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TRANSFORMER LIFE MANAGEMENT CONSIDERATIONS

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Transformers Condition, Failure Model, Life Shorten Factors,
Failures Analysis, Tests Effectiveness, On-Line Monitoring,
Condition Monitoring, Life Extension

INTRODUCTION

I n the 1990's there has been considerable interest in the subject of life management. The term "Life Management" has been used to describe a scope of operations including: specification, procurement, design and manufacture, maintenance, condition monitoring and assessment, rehabilitation, refurbishment, life extension, etc.
Responding to the needs of utilities, CIGRE SC-12 formed a new WG 12.18 "Life Management" and defined its terms of reference as follows:
"Using the existing body of knowledge and technologies, and looking into the future, to develop guidelines with the objective to manage the life of transformers, to reduce failures, and to extend the reliable life of transformers in order to produce a reliable supply of electricity at least possible costs".
The work has been divided among three Task Forces, namely:

- TF1 - General Knowledge and Theoretical issues;
- TF2 - Diagnostic and Monitoring Techniques;
- TF3 - Operation of Transformers.

The objective of all three Task Forces is to provide practical tools which may be used by all those charged with managing transformer assets[1].
The overall goal of Task Force 1 is to provide a practical Guide to the main types of failures suffered by transformers and means of managing these to optimize asset life and usability. The cornerstone of the Guide would be identifying Cards for each important failure type, describing all relevant aspects.
The primary work of TF2 is to report on methods and methodology used by experts, as well as on effectiveness of diagnostic test procedures.
The initial work of Tf3 is focused on collection and assessment of effectiveness of the various methods that have been used to treat transformers after a problem has been diagnosed and on methods of Life Extension.
The primary results of the works will be discussed at the Sydney Transformer Colloquium.
The goal of this paper is to discuss some life management considerations looking into the future on the base of current activity of WG12.18 and ZTZ-Service Co. experiences.

CONDITIONS OF TRANSFORMERS IN THE COURSE OF LIFE-CYCLE

Condition is the state of health of an equipment. The normal (permissible) condition can be disturbed by defect appearance (abnormal reversible-mode deterioration) and / or by fault occurrence (abnormal irreversible deterioration of destructive mode).
One can define (Figure 1):

- defect-free condition (on the base of physical consideration);
- permissible (specified) condition after manufacturing;
- permissible (by Installation Guide) condition prior to commissioning;
- permissible (by Maintenance Guide) condition in service;
- defective condition;

- faulty condition;
- failed condition.

FIGURE 1

As a deterioration process is practically inevitable phenomenon, the normal condition of equipment in operation is some conventional state which is characterized capability of the transformer still to withstand operational stresses.
Defective condition is the state that causes significant decreasing the withstand strength of a transformer and results in fault occurrence and followed it failure.
Example of defective condition is water contamination, when the critical states can occur :
- Emergence of elevated (over 40 - 50%) relative oil saturation and relevant rapid reduction in dielectric strength followed by partial discharge, creeping discharge or other type of fault.
- Formation of water vapor bubbles in oil due to pushing vapor out of cellulose after rapidly increasing temperature of winding during emergency overload.

Determination of the normal and abnormal conditions, description of characteristics of defective/faulty condition in interconnection with characteristics of defect/fault on the one hand, and with functional usability of an equipment on the other hand, are life management task of priority.

FUNCTIONAL FAILURE MODEL

Functional serviceability of a transformer is determined by its three key properties:
- dielectric withstand strength;
- mechanical withstand strength;
- integrity of current-carrying circuit.

There are also other important functions:
- proper heat transferring from transformer's components into cooling media;
- transfer load excluding overheating phenomena, appearance of localized hot-spot, gassing, excessive vibration and sound, etc.

However, sometimes a transformer can keep serviceability being in fault condition (overheating, gassing, etc.), but it will immediately fail if short-circuit or open-circuit happen.

