Design Review as the First Step of Transformer Life Assessment

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Abstract

This paper presents some practical guidelines to implement the transformer design review methodology in order to assess sensitive points in design locations, which would be responsible for occurrence of possible critical condition and failure.

Introduction

Design Review is a critical step in a Transformer Life Management program. Responding to the needs of utilities, CIGRE SC12 developed several documents including "Guidelines for conducting design reviews for transformers," "Users Specification," "Static Electrification" (how to consider design features to prevent static electrification phenomenon) and "Short circuit Performance" (how to estimate mechanical safety margin) that contain recommendations on how to approach a new design. The WG 12.18 Life Management [1] has highlighted the Design Review as a diagnostic tool.

The life of a transformer may be introduced as the change of its condition with time under impact of thermal, electric, electromagnetic and electrodynamics stresses, as well as under the impact of various contamination and aging processes. The withstand strength of the transformer will naturally decrease over its life due to various ageing processes (normal ageing), but may deteriorate faster than normal under the influence of contaminants or destructive processes.
A failure occurs when the withstand strength of the transformer with respect to one of its key properties is exceeded by operating stresses. Therefore Identification the locations with minimum safety margin would be critical to anticipate likely problems
Experience has shown that Life assessment program, namely the scope of tests and their interpretation depend on two design features:

- Sensitive points of the core and coil assembly and transformer components and their likely failure modes
- Variability of the design (diagnostic accessibility)

Design review is a key procedure to determine a transformer functional failure model, which would answer the questions:
What defects and faults can be expected in particular transformer components related to the particular functional subsystem?
What is the possible path of defect evolution into the malfunction, and then failure?
Failure model allows Minimizing diagnostic program and Selecting the most economic way, e.g. comprehensive oil analysis, to identify equipment, which really need in special attention

Specific subjects of design review

Design Review is a vital means to gain an insight into transformer structural features, to understand function and structure of transformer components and to determine sensitive parts of components and their expected failure modes. Particular attention should be paid to the following:

- Identification of the transformer composition and functional purpose of the main subsystems, namely: *Electromagnetic circuit; Current carrying circuit; Dielectric integrity; Mechanical structure; Cooling; Bushings (design and arrangement); OLTC (design and arrangement); Oil preservation and expansion system; Protection and Monitoring arrangements*
- Identification of diagnostic related parameters from a fingerprint factory test.
- Estimation of dielectric safety margin and sensitivity of "weak" points to normal deterioration.
- Estimation of mechanical margin of windings in real operating conditions (magnitude of through fault current).
- Estimation of thermal –cooling performance, especially winding temperature profile and relevant characteristics of coolers
- Design review and assessing the "sensitive points" and possible failure modes in the bushings and OLTC considering conditions of their operation, service experience and especially failure analysis of particular style number.
- Assessment of design factors influencing diagnostic effectiveness (Design Diagnostic Accessibility)

Transformer design performance

Core

Design review includes typically core configuration and assembly, steel laminations; join pattern, insulation, clamping, grounding, and basic parameters

The maximum flux density in any part of the magnetic circuit should not attain a value that causes saturation under any of the specified voltage and tap position including permissible oversaturation 110% Temperature rise of the core should be a subject of particular considerations. Under normal operation the temperature of any part of the core in contact with oil should not exceed 120 and 130C under permissible overexcitation. In some old design core temperature could be up to 160-170C [2]

Sometimes core temperature can initiate generation of stray gases including hydrogen **[2]**

Case1 Generation of CO, CO2 (Fig.1)and H_2 (20-30 ppm) in the bank of single-phase transformers 500kV just after commissioning during 18 months of operation at 50% load. Evolution of stray gas from Nytro-10GBN oil under effect of temperature has been suggested Estimated core temperature 90-95^{0}C

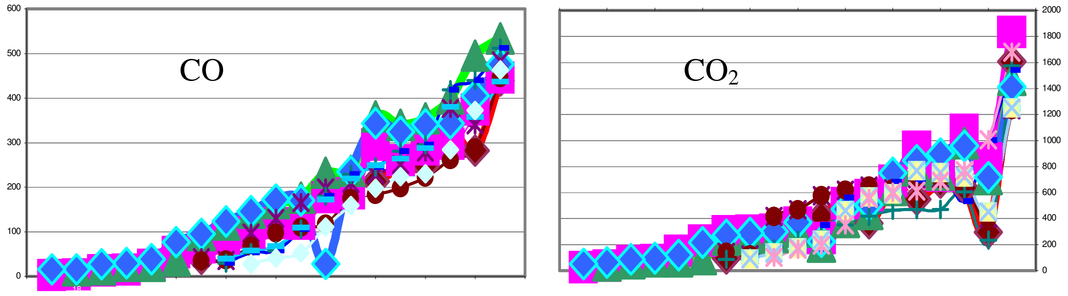

Fig.1 Evolution of CO and CO2 gases in the 500 kV transformers

Study of the oil temperature response revealed notable trend of gas evolution under effect of operating temperature, especially at presence of stainless steel

