What research and technique are required to improve life management of transformers?

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WHAT RESEARCH AND TECHNIQUE ARE REQUIRED TO IMPROVE LIFE MANAGEMENT OF TRANSFORMERS

By Victor Sokolov, ZTZ – SERVICE Co., Ukraine

DESIGN REVIEW, INSULATION DETERIORATION, AGING DESEASE, FROM CHARACTERISTICS MONITORING TO CONDITION MONITORING, REALLY EFFECTIVE DIAGNOSTIC METHODS, PROBLEMS OF DETECTRION AND IDENTIFICATION,,CONDITION REHABILITATION, LIFE EXTENSION SPEC[F[CATION

“ Life Management “ for transformers is a scope of actions, which begins with the specification and concludes with “the End of Life”.” Life Management “ is indeed the key to optimize maintenance , and particularly to solve efficiently the problems: “How to move from time – based to condition –based maintenance?” “ How to extend reliably the Transformer Life?”Etc. SC-12 CIGRE discussion in 1998 has shown that the existing body of knowledge is not sufficient to attribute some phenomena and to define sufficient effective technologies. This paper is an attempt to answer some questions in the topic “What research and techniques are required to advance the technologies of “ Life Management.”

DESIGN REVIEW IS THE FIRST STEP OF CONDITION ASSESSMENT

Design review is a vital means to gain an insight into transformer structural features with the goal to define the probable failure model, to understand symptoms of abnormality and to assess the probable residual life of the unit’s components.

- Experience has shown that Life Assessment program shall include:
- Evaluation of maximal temperature of windings and oil on real operative conditions and distribution of temperature across the transformer.
- Estimation of dielectric safety margin and sensitivity of “weak “ points to normal deterioration.
- Estimation of mechanical margin of windings on real operative conditions (magnitude of through fault current).
  Sensitive points of components and their expected failure modes
- Controllability and testability of the equipment, and particularly presence of details, which may mask the change in a transformer condition or even prevent to condition assessment.

Tight cooperation between utilities and manufacturers is necessary. However, on many occasions the manufacturer does not more exist. The problem arises: how to analyze the design on conditions of shortage of documentation and service advisement. Developing a special Guide with recommendations how to process design review, and with application of some catalog of typical old transformer designs would be very important task.

WHAT'S KNOWN AND UNKNOWN ABOUT LIFE SHORTEN FACTORS.

AGENTS OF DEGRADATION

Water, oxygen, oil aging products (acids particularly) and particles of different origin are agents of degradation, which can shorten transformer life significantly under impact of thermal, electric, electromagnetic and electrodynamics stresses.

Processes of insulation deterioration involve slow diffusion of water, gases, and aging products and therefore affect basically only a part of insulation structure, so called "thin structure" (paper insulation of turn and coils, pressboard sheets, etc., which comprises typically 40-60% of the total mass.

Impairment of insulation condition begins since the time of transformer shipping. Shipping without oil results in deimpregnation of insulation and saturation with gas (nitrogen), and in some moisture ingress as well. When windings and core covered with oil, it may cause ingress of wet air or even "live water" through unproper sealing, since temperature change of oil volume in the tank works as a pump.

Life management technique shall consider mechanisms of deterioration and processes of selecting the optimum methods of rehabilitation.

Water contamination

The main source of water contamination is atmospheric moisture, and the main mechanism of water penetration is viscous flow of wet air or free water through poor sealing under action of pressure gradient. Moistening insulation during exposure to atmospheric air is another significant factor. Aging can produce a substantial amount of water only if insulation is subjected to elevated temperature and destructed significantly. In this case water is concentrated basically in the vicinity of the "hot spots" in the winding.

Distribution of moisture in a course of transformer life is kept quite non-uniform. The most of the water is supposed to store in the "thin structure" operating at oil bulk temperature (20-30% of the total mass).

Water equilibrium in "cellulose – oil" system follows the same law as in "cellulose – vapor (air)", the difference being in slow process of reaching the equilibrium.

