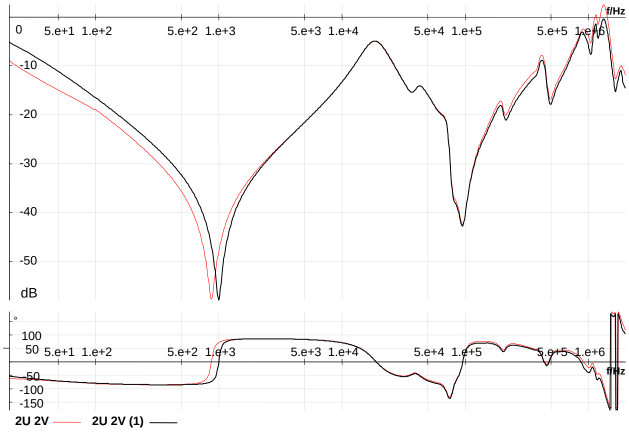


Measured and simulated loss factor tan δ in function of the applied voltage

Figure 8: Test circuit and typical results of DRA measurements

3.2.3 Check of mechanical properties by Frequency Response Analysis (FRA)

Defects caused by mechanical stress, i.e. deformations and movement of windings, are theoretically detectable by measurement of the transfer function T of the RLCM network (R=resistance, L=inductance, C=capacitance, M=mutual inductance). Transfer function T is defined as a ratio of "response-signal" to the "reference-signal" evaluated in amplitude and phase. Depending on the equipment used for the frequency response analysis (FRA) measurement, the transfer function is measured as the ratio of voltage signals, current signals, voltage to current signals (impedance) or current to voltage signals (admittance). In practice, by using swept frequency method, the measured transfer function T is evaluated as the voltage ratio. The output of a swept sinusoidal signal (10 V peak to peak, 10 Hz –> 10 MHz, swept frequency method) and one measuring input (reference) of the analyzer are connected via screened coaxial cables to one terminal (e.g. HV-bushing). The third lead (response) of the analyzer is connected either to the other end of the winding (e.g. neutral terminal) or to the LV-winding [10]. The connection of leads of measuring equipment to bushings and typical results are shown in **Figure 9**. The presented example shows a comparison between an FRA measurement in the factory and the repetition after installation in a power station. No relevant differences are visible. The shift in the first resonance near 1 kHz stems from the different magnetization state of the core.



Example of the amplitude of the transferfunction as ratio of voltage (measurement from terminal 2Uu to 2V).

Example of a FRA measurement at low voltage terminals of a power station transformer (measurement from terminal 2U to 2V)

Figure 9: Test circuit and typical result for an FRA measurement, on a new 3-phase power station transformer 65 / 9 kV, 26 MVA, connection scheme YNd5

4. FINGERPRINTS FOR CONDITION BASED MAINTANACE (CMB)

The goal of a BKW Energie AG maintenance strategy is to have a complete record of Fingerprints for all transformers in the network to have a solid basis for reliable judgment of the serious problem after alarm or outage of the transformer.

4.1 Reference fingerprints

To ensure an excellent quality of the transformer, one needs to start already during the procurement phase. For new transformers beside the recommendations in international Standards, both the special tests like lightning test with positive and negative polarity and heat run test, as well as requirement like no measurable PD at nominal voltage (fingerprint) are demanded to confirm the correct design and precise manufacturing and final assembly processes in the transformer factory. After the successful delivery test in the HV-laboratory, beside the standard fingerprints (see chapter 3.1), frequency response analysis (FRA) is performed to record the original mechanical properties (fingerprint) of the new transformer before the transport.

After the final assembly on site for each new transformer "**reference fingerprints"** are recorded as follows:

- DC-Winding resistance (comparison with calculated and measured values in the factory)
- Voltage ratio (comparison with calculated and measured values in the factory)
- Dielectric-chemical properties of the oil (including oil conductivity measurement)
- Frequency response analysis measurement (comparison with the results in the factory)
- Dielectric response analysis measurement (reference Fingerprint)
- Partial discharge measurement up to 1.2 of nominal voltage (comparison with the results in the factory)
- Capacitance and dissipation factor measurement of assembled bushings (reference Fingerprint)
- Dissolved Gas Analysis (DGA) is carried out as a reference fingerprint after ca. 3 month of operation of the transformer

For service aged transformers the standards and new fingerprints are recorded under following conditions:

- Capacitance and dissipation factor measurement of assembled bushings (repetitive measurement recommended all 5 years or less). Using the advantage of the disconnected transformer from the network reference fingerprints are performed and partly compared with the results of the delivery test.
- In case of the oil leakiness of the tank a major revision of the active part of the transformer is carried out. In this case the first reference fingerprints are recorded before the revision to make sure, that there are no serious changes in the characteristic values of the transformer. After the revision the second reference fingerprints are recorded as a basis for the future condition based maintenance.
- In case of increased content of dissolved gases in oil (DGA results) the defect specific diagnostic methods are used to find the origin of the problem. If DGA results indicate a PD-activity in the insulating system, on-site PD-measurements are carried out. If there is an assumption about hot spot in the insulating system, dependence on the load and eventually measurement of dielectric response may help to identify the problem.
- In case of spontaneous outage of the transformer by the protection system (Buchholz relay or differential protection) both the standard and advanced fingerprints are recorded and results are compared with previous measurements if available.