Table1 Effect of temperature and steel on Gas evolution from Nytro-10GBN oil at 100^0C

	H_2 ppm			CO_2 ppm			CO ppm		
	Time, hour								
	0	24	72	0	24	72	0	24	72
Blank oil	0	29	92	143	178	674	0	34	151
Oil with present of steel lamination pattern	0	30	120	143	223	782	0	127	200

Tests performed in the ZTZ – Service Material Lab

Overheated parts of the core being in contact with cellulosic material can cause intensive pyrolysis and furans generation

Case 2

Condition assessment of 250 MVA, 15/400 kV shown symptoms of insulation heating: concentration of 2FAL= 19.2 ppm, concentrations of CO= 899 and CO2 =1034 ppm'
However, there was no reason to expect any significant aging of winding insulation since the estimated hot-spot temperature during actual operation was less than 85°C.
Measurements of DP revealed that the maximum aging factor was only $\eta = {DP_0}/{DP} - 1 = 0.54$.
Visual examination of core and coil revealed that high furfural concentration was caused by local overheating of the magnetic core and the insulation sheet adjacent to the yoke due to short-term overexcitation in service.

Windings

Design review includes windings arrangement, construction, conductor configuration and cooling arrangement.
Winding arrangement and especially presence of grounded electrostatic shields influences on effectiveness of diagnostic characteristics (PF, capacitance, leakage impedance, etc.). Winding construction, e.g. disc (continuous, interleaving, intershielded); helical, layer should be considered in detail

Major insulation arrangement

Major insulation review allows to recognize determinant insulation spaces, their oil-barrier/paper composition and possible diagnostic accessibility

Diagnostic related parameters from a fingerprint factory test

Valuable diagnostic information may be obtained from design calculation and factory tests

Volts per turn

This is a fundamental design parameter, which allow to determine magnetic flux density, number of turns in each winding and relevant voltage between turns, coils, and taps
Flux density may be estimated from a simple equation

$$B = \frac{Volts\_per\_Turn}{4.44 \bullet f \bullet S}$$

where f is power frequency and S- is cross sectional area of magnetic circuit

Turn Ratio

This is well known routine method however there is still some misunderstanding in its application and interpretation. Some utilities consider test accuracy on the level of 1-2%. According to IEEE the accuracy of the method shall allow to obtain the difference between calculated and measured data by 0.5%. That is good enough to verify e.g. correctness of taps connection (1.25-1.5%).

However it is important to verify the difference between the number of tap's turns by one turn. It is possible by means measurement turn ratio between Tap winding and the winding, which have a comparable number of turns, e.g. LV winding.

In case of HV winding of ENV transformer the difference between phases by half of turn may results in significant rise of losses. HV winding may consist of 500-1000 turns and accuracy of the test to determine such a difference should be less than 0.1-0.05%. Such accuracy can be achieved by means of the test with opposite connection of parallel parts of the HV winding

No-load loss and magnetizing current

Measurement of no-load losses/ phase and no-load current at LV (110/320/380 V) is very effective tool to detect the difference in magnetic resistance of similar parts of the magnetic circuit and verify the condition of electromagnetic system in case of abnormality symptoms occurrence.

On-load current consists of inductive component (magnetizing current itself), resistive and capacitive components (Fig 2). The latter introduces value of turn-to-turn capacitance and the only dielectric tool to detect deterioration of conductor insulation

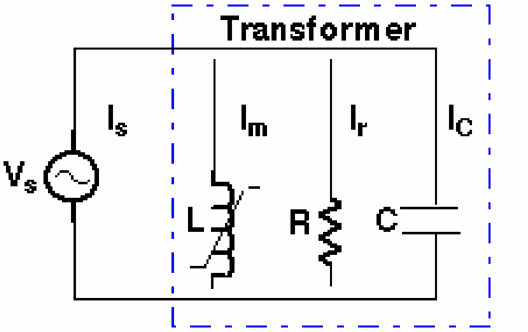

Fig.2 Components of no-load current

Stray loss component as a diagnostic tool

No-load losses value consists of the Joule loss, stray loss component within the winding and stray loss outside the winding. The latter could be a tool to identify some problems (e.g. gassing) that associated with occurrence loops for circulating current, whereas the winding stray loss component could very effective and likely the only tool to detect short-circuit between parallel strands.

$$P_{OL} = \Sigma(I_i^2 \cdot R_i) + P_{Str.W} + P_{StrOutside}$$

Stray loss component outside the winding could be measured on the transformer without tank

Losses above guaranteed values are not only economic but also reliability related technical factor. Additional losses in one of the winding can result in its faster deterioration. Therefore distribution of losses between phases should be recommended as a routine test as well as a part of predictive maintenance program.