Parameters of moisture equilibrium depend on the structure of cellulose (they are different for Kraft-paper and for pressboard), temperature, presence of gases, water-in-oil solubility. Empirical approximation (e.g. Piper's curves) may be used only for rough estimation of water content level.

Water content in turn insulation is substantially lower than in pressboard barriers due to higher temperature. However, influence of temperature field makes non-uniform distribution of water in the layers (elevated concentration in outer layers).
Solid insulation is a water accumulator and the main source of oil contamination in operating transformer.
Oil is a water-transferring medium. Water is present in oil in soluble form and also in "hydrate" form being absorbed by polar aging products (aromatics).
There is a correlation between solubility of water and aromatic content in oil. Correspondingly, appearance of polar products results in increasing water solubility.

<u>Dangerous effect of water can be summarized to the following:</u>

Free water

Ingress of free water may "kill" the transformer immediately. Drops of water in viscous oil may work as a particle generator being exploded under influence of electrical field.
Ice is another critical problem. In spite of the fact that oil density is specified to be less than density of ice, forced or even convective oil flow can be strong enough to pick up the ice into a critical area.

Soluble water

Dielectric safety margin of both major and minor insulation contaminated with water is determined by dielectric strength of the oil. Dangerous effect of water is a sharp reduction of dielectric strength of oil with increasing saturation percent due to increasing conductivity of the particles available, or to emulsion formation in the vicinity of surface-active substance.
Monitoring the defective condition means monitoring the oil percent saturation, particles and polar oil aging products.

Water in solid insulation

Water accelerates aging decomposition, depolymerization of cellulose is proportional to water content. This process becomes much more dangerous in presence of acids.

Water in turn/coil/insulation

That is the problem of a "hot transformer". Rapid rise of temperature (due to overloading) causes rapid rise of vapor pressure and pressing oil out of macrocapillaries of insulating followed with apparition of vapor-filled cavities on the insulation surface (bubbles).
Aging the oil activates the process due to reduction of interfacial tension. Another activating factor is presence of air gases (nitrogen).

Most of above mention issues are substantiated theoretically and based on experience as well. However, they warrant further discussion by relevant CIGRE experts and some assumptions must be verified by experiments.
I t was decided in September 1998 in Paris by WG 12.18 to develop the paper dedicated to "State of water and ins migration within transformer insulation system".It is to be presented at the SC12 Colloquium in Budapest

Particles contamination

CIGRE Working Group WG 12.17 “Particles in oil” has collected and evaluated a significant number of HV transformer failures being attributed to particles. Particle identification and counting were found to be the necessary procedures of the condition monitoring. It has been shown that *the most dangerous are conductive mode particles (metals, carbon, wet fibers,etc.)* Denomination of typical contamination level including possible dangerous level has been advised.

However this work, in our opinion, has to be continued, particularly in area of determination of permissible dielectric state of oil in operating transformer. The following factors shall be considered: the level of particles contamination versus class of voltage, presence of polar and surface-active aging products, denomination of interfacial tension of oil, identification of conductive-mode particles, limitation of percent of oil saturation and water content in paper. Possible origins of critical particle shall be complemented (including wearing of cooling system components and presence and dangerous of localized overheating in oil). The temperature dependant of interfacial tension seems to be the most important feature of the decomposition process as a whole including aging of oil, decomposition of cellulosic insulation, bubble evolution and oil dielectric withstand strength decrease.

Aging of oil

Some maintenance Guides still consider the oil as a separate component, which can be monitored and treated separately from the dielectric integrity. However, oil is a vital part of the transformer body and keeps responsibility for the condition of the entire organism. All impurities in the oil (water, gases, and aging products) are the “property” of all dielectric system. Aggressive decay products being adsorbed by insulation can destroy the cellulose and also kill new oil after refilling.