Transformer failure model has to answer the questions:
- what kind of defects/faults can be expected in a particular transformer components?
- what is interconnection between probable defect/fault and real operational stresses on the one hand and withstand strength on the other hand?
- what is the probable path of developing a defect into fault then to malfunction and failure occurrence?

In the Table I and II one can see some "rough material" for the failure-model definition: typical defects, fault and failure-modes in the "core and coil assembly" of a transformer and in oil-impregnated condenser-type bushing[2]. However, for particular transformer/bushing design and on particular operation conditions a more realistic model can be composed.
A failure model shall identify the goal of "Diagnostic and Monitoring System" (What to look for?).

ASSESSMENT OF THE FACTORS THAT SHORTEN THE LIFE

"Life Management" art must consider and monitor the factors that shorten the life. Knowledge of nature and substantially of the life limiting factors, which cause degradation of dielectric system, are of particular importance.

Paper degradation

Transformer insulation decomposition treated as a chemical phenomenon.
Mechanisms of paper degradation under effect of temperature, water and oxygen are shown in Figure 2 as results of summarizing some well known information[3] and of the latest[4] studying.

TABLE I
TYPICAL DEFECTS, FAULTS AND FAILURE-MODE IN CORE AND COIL ASSEMBLY

SYSTEM, COMPONENTS	**DEFECT**	**FAULT AND FAILURE-MODE**
Dielectric	Excessive water	Destructive PD
• Major insulation	Oil contamination	Localized tracking
• Minor insulation	Surface contamination	Creeping discharge
• Leads insulation	Abnormal aged oil	Excessive aged/overheated
• Electrostatic shields	Abnormal cellulose aging	cellulose
	PD of low energy	Flashover
Magnetic circuit	Loosening clamping	General overheating
Core	Short-circuit(open-circuit) in	Localized hot spot
Structure insulation	grounding circuit	Sparking/discharges
Clamping structure	Abnormal circulating current	
Magnetic shields	Floating potential	Gassing
Grounding circuit	Aging lamination	
Mechanical	Loosening clamping	Winding distortion
Windings		radial
Clamping		axial
Leads support		twisting
		Failure of insulation
Current carrying circuit	Poor joint	Localized hot spot
Leads	Poor contacts	
Winding conductors	Contact deterioration	Open-circuit
		Short-circuit

TABLE II

Mechanism of Aging
FIGURE 2

Hydrolysis is a dominant mechanism of paper degradation at the temperatures up to 110...120 °C.
Water content in paper and oil decay products (which can cause degradation even at law water concentrations) are two life shorten factors which have to be monitored in the first instance.
However, hydrolysis is "a silent killer" as it does not cause any by-product which can indicate problem through oil analysis.
Direct measurement of DP or mechanical properties of paper are only the tool to estimate the rate of deterioration.
On the other hand, pyrolysis produces a number of by-products including furanoid compounds. It means that generation of e.g. furfurol can be a symptom of overheated cellulose rather than of its general degradation.
Monitoring of oxygen is important basically to prevent excessive deterioration of oil.
Traditional understanding the end of life involves mainly mechanical destruction of cellulose. However, investigation of the functional life models of winding[4] has predicted predominantly dielectric end of life. Studying of the combined effect of thermal aging and periodical short-circuit stresses on the electrical strength of turn-to-turn insulation showed that the most probable life-limiting factor of overheated temperature and turn insulation contacted to aged oil is degradation of dielectric strength due to effect of conductive oil decay.
One can consider that approach to estimation of loss of life[30] using the Arrhenius law the Montsinger rule needs to be improved. This approach gives underestimating life for dry, low oxygen insulation and, on the other hand, significant overestimating life for moisten insulation being in contact with aged oil.

Water

There are two main origins of water contamination:
1) in-service moisture ingress through breathing system, through poor gaskets, from water cooling system and
2) repair works with oil draining, refilling, etc.
Cellulose insulation is both accumulator of water and a main source of oil moistening. Typical structure of solid insulation consists of two parts:

- a "thin" structure (pressboard barriers, conductors insulation, etc.) that is distinguished by a rather large surface and a relatively small total mass;
- a "thick" structure , such as supporting components. This insulation is distinguished by a relatively small absorbing surface and a large total mass.