Winding resistance

Electrical circuit for winding resistance test could be typically introduced as four components: windings itself, leads, unmovable contacts of leads and bushings, and moveable contacts of LTC (fig 3)

Information about values of each component would be valuable contribution to the benchmark data

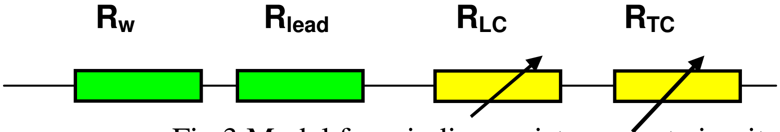

Fig.3 Model for winding resistance test circuit

R_W and **R_{lead}** can change only in case of irreversible damage and the main objectives of the preventive tests should be possible inadequate contact performance (change of **R_{LC}**) or deterioration of (LTC) contacts (change of **R_{TC}**). However sometimes a special test circuit is required to identify a change of comparatively low resistance.

Leakage Impedance

In fact reactive component of the leakage impedance, namely leakage reactance can serve as an effective characteristic of winding movement.

Local deformation of winding results in some reduction of its diameter; and some change of leakage reactance occurs in the results of the winding diameter reduction only. Thus, the relative change in leakage reactance can serve as a rate of the radial buckling of the winding.

Leakage reactance in % is expressed by the well-known Rogowsky formula:

$$X_{sc} = \frac{24.8 I_r \cdot n \cdot \rho \cdot \Sigma RD}{E \cdot H \cdot 10^4}$$

where ΣRD in cm^2 is defined as follows (see Figure)

$$\Sigma RD = \frac{b_1 R_1}{3} + c \cdot R_{12} + \frac{b_2 \cdot R_2}{3}$$

I_r is the rated current

n is the number of turns

E is the volts-per-turn

ρ -Rogowsky coefficient

$H = (H_1 + H_2)/2$ is the average height of the windings.

The relative change in leakage reactance can be expressed as:

$$\varepsilon = \frac{X^I - X}{X} \cong G \cdot \Delta x$$

Winding capacitance

Capacitance of particular insulation space (between the windings, winding-shield, winding-ground, etc.) could be valuable and often underused parameter.

Together with leakage reactance, capacitance could serve as a quantitative characteristic of winding geometry. Test results with and without oil could advise share of oil in the particular insulation space and evaluate possible sensitivity of dielectric characteristics to insulation contamination, including insulation in LTC compartments

Estimation of Dielectric safety margin. Sensitivity to deterioration

The basic approach and methodology

- Verification if the test voltages comply with Principle of Insulation Coordination and International Specifications
- Calculation of distribution of the test impulse voltage across the minor and major insulation
- Calculations and in-depth analysis of electrical field considering all modes of test-voltages
- Calculation and imaging of electrical field
- Calculation of safety margin on the basis of assessment of dielectric strength of particular questionable areas including dielectric strength across the barriers, lath, etc. Incipient PD voltage is typically considered as characteristic of dielectric strength.

The following factors are considered to determine dielectric strength:

- Field intensity in the oil duct (under and over winding)
- Duct dimension;
- Insulation thickness on the electrodes (coil, capacitive ring, etc.);
- Shape of electrodes and corresponding degree of field nonuniformity;
- Barriers and insulation collars arrangement, and their dimensions;
- Voltage distribution across the winding including axial component of field intensity;
- Difference in dielectric strength of oil duct between barriers and ducts over/under winding;
- Insulation processing level;
- Possible tolerance.

Permissible field intensity values are based on fundamental investigation of transformer models and service experience t

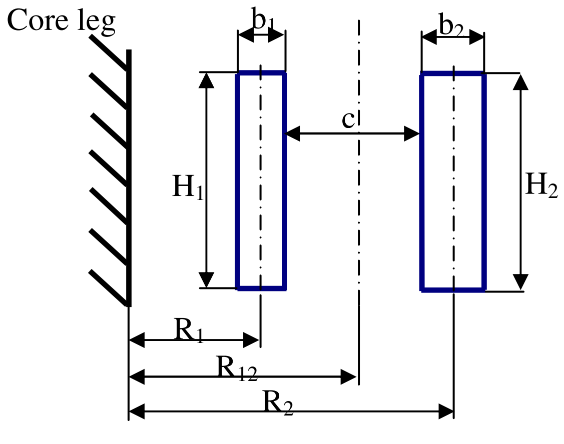

Figure 4
Geometrical Parameters of Windings

Insulation coordination

Insulation of a transformer is subjected to exposure of lighting impulse and switching surge including sometimes very fast frequency overvoltage. On the other hand a determinant voltage could be different for different insulation parts.
Basic Impulse Level (BIL) is often insufficient characteristic of short duration dielectric withstand strength and estimation of margin under effect both of full wave impulse and switching surge would be critical

Case3.