4.2 Practical example

The problem transformer shown in **Figure 10** is a phase sifting transformer (400 MVA, 400/220/49 kV) consisting of main and regulating transformer in separate tanks. Both transformers are equipped with on line gas monitoring system (Hydran). The standard and advanced fingerprints have been recorded in 2003.

Figure 10: Phase shifting transformer (400 MVA, 400/220/49 kV)

In year 2012 during the switching of the tap changer from the step position 28 to step position 27 under load, there was a Buchholz alarm from the regulating unit. Further voltage regulation back to the step position 28 and to the step position 29 caused tripping of both transformers (main and regulating unit) by Buchholz relay.

Directly after the disconnection of the transformer unit oil probe from the regulation transformer was investigated using portable Kelman system for on-site DGA (see **Table 2**). There is an increase of Hydrogen, Ethylene and Acetylene. Ethylene and Acetylene are typical gases for an electrical arc in oil. Due to the constant amount of the Carbon monoxide, there is obviously no paper involved in the incident. The screening of standard fingerprint did not show any deviations. Based on these results and having in mind, that limits of dissolved gas components were not reached yet (besides Ethylene and Acetylene which are typical for spontaneous incident), it was decided to continue the service of the transformer by the permanent survey of the gas content behavior during the operation using the gas monitoring system. Additionally it was recommended to keep the transformer unit in the tap changer position 29 until further investigations would be possible. The results of the gas monitoring system over the time period before and after the incident are shown in **Figure 11.** Both the spontaneous increase of the gas content after the incident and the expected decrease of dissolved gases during the operation of the regulating unit was confirmed by the gas monitor (see **Figure 11).**

Gas-components	Hydran 08.1.2012 (Monitoring)	Hydran 14.2.2012 (Monitoring)	Actual [ppm] 14.2.2012 (Kelmann)	Limits [ppm]
Hydrogen [H_2]	(80)*	(220)*	106	200
Methane [CH_4]			25	50
Ethane [C_2H_6]			3	15
Ethylene [C_2H_4]			99	60
Acetylene [C_2H_2]			55	15
Carbon monoxide [CO]			293	1000
Carbon dioxide [CO_2]			2017	10 000

Table 2: Results of the DGA after the tripping of the tarnsformer unit
( )* total amount of gas recorded by Hydran including mostly
$H_2 + CO + C_2H_2 + C_2H_4$

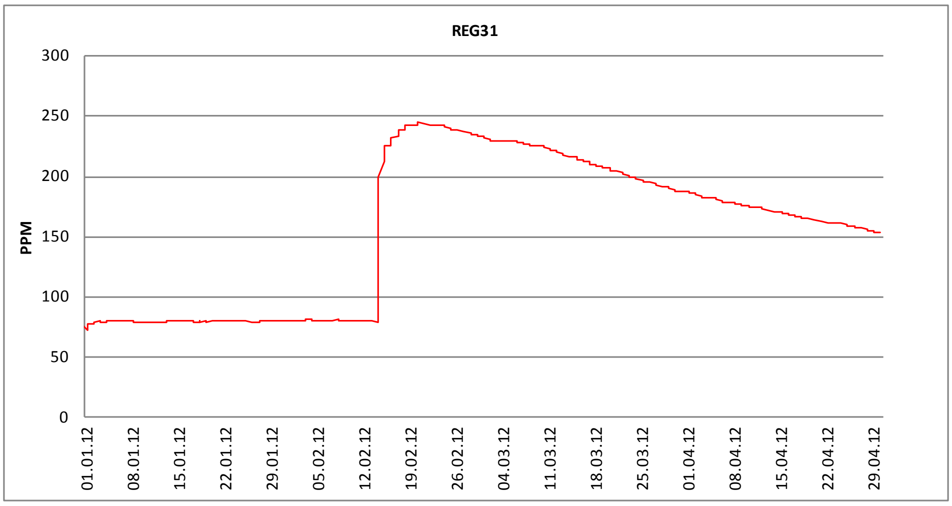


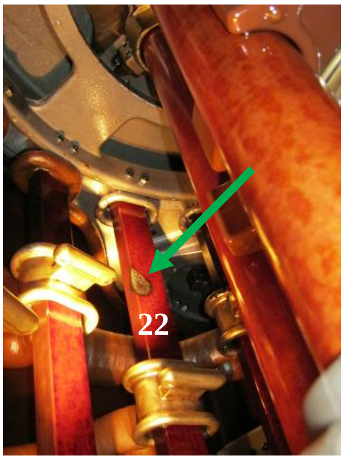
Figure 11: Gas content development during the period before and after the incident (Hydran)