Experience has shown[6] that the most of the water is concentrated in approximately 30% of cellulose mass, particularly, in "cold thin" barriers which operates in balk oil temperature. About 10-15% of the mass that operates at the lowest temperature can form some "wet zones" with water content which are 1-2% higher than average.
Inherently uneven distribution of water in the composite structure makes it difficult to use a traditional "two components" model based on simplified equilibrium between the oil and cellulose.

Oil is a water transfer medium. However, moisture in the oil influences the dielectric strength of the oil-barrier insulation in the whole. The dangerous effect depends on the condition of the water: dissolved, bound, emulsified and condensed (free water) .
The dielectric strength of the oil containing dissolved water is dependent on the relative water content or percent of saturation which is a function of temperature[7].
Thus, "Life Management" problems are: to assess water content in a thin structure and particularly, in the "wet zones", to prevent migration of the significant quantity if water in oil and emergence of excessive percent of saturation; to assess water content in the conductor insulation on consideration of aging and vapor bubbling; to exclude forming of emulsified or free water.

Contamination

Particles in the oil is a vital problem, particularly, in EHV transformers. CIGRE WG 12.17 is charged to work out recommendations about dangerous level of particles contaminations, methods and methodologies of detection and identification, etc.
Dangerous change in the transformer system may be caused by contamination of insulation surface with conductive-mode particles. This phenomenon is a specific problem in the shunt reactors, where particles can be attracted to the winding by excessive electromagnetic stresses. Concentration of condensed oil aging product in

the zones of excessive dielectric stresses may also essentially reduce withstand strength. The problem is how to assess surface deterioration, particularly, in the aged EHV transformers.

Aging of oil

This is a time to change a traditional relation to oil as to a separate component which can be monitored and assessed separately from the dielectric integrity and changed like a pump or bushing, etc.
Oil is a part of a transformer body which, similar to the blood in the human being body, is responsible for the condition of all the organism.
On the other hand, all impurities in the oil (water, gases, particles, aging products) are "property" of the all dielectric system. Paper insulation acts like effective filter and filters decay products out of oil.
Active decay products being absorbed by insulation can destroy cellulose, however, those product can kill also a new oil after refilling.
A phenomena of masking the real condition of oil due to absorption of aging product by insulation should be taken into account too.
One can consider the following specific goals of oil monitoring:

- Assessment of dielectric condition of a transformer (in correlation with dielectric characteristics of insulation):
    - water, particles, resistivity, tan δ, polarization index, dielectric strength, impulse strength, PD appearance, etc.
- Assessment of by-products using oil as an informative medium[8].
    - DGA, furan, dissolved metals, phenol, cresols.
- Assessment and prediction of aging status.

Characteristics of the oil during aging kinetic are dependent on the type of the oil. However, the following defective conditions could be considered:

- Appearance of sludge (or potential sludge) in the period between tests.
- End of induction period(trend to rapid deterioration).
- Presence acids and non-acid polars which can accelerate decomposition of cellulose.

What is happening with large transformers?

Many of utilities have reported that they operate a huge population of an aged equipment. The questions come: what are the rate and causes of the failures? What kind of aging diseases could be expected? How the life management procedures could prevent forced outages and extend the life? Answers to these questions need permanent collection and analysis of information: "What is happening"?