Design review of the autotransformer 240/110 kV (Table 2)
Estimation of safety margin in autotransformer shown in the critical insulation space between series and common windings a positive margin under effect of Full wave impulse and negative margin under effect of switching surge

Table 2 Estimation of safety margin in the autotransformer 240/110 kV .
Oil axial duct under HV in the space between series-common windings

Safety margin , %	Determinant Voltage
-8	Induced 1 min (non specified)
-7	Switching impulse 540 kV (non specified
11	Full wave 650kV (specified)

It's important to emphasize that aging of oil and deposit of sludge in the locations of high field intensity can effect significantly of the impulse strength. The minimum breakdown voltage at switching surges may decrease approximately by 15% after aging. Increasing the concentration of particles from 50^{3} up to 160in cm^{-3} may decrease switching surge breakdown voltage additionally by 10%.
Therefore margin less than 20% should be a subject of considerations

Determination of effective set of diagnostic actions

Insulation Design review could be a key tool to determine diagnostic priority.

Case 4.

Design review of Shunt reactors 60 MVAR, 400√3 kV (Table 3)

A family of shunt reactors has been reviewed in order to develop failure model and main objectives for diagnostic program. It was found that insulation performance is practically determined by impulse withstand strength and occurrence of surface discharge across the winding insulation. Apparently contamination of surface with conductive particles reduces the value of critical field intensity. Accordingly particles in oil monitoring was advised as a main diagnostic procedure

Table 3 Estimation of dielectric safety margin in the shunt reactor

Component	Safety margin	
	Switching surge	Lighting impulse
Coil-to-coil	5.8	1.55
Turn-to-turn	10.8	6.6
Oil-barrier major insulation	2.6	1.75
Along the winding	1.27	1.17

Case 5

Design review of Generator Step Up transformers 417 MVA, 24/787√3 kV

Construction review and estimation of insulation safety margin revealed space “bushing installation-tank” as a sensitive location, which practically determines operative reliability of the insulation assembly.

Withstand strength of this space depends predominantly on the condition of oil and also on surface conductivity of pressboard barriers.

Thus potential reduction of dielectric strength of oil from particles, water including bound water absorbed with oil aging products (especially surface active substances); from any possible source of bubble evolution, as well as contamination of barriers surface appeared to be main objectives of diagnostic program

Table 4 Estimation of dielectric safety margin in the 417 MVA.24/750 kV GSU transformer

Insulation Component	Safety margin	
	Under effect of Switching surge	Under effect of the full wave Lighting impulse
HV turn-to-turn	4.8	1.75
HV coil-to-coil	3.5	1.41
Between HV-LV windings	1.6	1.57
HV-winding- tank	2.2	2.36
HV bushing-tank	1.2	1.26

Clarification of insulation failure reasons

Experience has shown that insulation construction review and estimation of safety margin might be very valuable procedures of failure investigation. Irrespective of likely cause of failure origin: moisture contamination, static electrification, etc. margin consideration may advise most appropriate corrective actions.

Case 6

Design Review of 650 MVA345kV, shell type GSU transformer

Transformer exhibited a number of insulation failures, which were associated with static electrification phenomenon.

The discharges were concentrated near the 45-degree area where discharges have originated in most of the known static electrification cases. However, the main damage was on the surface of an angle that goes around the insulation on the first coil at the 345 kV end of the winding
The insulation construction review (Fig.5) shown that failed location is distinguished itself by minimum margin and switching surge is likely determinant voltage. Assuming switching surge magnitude as 870 kV and average field intensity in the space HV-LV E_{av}=8.7 kV/mm we found that effective field intensity could be E_{ef}=10.5-11.5 kV/mm. Assuming permissible field intensity (on the basis of Partial Discharge incipient voltage) E_{per} =8.9-9.4 kV/mm we found that safety margin of the space under effect of switching surge could be in some cases less than 1.It means that this insulation space could be sensitive to any deterioration caused as by static electrification as well as also by particles contamination or bubbles occurrence (for instance presence of residual air after oil refilling)

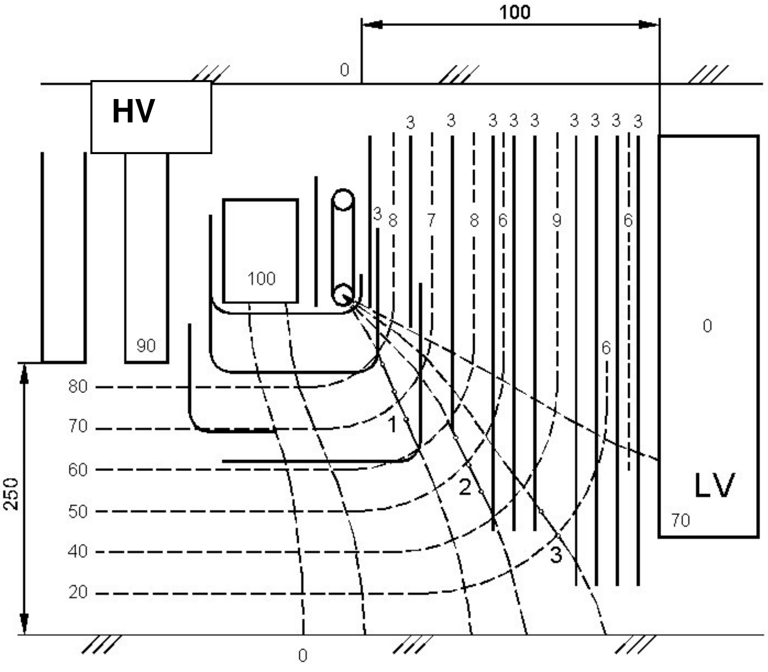

Fig 5

Sensitivity to deterioration

It’s well known that contamination if insulation with water, particles, and bubbles causes a high Risk of Critical Defective Condition in Dielectric system.
It was discussed at the TechCon 2002 [3] that

- Presence of Bubbles in Oil May Cause Occurrence of Critical PD Even at Rated Voltage.
- Sudden Ingress of Free Water May Cause Failure of the Transformer Immediately.
- Increasing the Relative Oil Saturation in Presence of Particles (Fibers) Results in Sharp Reduction of Dielectric Strength of Oil.