There is a time to reconsider scope of tests and limited parameters, which characterized oil aging level. Defective condition of oil may be defined as the following:

- *Appearance of sludge in the period between the tests.*
- *End of the induction period (trend of accelerated degradation).*
- *Presence of acids and non-acid polars, which accelerate cellulose decomposition.*

Paper aging decomposition

Insulation decomposition treated as a chemical phenomenon. Three mechanisms of degradation: HYDROLYSIS, PYROLYSIS and OXIDATION are acting simultaneously. Hydrolysis is a dominant mechanism at the temperature up to 110-120 °C.

An elementary act of hydrolytic destruction takes a hydrogen atom to trigger the process of severing a cellulose molecule and a molecule of water.to neutralized one of the severed part Degradation process comprises scission of molecule (de-polymerization without by-products) and shipping off the end rings with formation of levoglucosene, furanic compounds and water.

Rate of number of molecule division of both types is proportional to water content and acid number. Thus, estimation of "Loss of Life" is sound only if both of these factors are taken into account. One can expect some correlation between DP and initial furanic formation, but hardly between DP and degradation gases CO and CO_2 since the latter are basically products of pyrolysis – another mechanism of degradation.
Rate of furanic generation at normal aging is rather low (less than 50 Ng/ml per year) and concentration of 2-furfurol exceeded 1000 Ng/ml (1 PPM) one can expect some excessive aging basically due to overheating of the insulation.
Thus, one can emphasize that there is a Life Management tool to detect abnormal aging, but method of normal aging assessment is still questionable. Analysis has shown that experimental works available are not sufficient, particularly to determine the temperature coefficients of Hydrolysis mode and Pyrolysis mode cellulose decomposition..
I t is expedient to set up a joint group of experts from SC 12 and SC 15 to fulfil the following tasks:

- *Presentation of the theoretical model of the process of aging decomposition of cellulusic transformer insulation*
- *Carrying out effective experiments to define of velocity constants of degradation considering impact of temperature, humidity and acidity of the cellulosic material in the oil medium*
- *Developing Guide for assessment of residual Life of transformer insulation, including assessment the hot-spot temperature.*

WHAT IS THE CRITICAL AGING DISEASE?

The best means to answer the question "What's happening with the aged transformer?" is failure analysis. Systematical issue of survey with analysis of aged large Power Transformers Failure Causes is of high importance. One can presume that critical "thermal" aging is a probable cause of failure only of some particular old design e.g. bad cooling of the coils due to overinsulating, improper estimation of value of circulating current in winding or in leads, reducing the rate of oil flow, etc
ZTZ-Service Co. has opportunity to observe periodically the condition of Power Transformer population rated ≥ 100 MVA, 110-750 kV (about 5,000 units). In Figure 1 and 2 the distribution of failures in 1996-1997 is shown in comparison with failures of similar transformers reported in the 1996-1997 and 1997-1998 Doble Technical Questionnaires. Irrespective of difference in design and geography of utilization, some general trends can be suggested:

- Over 70% of failures occur after 20 years in service due to some aging diseases..
- Accelerated deterioration of components: bushings and LTC (over 50% of failures). The main problems are:
    - Local defects within the bushing core (moisture ingress, ink migration, etc.);
    - aging of the oil, particularly, in the space between the core and lower porcelain;

- deterioration (overheating) of fixed and moving contacts of LTC;
- Degradation of dielectric withstands strength of LTC.

- Impairment of the condition of main and minor insulation (≈ 20%) due to contamination, ingress of moisture, reducing the impulse withstands strength. Only 3% of failures the excessive aging decomposition involved.
- Mechanical weakness, winding distortion (12%).

The general conclusion is: **over 80% of failures could be predicted and prevented by more effective diagnostic system.**The most of defects caused failures are of reversible mode and could be corrected in-field condition.

It is important to note that regular survey of service experience including failure records must be aimed at determination of the real state of aged transformer and its peculiarities in transformers of different application (step up generator transformer, transmission units.etc.)