Failure analysis

A failure is usually a "tuning fork" of Life Management procedures. Reported date about transformer failures[4,9,10,11] and particularly analysis of failures of transformers rated above 100 MVA performed by ZTZ-Service Co. (see Figure 3) showed that irrespective of geography of transformer operation and difference of design some general trends can be extracted:

- Over 80% of total failures of Large Transformers occur due to some aging diseases and could be prevented by effective diagnostic system. Those are:
    - shortened life due to accelerated deterioration of components: e.g. after 10-12 years critical aging of the oil in the bushings and relevant failures[12], critical deterioration of unmoving contacts TC and relevant failures after 6-8 years[13,14];
    - developing the congenital disease: e.g. overheating of the HV winding coils due to poor cooling and coil-to-coil short-circuit after 30 years[15], poor manufacturing the winding transposition and short-circuit between conductors after 27 years[16];
    - change in the condition due to aging, ingress of water, particles contamination, loosening the contacts and clamping forces, vibration, unusual stresses, etc.

Failure of Power Transformers Rated more 100 MVA, 110-750 kV
in 1994-95 due to Hidden Defects.
120 Cases Collected by ZTZ-Service Co. in the Utilities of CIS Countries
and Reported in the 1995-96 Doble Technical Questionnaires on Transformers
FIGURE 3

- Over 70% of failures occur due to reversible mode defects or due to faults which could be corrected in-field by preventive maintenance.
- Only some of 5% of excessive aging of cellulose as an initial nature of damage involved. In most of cases excessive overheating was a probable cause. It means that a significant thermal margin of a population can be expected.
- The critical parts of transformer are:
  - winding (degradation of dielectric withstand - particularly, of HV winding; and mechanical withstand - particularly, of internal windings);
  - bushing (localized faults in the core, deterioration of the oil);
  - LTC (particular deterioration of the contacts and degradation of insulation);
  - core and magnetic shields (particularly, in very large transformers).

In-field detected problems

Answering the question "What mode of defect/fault can be expected in the normally operating transformers?" the condition of 140 transformers rated 63...1250 MVA and 110-750 kV came from seven manufacturers have been analyzed[17] using basically untraditional diagnostic methodologies.
The age of assessed units: up to 10 years - 9%
11-20 years - 53.5%
20-40 years - 37.5%
In total 514 hidden-mode defects and faults have been revealed (Figure 4), basically in the units being in operation over 15-20 years. In the most of cases predicted problems have been verified by internal inspection.
61.7% of the total number of problems were identified in "core and coil assembly", 20% - in bushing, 18.6% in LTC and cooling components.
71.6% of problems in "core and coil assembly" involved reversible mode defects: excessive moisture, contamination of oil and insulation, aged oil, loosening the clamping, etc.
28.4% of problems in active part involved some irreversible damages as localized overheating, traces of discharges, winding distortion, etc.

Transformer Defects Classification[17]
FIGURE 4

However, about 80% of these problems could be corrected without disassembling the active part.
2.8% involved overheating of the cellulose insulation.
Similar work with assessment of the condition of in-service transformers[19] has confirmed that in the normally operating equipment a number of problems can be detected using untraditional methodology. 51.5% of equipment have been found to be in defective condition:
- aged oil - 18.4%;
- overheated cellulose - 15.4%;
- wet cellulose - 9.5%;
- arcing in oil - 6.6%.

However, only a small population of the assessed group (10%) had test results that indicated serious problems requiring immediate attention.
Both failure analysis and condition assessment data have shown importance and wide prospects of life management procedures: roughly over 70% of problems can be predicted and corrected in-field conditions.
15-20% of aged transformers being in defective condition require probably in-factory or in-workshop restoration, however, timely detection of problems can really prevent serious failure.

EFFECTIVENESS OF DIAGNOSTIC TESTS PROCEDURES

Most of utilities are trying to detect abnormality in the equipment without its deenergizing. A general trend is increasing importance of laboratory testing as new and better tests become available.
Experience shows[17] that over 60% of transformers problems have been detected through oil analysis (excessive moisture, some particles contamination, overheated cellulose, aged oil, arcing and localized hot spot, etc.). Some special tests as vibration, acoustic, thermoscanning, etc. have been used basically as complementary tests to assess the internal (hidden) condition. However, the letter have been very effective to detect exterior-mode defects and problems in the cooling system.
Over 30% of problems could have been detected predominantly through Off-Line tests: winding distortion, surface contamination, incipient deterioration of LTC/leads contacts, some bushing problems, etc.