However sensitivity of particular insulation design to deterioration of dielectric withstand strength is very different.
For example the typical subject of concern is attributed to possible evolution of moisture vapor bubbles out of heated conductor insulation during overloading

Bubbling form heated winding. So what

Dangerous effect of bubble in oil lies in likely PD occurrence at rated voltage.
In accordance with Pashen’s low breakdown voltage of air bubble e.g. d=0.4 mm in diameter is 0.8-1.0 kV
Bubble voltage (U_b) depends on coil-to coil voltage (U_{coil}), oil duct thickness (S) and turn insulation thickness (Δ

$$U_b \frac{d}{d+\Delta_p \frac{\varepsilon_{air}}{\varepsilon_p}+S\frac{\varepsilon_{air}}{\varepsilon_{oil}}}\cdot U_{coil}$$

Assuming dielectric permittivity of oil $\varepsilon_{oil}=2.2$, air $\varepsilon_{air}=1$, and paper $\varepsilon_p=3.8$ we have that PD in bubble can occur if coil-to coil voltage averages 5-10 kV.
Therefore bubble evolution can pose hazard practically only for interleaving winding and also for some tap and layer type windings

Estimation of Mechanical safety margin

The basic approach and methodology

- Calculation of through fault current
- Assessment of short circuit performance

The guide used for assessment of short circuit performance was basically suggested by Dr. Lazarev (VIT Zaporozhye) and comprises the following calculations:

- electrodynamic stability of the windings under the action of radial electromagnetic forces;
- conductors strength in bending with axial and radial electromagnetic forces;
- critical tilting forces of windings conductors;
- rigidity factors of windings under axial deformations;
- rigidity factors of pressing structure and reduced masses of yoke beams;
- electrodynamic stability of windings at axial oscillations, caused by the action of axial electromagnetic forces.

In order to estimate radial stability of particular winding the following algorithm has been advised:
Definition of permissible and critical stresses
Calculation of actual stresses, namely

- Average stress from radial forces, MPa
- Residual (plastic) radial displacement, mm
- Bending moment due to axial forces, N•m
- Bending moment due to radial forces, N•m
- The maximum axial force, kN

Determination of effective set of maintenance actions

Case 7

Operation conditions and Design review of Generator Step Up transformers
417 MVA, 24/787√3 kV

The problem with short-circuit events has been recognized as the most critical one due to the unusual concentration of power on the 750 kV bus bars [4]. The three likely events with GSU transformers that were considered and evaluated were: single-phase short circuit of the 750 kV side, three-phase short circuit on the 24 kV side, and an internal breakdown of high-voltage winding-to-ground insulation. The value of a short-circuit current ratio exceeding 75% of the normal ratio (6.75·0.75=5.06) has been defined as a "critical event". Such event requires assessment of the possible winding distortion. In the case of a catastrophic event with internal short-circuit "Line 750 kV - ground" (e.g., bushing failure, breakdown of high-voltage winding-to-tank insulation) the current can exceed 30 kA. It could result in an arc that generates up to 135 MJ/s with a corresponding generation of gas up to 75 m^3/s. It is obvious that such an event must be prevented by all means.

Table 5 Through Fault Current in GSU Transformers

Event	**Through-Fault Current**				
	HV		**LV**		**Normal**
	kA	**Ratio**	**kA**	**Ratio**	**Ratio**
Single-phase short-circuit on 750 kV	3.21	3.51	68.43	3.94-	
Three-phase short-circuit on 24 kV	5.28	5.76	173.3	5.76	6.75
Internal short circuit 750 kV to ground	30.5				

Estimation of the mechanical margin (Table 6) shown as the "weak point" radial distortion of the low-voltage (LV) winding external layer in the case of a short-circuit fault on the 24 kV side. A single-phase short-circuit on the 750 kV side does not significantly affect the mechanical behavior of the windings; however, the electromagnetic stress can cause the movement of the magnetic shields and the appearance of localized hot-spots.