To confirm, that the spontaneous increase of gases was caused by a single event (electrical arc in oil), it was decided to repeat the switching sequence and to perform the dissolved gas in Oil analysis (DGA) before and directly after the on load switching. The results are summarized in **Table 3.**

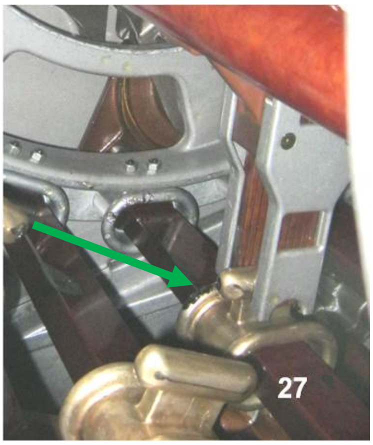
The amount of Ethylene and Acetylene (typical gases for electrical arc in oil) exceeds the recommended limits already before the switching test. Due to the demand of the energy transfer in the substation, it was not possible to keep the transformer unit in the tap position 29 as requested. After the switching test (tap positions 31->30->31->32) there is an additional increase of these gases (see **Table 3**). Based on these result it was decided to remove the oil and to perform a visual control of the tap changer on site (manhole on the tank). As shown in **Figure 12**, there are high current marks at contacts 29 and 27 and the on the insulating rod between contacts on the tap changer selector of the phase W. Such high current marks are caused by the changing tap selector contacts under load. During normal operation of the on load tap changer (OLTC) the switching of tap selector contacts must be current free. The reason for switching tap selector contacts under load was a mechanical damage of the OLTC-unit itself as shown in **Figure 13.**

Gas-components	**Before switching [ppm]** 26.4.2012 (FKH)	**After switching [ppm]** 30.4.2012 (FKH)	**Hydran** 26.4.2012 (Monitoring)	**Limits [ppm]**
Hydrogen [H_2]	95	92	(164)*	200
Methane [CH_4]	29	35		50
Ethane [C_2H_6]	2	3		15
Ethylene [C_2H_4]	130	160		60
Acetylene [C_2H_2]	77	120		15
Carbon monoxide [CO]	340	370		1000
Carbon dioxide [CO_2]	1900	2300		10 000

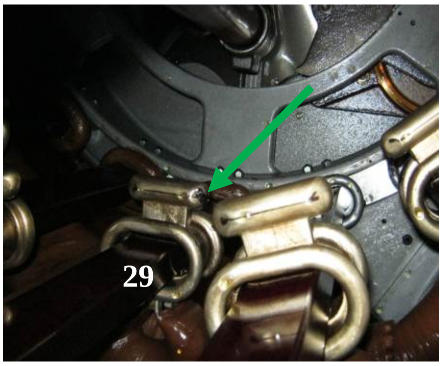
Table 3: Results of the DGA (FKH laboratory) before and after the switching test
( )* total amount of gas recorded by Hydran including mostly
$H_2 + CO + C_2H_2 + C_2H_4$



Carbonised track on the insulating rod



High current marks at contact 27, phase W



High current marks at contact 29, phase W

Figure 12: High current marks at contacts of the tap selector

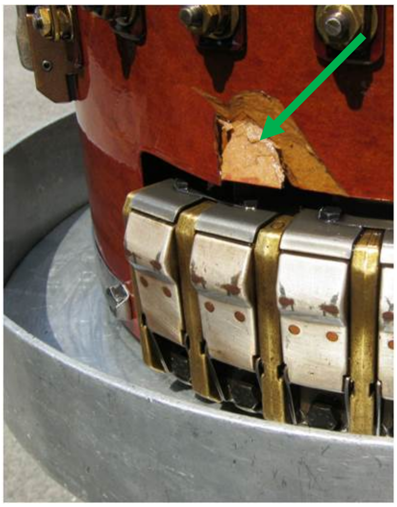


Figure 13: Mechanical damage on the OLTC-unit

Based on these results of the visual inspection on-sit It was decided to perform a detailed investigation and repair of the on-load tap changer in the repair shop at Axpo Power AG. The visual inspection of the active part of the regulating transformer did not show any damage. After the repair of the OLTC and re-assembly of the regulating transformer on-site, both standard and advanced fingerprints including PD-measurement with external voltage source were carried out. All results confirmed a good quality of the repaired transformer.

5. CONCLUSIONS

Results of on-site diagnostics methods deliver together with the knowledge of operation conditions and of the design of the transformer an important basis for the reliable judgment of the condition of both, service aged transformers and transformers after an outage. The consequent application of both the standard and advanced off line diagnostics methods on-site delivers important data for an efficient and cost optimized service concept for transformers. In this contribution the actual service concept applied for all power transformers by major utilities as BKW Energie AG and Axpo Power AG were discussed. The efficiency of the service concept was demonstrated on practical example.

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