EFFECTIVENESS OF SOME DIAGNOSTIC METHODS

Excessive water

Traditional test of water content in oil at erratic temperature was qualified as the test for rough indication[17,21]. A good correlation between predicted and directly measured moisture in cellulose was found by means of "Water heat run test"[6]: estimation the change in water content in oil after heating up the transformer to the maximum rated temperature and maintaining this temperature long enough to allow a significant quantity of water to migrate into the oil. Four sources of water contamination have been advised (Figure 5).

Classes of Water Contamination

(Estimated increase of water content in oil due to desorption out of the solid insulation at 70 °C and where in the initial state 30% of the pressboard had water content of 2% by dry weight)

FIGURE 5

Oil and insulation surface contamination

The most effective tools were particles counting (especially after artificial agitating the oil) and estimation of the oil condition and surface contamination through dielectric characteristics. However, in some cases inspection has detected severe contamination of insulation with metal particles or polar products without essential change in characteristics of oil and oil-barrier space.

Evaluation of the condition of insulation surfaces is especially important and difficult at a time in shunt reactors. The effect of the electromagnetic field on conducting and polar particles in the oil results in deposits on the barrier surface.

Effectiveness of traditional dielectric characteristics (Power Factor, Capacitance, DC insulation resistance) can be significantly improved taking into account dielectric composition of the testing space and correlationship between solid and liquid components, as well as temperature effect of contaminants on dielectric parameters[22]. It was found a good correlation between real and predicted water content in the barrier of interwinding insulation, contamination of the oil in the space, some deterioration of insulation surface. Qualification of effectiveness of dielectric parameters as diagnostic tools is shown in the Table III.

TABLE III

Effectiveness of Detection and Identification of Typical Defects in the Typical Major Insulation through Dielectric Parameters

SPACE	COMPONENTS	DEFECTS	EFFECTIVENESS OF IDENTIFICATION
HV (outer) - TANK	Oil	Contamination	High
	Oil-barrier	Oil contamination	High
		Moisture in barrier, surface contamination, discharge along surface	Low, due to relatively small volume of solid insulation
	Coil support insulation, shunting insulation of leads, LTC, bushings	Contamination, local moisture concentration	Low, due to relatively small capacitance, only severe contamination can be detected
HV - LV	Oil-barrier	Moisture in barrier, oil contamination	High
		Surface contamination, discharge along surface	Medium
LV (inner) - CORE	Oil	Contamination	High

	Oil-barrier	Moisture in barrier	Medium
	Coil support insulation, Shunting insulation of leads, LTC, bushings	Surface contamination, local moisture concentration	Medium
PHASE-TO-PHASE	Oil-barrier	Oil contamination	High
		Moisture in barrier	Low, due to relatively small volume of solid insulation
		Surface contamination, discharge along surface	Medium

Excessive aging of cellulose

Three basic test methods have generally been used: tests for carbon oxides, tests for furan compounds and degree of polymerization (DP) of paper samples.
The DP test provides the most reliable indication of the overall aging of cellulose. However, deterioration of paper in the "hot spots", which are located usually in non-acceptable parts for inspection or sampling remains to be questionable.
When high carbon oxides are detected, it is usually considered as a symptom of cellulose overheating. But it may often due to oil overheating< when sufficient oxygen is present. e.g. of 7 cases reported in [18] as symptom of high paper overheating on the base of DGA interpretation, 4 involved overheating of loose LTC contacts, 1 - PD in the oil part of bushing, 1 - no fault found, and only one involved damage of LV winding.
High concentrations of furfural-furfural are clear indication of cellulose degradation. However, FAL, as well as carbon oxide is probable symptom of excessive overheating of insulation[21]. The general aging degree of insulation, as well as overheating of a small amount of paper, remains to be questionable. Assessment of insulation aging remains an expert's task.