HOW TO IMPROVE EXISTING CONDITION-BASED MAINTENANCE

CIGRE WG 12.18 came to a conclusion that there is no alternative to multi-step monitoring approach. There are several proposals for discussion. ZTZ-Service Co. has experienced quite successfully the following program:

- *Definition of the probable defects or "sensitive points" in the particular transformer on the base of design review and in-field experience.*
- *Utilization of group of methods, which characterize the particular defect. Correlation between relevant methods is considered.*
- *Application of multi-step diagnostic procedures:*
    - **Detection** – basically in-service procedures to find abnormality and unusual operating event;
    - **Confirmation** of abnormality – some complementary e tests;
    - **Identification** of the problem – typically off-line tests;
    - **Prediction** of the future condition – functional-mode tests (typically, life assessment program);
    - **Verification** – tests and checks after draining of the oil.

Diagnostic characteristics of some typical defects are classified in the Table 1. Condition monitoring in practice is a test-questionnaire in terms to detect specific condition, e.g. excessive water or particle contamination, abnormal heating, winding distortion, etc.
The only diagnostic parameter allows detecting presence or rather probability of the defect. However, that is similarly to look for change along one axis. At least two parameters are necessary to quantify the defect, as well as to ascertain its presence.
Detection of defective condition shall consider also influence of defect on the condition itself. E.g., if excessive water content is suspected, particle contamination and oil aging rate shall be taken into account to predict dangerous effect of water.

Establishment of the interconnection between diagnostic parameters is a critical step to verify authenticity of diagnostic conclusion. E.g. moisture in solid insulation effects on polarization current and, accordingly, results in appropriate response of all dielectric parameters: PF, insulation, RVM, etc. Quantitative correlation between those parameters may be found.

MOVE FROM DIAGNOSTIC CHARACTERISTIC'S MONITORING TO CONDITION-BASED MONITORING

Traditional and agreed-upon approach to the monitoring (detection) and diagnostics (identification) of HV Power Transformers follows typically the process:

- Periodical tests of the parameters, which are recognized as characteristics of the equipment.
- Selection of some preferential (convenient and effective) characteristics (e.g., DGA, water-in-oil, oil-screen test).
- Measure of a set of characteristics cyclically or when some questionable event occurs: e.g., PF tests, exciting current, ratio, DC winding resistance, PD tests, etc.
- Looking for some new (more effective) tools: furans, FRA, RVA, etc.).
- In terms of interpretation – looking for trend: change in magnitude and rate of each tested parameter in comparison with nameplate data, commissioning benchmark and previous data.
- Definition of limited and critical values for each tested parameter on the base of experience.

<u>This approach basically leads to monitoring of the characteristics of a transformer.rather then its condition</u>

Disadvantages of this approach are:
- Questionable correlation between tested parameters and defect, and defective condition particularly.
- Uncertain or false diagnosis is possible.
- Unnecessary tests are often carried out.

Some misunderstanding in interpretation of diagnostic parameter is possible, e.g., look for correlation between PF test and winding distortion, and between other incompatible notions.

Life Management of transformers *shall follow the same process for the resolution of problems as for the management of human health: symptoms of illness – anamnesis – focused examination – diagnosis – cure.*
However, as to Power Transformers, existing body of knowledge is not still sufficient to define similarly to medicine, a set of strong recommendations "What to do in a case of…?"
Objectives of a future Life Management program could be likely:

- Definition of parameters of particular defect;

- Finding correlation between characteristics of defect and relevant diagnostic characteristics of a transformer;
- Definition of the image of defect;
- Determination of the characteristics of defective condition considering its possible evolving to failure.

As an example the approach to the condition assessment of the condenser-type bushing :

- Localized defect within the condenser core is characterized through relevant parameters: relative capacitance of the defective area and loss factor.
- Dielectric response of the core shows change in overall characteristics: capacitance (leakage current), dielectric loss and in the sum (imbalance) current of three-phase bushings.
- The equations, which give the connection between the parameters of defective area and overall characteristics, are defined as well as the image of the defect through relevant characteristics.

This approach shows the way of a significant improvement of diagnostic technique, as well as of possibility to implement effective and efficient On-Line monitoring and expert system.