Table 6 Mechanical Strength Margin of GSU Transformer Windings Under Conditions of 3-Phase Short Circuit on 24-kV Side

Winding	**Margin**	
	Radial Stress Stability Margin	**Axial and Radial Stress Strength Margin**
LV inner layer	2.9 - 5.8	2.26
LV outer layer	0.9 - 1.7*	1.26
HV	-	1.27

* considering release of pressure

Assessment of Thermal performance

Typically a manufacturer calculates mean temperature rise of a coil (winding) above mean rise temperature of oil considering the heat flux density, real cooling surface, thermal conductivity of insulation, ratio of winding radial dimension and cooling duct, and temperature drop in insulation

Some coils (sections)), which due to additional heat by stray losses and/or poor cooling have temperatures higher that the mean conductor temperature or so called the hot spot temperature.
The hot spot temperature rise is typically introduced as sum of the hot spot temperature rise of the coils above oil and the top oil temperature rise above ambient
The mean temperature rise of oil above ambient is considered to be equal mean rise temperature of oil outside the windings or in the cooler
Accordingly the drop of temperature across the winding is considered to be equal to the drop of temperature across the cooler and the top oil temperature is taken as the maximum oil temperature
However the difference in temperature between top and bottom of winding could be essentially greater than drop of temperature in the cooler.
IEC advises that ”top –oil temperature, as measured during a temperature rise test, differs from the temperature of the oil leaving the winding… In fact, the top oil is a mixture of various flows which have circulated along and/or outside the various windings”. IEC suggests also that oil temperature in a vertical channel close to winding can be substantially higher than top oil temperature but can not be determined by means of oil temperature measurement outside the windings.
The more realistic model for temperature distribution is shown if the Fig.6.
ZTZ-Service developed a new method of calculation of winding temperature profile
The method is based on the fundamental physical principles of hydrodynamics and heat exchanges considering natural and forced (mixed) fluid convection along the vertical cooling channels and dependence of oil thermalphysic parameters on temperature
Axial rise of oil temperature is calculated considering coefficient of moving pressure gradient, coefficient of axial rise of oil temperature, and constant of oil flow friction

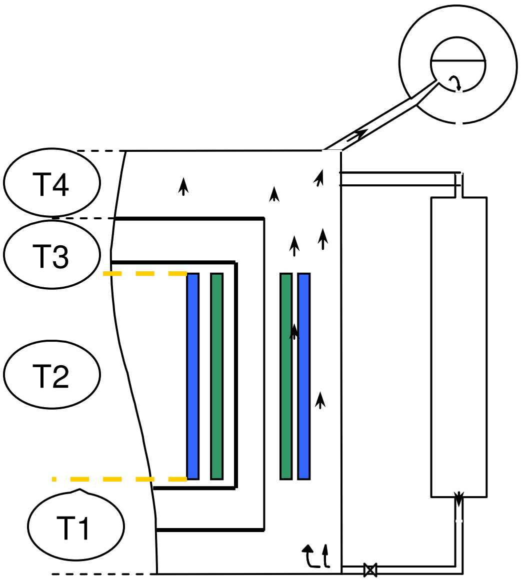

Fig.6 Temperature distribution across a transformer
Level T1-oil from the cooler heated somewhat by the bottom yoke of the core
Level T2—mean temperature of the oil in the axial cooling channels being heated by winding losses
Level T3-oil leaving winding (maximum temperature)
Level T4-mixture of the oil le4aving winding and outside oil (top oil temperature)

Case 8

Design review of 730 MVA, 420 kV transformer

Estimation of temperature profile revealed a high temperature of the top coils of LV winding and permitted the following conclusions
Drop of temperature in the cooling vertical channels could be substantially higher than drop of temperature in the coolers (tank) . Accordingly top oil temperature is a substantially lower temperature of oil leaving winding
Values of the mean rise winding temperature above the air meet practically specified quantity (65 ^{0}C). However, mean rise temperature does not show a real picture of the windings heating especially if radial cooling ducts are diminished. Fig.9 shows that assuming rated radial ducts 14 coils of the LV$_2$ winding may have rise of temperature above 65 ^{0}C. In the case of diminished ducts more than 50 coils may have temperature rise above 65 ^{0}C and 4 coils –above 80 ^{0}C. Difference insulation temperature predetermines nonuniform decomposition of insulation. Amount of heated insulation that subjected to accelerate wear was estimated as less than 2 % of total mass of conductor's insulation.