Local overheating and discharges in oil

DGA is indisputable a very effective detector of abnormalities. In combination with DC transient resistance it is a good tool to identify problems in current-conductance circuit. However, there is often a problem how to locate, recognize the cause, determine the dangerous level and predict development of the fault which involved local overheating and/or discharges in magnetic circuit (core components, shields, etc.).
Such faults do not usually effect directly on functional serviceability of transformer. That is why in some cases really elevated in principle defective concentrations of combustible gasses are recognized to be as permissible ones. In some cases numerous traces of action of high temperature and discharges in vital zone of transformer have been found on the following conditions: gas concentration was lower than limits recommended by IEC 60 599, no visible arising concentration with time. Determination of above mentioned problems remains an expert's task which requires good understanding a design feature and operational condition of the equipment.

Winding distortion and loosening the pressure forces

It was reported[17] a good correlation between relative change in leakage reactance TLR and radial-mode winding distortion. Using approach with determination of image of distorted winding through change in inductance one can identify and quantify extend of deformation. However, TLR method has failed to detect twisting deformation and some axial deformation. Definition of reliable diagnostic techniques is a current topic of CIGRE WG 12.19. A new promising method is frequency response analysis (FRA)[23]. FRA tests can be a reliable and sensitive means of detecting winding movement and other faults which affect transformer inductances and capacitance.
It was reported also correlation between winding pressure forces and vibration response. However, in many cases loose clamping the windings had not been predicted by tests.

ON-LINE MONITORING EFFECTIVENESS

Significant advancing of On-Line monitoring techniques has stirred interest of utilities and manufacturers to the subject[24,25,26].
Service experience and theoretical views have shown some specific benefits of On-Line technique:

- On-Line sensors can not only indicate to the problem, but to activate improvement of the transformer condition.
  E.g., moisture sensor can detect excessive water in oil and activate increasing of the oil tempera ture to reduce dangerous rate of relative saturation.
- Some faults can be exposed only under effect of operating stresses.
- On-Line system can monitor defective condition and prevent a failure, particularly, catastrophic one.

On-Line technique can be used as in permanent, as well as in temporal application (to monitor defective condition). Some of the techniques have been in service many years and experience with their application can be considered.

- **On-Line gas-in-oil monitors**

This is one of the best diagnostic tool available at this time. Several tens of faults have been detected by Hydran technology[27]. Those are: overheating of contacts of LTC, leads and bushings, thermel faults due to circulating current in adjacent metal parts, sparking discharges in electrostatic shields, bushing shields, etc.
There have been convenient evidences of fast fault developing for a short (1-3 days) time what could not be detected and prevented by any periodical tests by On-Line monitoring.

- **On-Line bushings monitoring**

Over 25 years experience with On-Line bushing monitoring (using as diagnostic and protection tool the imbalance of the three leakage current) has shown that bushings explosions due to a breakdown of the core can be virtually eliminated[28].

- **Acoustic sensors**

A number of faults has been revealed through acoustic sensors which application follows usually negative DGA analysis.
The typical defects were:

- Open circuit in grounded leads of core and electrostatic shields.
- Loose bushing shields clamping.
- Loose winding clamping bolts.
- Extraneous core earth.
- Contacts of LTC damage (sparking).
- Bracing connection between parts of LTC selector (free potential).
- Creeping mode discharge at developed stage.

There have been encouraging results of application temperature and vibro-acoustic sensors to monitor condition of LTC.

There have been reported also promising experiences with application of moisture-in-oil sensors, gas (methane) sensor for diagnostic of hot-spots in LTC compartment, internal mode acoustic and electrical PD tests and On-Line monitoring winding distortion problems[11].

CONDITION MONITORING CONSIDERATIONS

There is a common trend to advance monitoring and diagnostic system to obtain reliable information about the condition of transformer and essential economical benefit a time.
Condition-based multistep diagnostic tests system seems to be a subject of intensive development. The objective of "Life management" art is to formalize this process.
Framework of condition based monitoring shall be backed up by:

- Failure model of the equipment at the particular operation condition to answer the question "What to look for?".
- Characteristics of the typical defects and followed from them monitoring program ("What to test?").
- Threshold of defective condition ("When to cry"?).