WHAT DIAGNOSTIC TOOLS ARE REALLY EFFECTIVE – a view from experience

<u>In-service tests:</u>

- **Oil tests**

Experience has shown] that more than 60% of the latent defects have been detected through oil tests. However analysis of scope of different characteristics makes it difficult to identify type of the problem. Diagnostic Effectiveness of oil parameters may be improved by means of denomination of oil tests on four groups:

- *<u>Identification</u>* – parameters, which specify the oil and remain practically unchangeable in the course of life
- *<u>Aging status</u>* - parameters relevant to aging process;
- *<u>Dielectric status</u>* – parameters, which affect to the dielectric safety margin (water, particle et al);
- *<u>Diagnostic tests</u>* – utilization of oil as diagnostic medium.

The most effective diagnostic components are by-products relevant exclusively to degradation process – DGA, furans, and dissolved metals, et al.

DGA is indisputably the best detector of abnormalities.

However, there is still a number of problems:

- **Difference in the rate of gas generation in different oils**
- **Migration of gases between the oil and cellulose**
- **Unusual sources of gas generation**
- **Location of the source of gas generation.**

One can expect some new benefits from advancing DGA technique, namely:

- **Detection of overheating of the contacts in the LTC divertor compartment;**
- **Detection of low temperature faults (150-400 °C) using C_3 – C_5 hydrocarbons, particularly, C_4H_8 buten-1.**
- **Determine the correlation between amount of gases and dissipated energy.**

Further advance as to diagnostic tools must be an objective of joined activity of experts of SC 12 and SC15.

Assessment of water contamination

Experience has shown a good correlation between predicted and real level of water contamination using *Water Heat Run Test technique*
To assess the problem, loaded transformer is heated by means of reduction of cooling up to the maximal possible temperature to reduce oil percent saturation and to obtain a "moisture potential" in the vicinity of insulation service. Duration of the tests shall allow "discharging" the insulation and building up a notable amount of desorbed water in the oil.
To detect water content over 1.5-2.0%, the temperature 60-75°C and test time of 3 days has been recommended. However, experience has shown that water contamination over 2% or presence of free water may be assessed using the rate of water build up in one day only.

On-Line bushings monitoring

There have been more than 25-years experience with on-line condition monitoring of the condenser-type HV bushings using as diagnostic tool and protective alarm relative change of modulus of the sum current the three-phase bushings leakage current system. Experience has shown that the method may be effective and efficient solution to prevent bushing explosion. The benefits of the method are:

- Reliable definition of the incipient fault within the core associated with shorted (two or more) layers.
- Prevention of dielectric breakdown of the core and overflashing across the core surface.
- Indication of deterioration of the bushing associated with deposit of semiconductive sediment on the inner porcelain.
- Estimation of PF and capacitance in-service conditions.

- ## On-line partial discharge measurement

The recent progress in the digital technique opened opportunities in effective rejection of external interference, detecting weak PD signal and diagnosing the state of a transformer similarly to laboratory test at the transformer factory Experience with application in 1998 of PD Analyzer (type UPDA Twins) has shown the test technique allows achieving fully acceptable level of residual noise (less than 20 pC on the Power plant and around 50 pC on the 330…750 kV substations). The source of critical PD in one of 750 kV autotransformers was detected, located and revealed by internal inspection.
The benefits of PD analyzer are also possibility to analyze the PD signatures, particularly, the power dissipated in PD, and in this way to utilize the diagnostic technique developed by CIGRE WG 15.01 (TF "PD signatures").

- # Off-line technique

30-35% of the problems can be detected predominantly through off-line tests only. Those are winding distortion, incipient faults in LTC contacts and termination, insulation surface contamination, some bushing problems, etc.