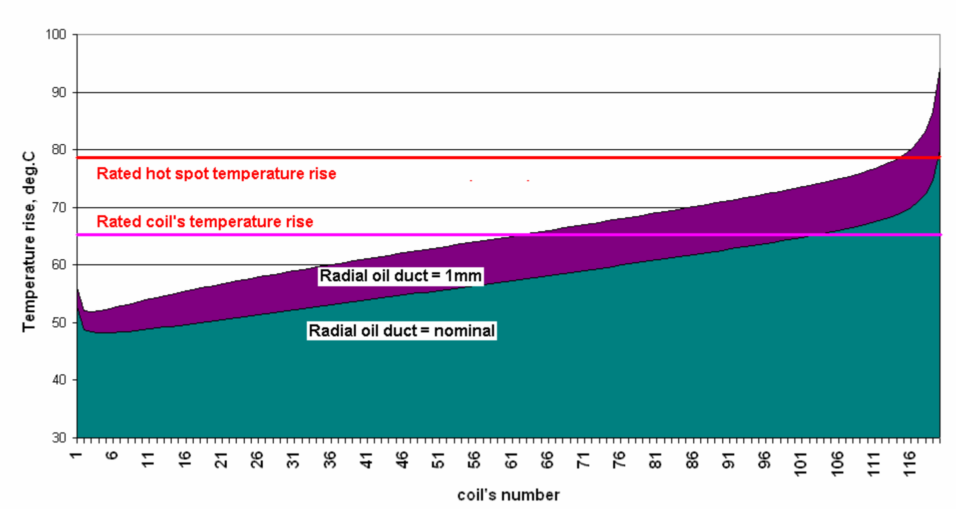

Fig 7 Temperature profile of the LV winding (temperature rise above air)

Determination of "sensitive" points in OLTC design

Case 9

Overheating the shunt contacts of the diverter switch

The problems with 1600 A LTC have been definitely localized on the diverter switch, due to overheating the shunt contacts. The overheating was caused presumably through limited movement of the contacts of the OLTC over time (which had operated about 5000 times in 20 years). However limited movement relates as to diverter switch as well as to selecting and reversing switch contacts but condition of those contacts are extremely different (Fig 8

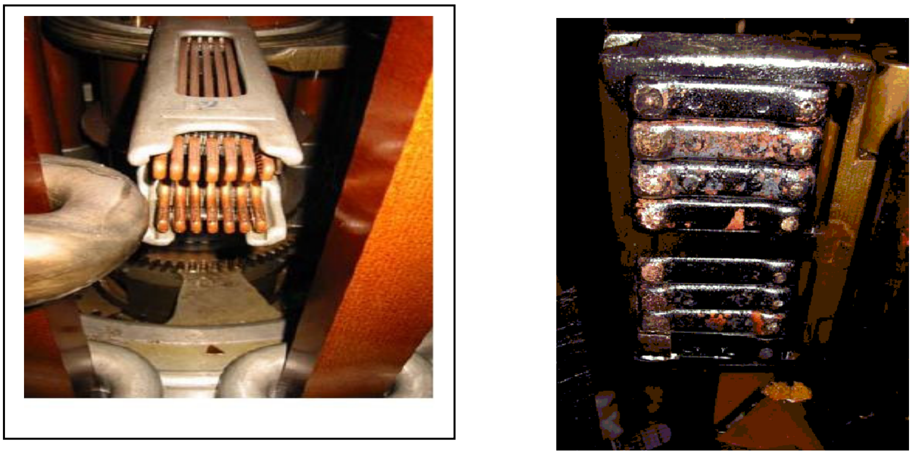

Fig.8 Comparative condition of the selector switch and diverter switch contacts

Overheating and cooking of contacts with limited movement is a typical and well known failure mode of closed heavy current contact pieces in insulating oil.
In most cases reversing contacts that subjected to minimum movement have been suffered.
One can admit that difference in contacts design and particularly the difference in resistance and temperature of the contacts could be the main factor.

According to IEC 60214 contact temperature rise limits shall be 20K above oil when carrying 1.2 times the maximum rated through current
Design review of the LTC shown that the diverter switch shunt contacts have a maximum temperature and could be recognized as the weak point, which need in special attention

Table 7 Temperature rise tests of the LTC 2000 and 1600 A

		Temperature rise ^{0}C	
		Current 2000 A	Current 2400 A
Diverter switch	Main fixed contact upper	12	**17**
	Moving main contact	13.5	**18**
	Main fixed contact (lower contact lamination)	12	**16.7**
Tap selector of the LTC 2000A	Moving contacts	10	12
	Connecting contact	10	13
OLTC 1600 A	shunt contact of diverter switch	**15,7** °C at 1600 A.	***21C*** *(estimated for 1920 A)*

Design Diagnostic Accessibility

The presence of an internally grounded electrostatic shield between the windings reduces the sensitivity of measurements of the dielectric characteristics of solid insulation

Case 10
Shunt reactor 400√3 kV

Internal grounding the electrostatic shield shunted the major insulation space

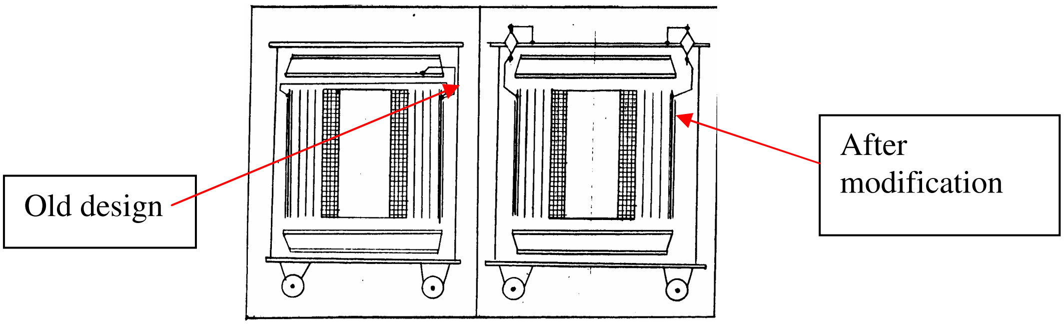

Fig.9

The electrostatic shields were modified (see Figure 11) to provide the possibility of directly testing the dielectric characteristics of the oil-barrier space and PD testing at an operational voltage using a balance circuit.