The first step of multistep monitoring system -*"Indication of Abnormality"* - may include acquiring the following information:

- Operation condition abnormality
- Functional status of cooling and LTC
- Routine test - basically oil analysis
- Complementary special routine tests as thermoscanning, acoustic, vibration, etc.

Application of simple On-Line sensors is an ideal objective.

The second step - *"Fault Identification"* - must identify the problem detected, assess the seriousness and fitting the equipment for service, and to define the scope of remedial repair, if necessary.

The third step - *"Prediction of Abnormality"* [17] - can be considered to predict dangerous developing the faults, particularly, to determine "Life Extension Program". The objective of prediction tests is to assess the condition of the transformer after subjection to ultimate rated stresses (load, temperature, overexcitation, etc.).

The fourth step - "Verification of the condition" - physical internal inspection, tests and sampling the insulation pattern for DP, furanoid, water, etc. after draining the oil and partial tear down of the transformer. A practical Guide for verification tests should be formalized*.

LIFE EXTENSION CONSIDERATIONS

Life Extension is a subject which merges the major operations on transformer to remedy its particular problems, restore the condition and inject into that some new life activity.
Economical motivation of Life Extension program is based on some technical premises:

- Most of the problems with aged transformers are of reversible mode or of repairable mode and can be corrected on site.
- Old transformer has much older design which can be better assessed and improved using modern knowledges and technique.
- One can provide a reliable technical guarantee for postrefurbishment service: if transformer has no major fault (distorted winding, overheating winding's conductor, etc.) it is possible to restore or essentially to improve its functional properties and reduce the rate of further deterioration.

The following Life Extension program has been experienced encouragingly[4]:

- Life assessment, taking into account "weak points" in the design.
- Correction of revealed and potential faults (known from experience with sisters transformers).
- Restoration of dielectric spare margin by means of :
  - drying, cleaning, regeneration (to meet requirements for new transformers);
  - some modification of insulation, if necessary(e.g., modification of exterior bushing insulation against the tank.

To prevent essential decomposition of cellulose during drying of moisten and impregnated with acid products insulation, as well as to extract oil decay products out of insulation a special regenerative mode oil is used in treatment process.

- Reducing the rate of further deterioration by means of :
  - installation of membrane-type oil protection;
  - modification of cooling system to reduce oil temperature.
- Recondition and upgrading the bushings and LTC (e.g., upgrading the reversor and selector contacts)
- Regasketing , elimination of leaks
- Improving controllability and protectionability
- Reducing operational stresses (through fault, current, overvoltages), if necessary

Economical aspects of Life Extension procedures shall be considered.
Developing a practical guide to the life extension program and particularly to tests and quality assurance program after refurbishment must be the subject of Life management activity.

CONCLUSION

1. Service experience confirms high perspectives of Life Management's art to optimize asset life of transformer population, to reduce failures and to extend the reliable life. Aging diseases up-to-now are mainly of reversible-mode defects and developing faults which can be defected and treated on-site.
2. Tight cooperation between utilities and manufacturers is necessary to assess "sensitive points" in old transformer design, to optimize maintenance policy and to find a scope of equipment improvements using modern knowledges and technologies.\
3. Deepening in understanding the mechanisms of developing the life shorten factors, determination of characteristics of abnormal condition, as well as the images of the faults theoretical issues to support monitoring and diagnostic art.
4. Condition-based multistep diagnostic tests system being composed in the cost effective way has to be the objective of priority. Collection of existing test methods considering their effectiveness the condition of Power Transformer.
5. A subject of priority may be economically justified Life Extension concepts and Guidelines for the relevant operations. It should be supported also by Specification for repaired and refurbished transformer including postwork tests and quality assurance.

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