- **<u>Leakage reactance as detector of winding distortion</u>**

Experience has shown a good correlation between the relative change of leakage reactance and radial-mode winding distortion. It was found feasible to identify the problem and quantity if as well using matrix of relative change of leakage reactance with respect to the winding in question. ZTZ-SERVICE has documented experience with identification of over 40 faulty units.
Advancing the new technique based on the Frequency Response of the faulty winding shows a good outlook to detect practically all the modes of mechanical failures (axial, radial, twisting) and to implement this method for On-Line monitoring.

- **<u>Dielectric characteristics of major insulation</u>**

Water content in the pressboard barriers, surface contamination level and oil contamination can be effectively estimated using temperature response of PF and DC Insulation Resistance of interwinding and winding-to-tank insulating spaces, taking into account value of relative portion of oil and solid insulation within the space
It's also feasible to improve substantially the detection of local insulation contamination, particularly, surface contamination and non-uniform moisture distribution using Frequency Response of polarization current, and relevant RVM technique.
All the dielectric characteristics should be analyzed and expressed mathematically through the parameters of polarization current.

- **Dielectric response of defective bushings**

Some typical bushing defects (excessive moisture in the insulating core, aging the oil within the core and relevant increase of dielectric losses, excessive aging the oil in the space between the core and porcelain, and presence of semiconductive sediment on the inner porcelain) may be effectively detected and identified through temperature dependence of dielectric characteristics, particularly PF of C_1 (core) and C_2 (test tap, potential tap). Moisture and aging result in exponential rise of PF with temperature. However, the porcelain surface contamination with semiconductive sediment brings to reduction of PF C_1 with temperature lower than minimal value (typically 0.3%) and in some cases down to negative value.

PROBLEMS OF DETECTING DEFECTIVE CONDITION

In our opinion there is no effective tool to detect the following defects:

- **DETERIORATION OF COIL AND TURNS INSULATION**
- WATER CONTAMINATION
- IMPREGNATION WITH OIL AGING RPODUCT
- DEPOLIMERIZATION WITNIH NORMAL AGING
- **OVERHEATING A SMALL AMOUNT OF CELLULOSE**
- **UNEVEN CONTAMINATION OF BARRIERS AND WINDING AND SURFICE**
- **TRACES OF CREEPING DISCHARCHES**
- **LOCALIZED HOT SPOT WITH LOW RATE OF GAS GENERATION**
- **WINDING TWISTING**
- **NONUNIFORM LOOSENING THE WINDING PRESSURE FORCES**

PROBLEMS OF IDENTIFICATION

- LOCALIZED WATER CONTAMINATION
- WINDING INSULATION OVERHEATING
- LOCALIZED HOT-SPOT OR DISCHARGES IN MAGNETIC CIRCUIT
- REGULATING WINDING OR PARTIAL AXIAL MODE DISTORTION
- CONTAMINATION OF BUSHING INTERNAL PORCELAIN

- LOCALIZED HOT SPOT IN LTC DEVERTER COMPARTMENT

CONDITION REHABILITATION CONSIDERATIONS

It is impossible to restore aging decomposition of cellulose insulation, but it is quite feasible to recover reversible change in the insulation condition and practically restore the initial safety margin.
It is also possible to reduce the rate of further insulation deterioration. It is apparent that Rehabilitation means in the first instance cleaning and cleansing the transformer body, namely removing moisture, particles, aging by-products and absorbed gases. Maintenance Guides typically specify some decreasing insulation test level (and correspondingly safety margin) after repair and refubishment of transformer. It would preferable if CIGRE could elaborate a concept and requirements for Condition Rehabilitation.Developing the Guidelines for OFF-LINE AND ON-LINE PROCESSING must be paramount task of future Life Management activity.
ZTZ SERVICE Co considers that after refurbishment insulation must withstand 100 % of test voltage and specifies the following rehabilitation program as a set of simultaneous actions:

- Drying out – achievement of residual moisture ≈ 0.5%.
- Cleaning (particles removing).
- Oil reclaiming – removing of aging products.
- Insulation regeneration – desorption and flushing out of the aging products using special regenerative oil.
- Degassing and re-impregnation of the insulation

TRANSFORMER LIFE EXTENSION CONSIDERATIONS

A subject of priority in future Life Management activity must be economically Justified Life Extension concepts and Guidelines for the relevant operations. It should be supported also by Spec for repaired and refurbished transformer, and test and quality assurance program.