- The presence of a waterproof dielectric (e.g. synthetic resin bonded paper or cast resin cylinder) in the oil barrier space prevents the estimation of water content in pressboard barriers through measurement of dielectric characteristics.
- The presence of a dielectric material with inherent elevated dielectric losses in the winding support insulation (neutral coils) and tapping lead cleat bars masks the change in the condition of the main insulation

Case 11
Shunt reactors 787√3kV
The present insulation design was found to include winding support insulation materials with inherently high dielectric losses (tan δ = 1.5-2.0 % at 50-60°C). Sensitivity to the detection of insulation contamination using measurements of the dielectric characteristics is therefore reduced. Correspondingly, the initial values of tan δ in the overall tests of the winding insulation were 1.0-1.7% at50-60°C. After modification of the electrostatic shields grounding similar to Fig. Direct measurement of PF of oil-barrier space had shown values of 0.15-0.2% or less.

Internal connection of tertiary windings and neutral ends of star windings prevents the evaluation of the condition of inter-phase insulation and comparison between phases
The presence of resistors in the circuit of the core causes distortion of dielectric characteristics (increasing power factor/tan delta of LV-core; HV-core; and decreasing power factor/tan delta of HV-LV

Case 12
Review the 630 MVA, 347/20 kV3-phases GSU transformer

Table 8 Effect of resistors in the grounding circuit on tanδ of insulation spaces

Core Grounding	**Insulation Space**					
	LV-CORE		**HV-TANK**		**HV-LV**	
	tanδ[%]	**C [pF]**	**tanδ [%]**	**C [pF]**	**tanδ [%]**	**C[pF]**
Through resistor	3.95	43835	0.22	7498	0.1	10098
Directly	0.22	43835	0.23	7505	0.15	10098

Grounding the magnetic core through direct contact, e.g. frames (core clamps) with the tank particularly and internal grounding the core generally, make difficult the identification and location of thermal faults caused by circulation currents.
The sensitivity of detection of hoop buckling by leakage reactance or capacitive measurements reduces with increasing voltage rating of the transformer (increasing inter-winding gap).Accordingly there is a low sensitivity of leakage reactance to deformation of layer type winding

Case 13
Review of comparative sensitivity of leakage impedance to winding buckling

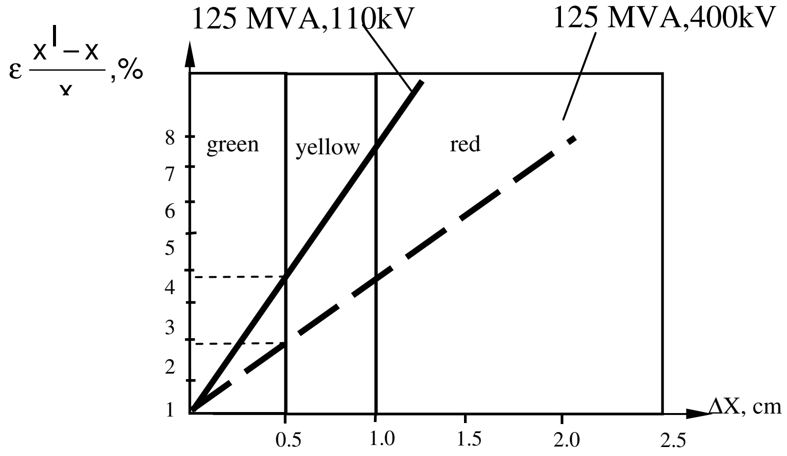

Fig.11

It was found that notable buckling of LV winding results in change of leakage inductance by 4% in the transformer 110 kV and only in 2.6% in the unit 400 kV

- Effect of oil dielectric parameters on the oil-barrier structure masks real condition of solid insulation.

For example, in the oil barriers structure with relative share of fluid 70% increase of the water content in the barriers from 0.5% up to 1.5% results in increase of power factor of interwinding space only up to 0.3%.

- Contamination of the barriers leads to reduction of PF of interwinding space measured by UST circuit due to appearance of leakage current to ground.
- Due to significant operating dielectric stresses, the cellulose insulation works as an effective filter trying to strain out the polar oil-aging products and conductive particles. A large barrier surface also promotes gas absorption from the oil. There is an effect of gas concentration reduction when a transformer is re-energized after being in a cold condition.

Conclusion

The scope of tests and their interpretation depend on sensitive points of components, their expected failure modes and on variability of the design (diagnostic accessibility). Design review should be a critical step of condition assessment. Implementation of the test program, which is focused on a detection of possible defects, allows ranking the remaining life of a transformer or a group of transformers

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