The following program has been experiensed encouragingly:

- Design review
- Life assessment considering “the weak points” in the design
- Correction of revealed and probable faults (learned from in-field experience and safety margin assessment)
- Insulation rehabilitation
- Reducing the rate of further deterioration:
  - sealing the transformer installation of membrane preservation system;

- reduction of temperature – modification of cooling system

- Recondition and upgrading (or replacement) of the bushings and LTC
- Modification to improve controllability – isolating the active part from the tank, taking the grounded leads out, et al)
- Re-gasketing
- Adaptation of the modern monitoring system
- Improvement of the protection system
- Reducing operational stresses (through fault current, overvoltages)
- Comprehensive Test Program

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- **DESIGN REVIEW IS THE FIRST STEP OF CONDITION ASSESSMENT**

OBJECTIVES

- IDENTIFICATION OF" **THE BLACK BOX"**
- DEFINITION OF THE FAILURE MODEL
- UNDERSTANDING SYMPTOMS OF UBNORMALITY
- ASSESSING FUNCTIONAL SERVICEABILITY

TYPICAL APPROACH

- INSIGHT INTO STRUCTURAL FEATURE
- EVALUATING TEMPERATURE DISTRIBUTION
- ESTIMATION OF DIELECTRIC SAFETY MARGIN AND SENSITIVITY TO DETERIORATION
- ESTIMATION OF MECHANICAL MARGIN ON REAL OPERATING CONDITION
- ASSESSING CONROLLABILITY AND TESTABILITY

REQUIREMENTS

GUIDE HOW TO PROCESS DESIGN REVIEW

CATALOG OF TYPICAL DESIGNS

STATE OF WATER AND ITS MIGRATION WITHIN TRANSFORMER INSULATION

PREMISES

- **LARGE POPULATION OF AGED UNITS LIKELY CONTAMINATED WITH WATER**
- **UNCERTAINTY IN EFFECTIVENESS OF METHODS AVAILABLE**
-
- OBJECTIVES:

- **HOW TO OPERATE EQUIPMENT IN QUESTION, CONSIDERING:**
  - ***Accelerating the aging rate***
  - ***Reduction of dielectric strength***
  - ***Bubbles evolution***

- **RANKING THE UNITS TO BE DRYED**

- **EFFECTIVE USE OF ON-LINE SENSORS**

REQUIREMENT

DEVELOPING AND PUBLICATION IN ELECTRA RELEVANT PAPER

PERMISSIBLE DIELECTRIC STATE OF OIL IN OPERATING TRANSFORMER

OBJECTIVES

DETERMINATION OF THE PERMISSIBLE FUNCTIONAL STATE OF OIL VERSUS CLASS OF VOLTAGE OR INSULATING LEVEL

FACTORS TO BE CONSIDERED:

- **THE LEVEL OF PARTICLE CONTAMINATION**
- **CONDUCTIVE MODE PARTICLES**
- **ORIGINS OF CRITICAL PARTICLES**
- **POLAR AND SURFACE ACTIVE AGING PRODUCTS**
- **INTERFACIAL TENSION OF OIL VERSUS TEMPERATURE**
- **RELATIVE SATURATION OF OIL**
- **FULL WATER**
- **WATER CONTENT IN PAPER**
- **ORIGINS OF UNUSUAL WATER PENETRATION**
- **AIR CONTENT**
- **REQUIRMENT**
- **DEVELOPING THE RELEVANT RECOMENDATION**

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AGING DECOMPOSITION WHAT IS THE NEWS

- **HYDROLYSIS IS THE DOMINANT MECHANISM OF CELLULOSIC DECOMPOSITION**

- **THE TRIGGER of the PROCESS is HYDROGEN ATOM WICH ORIGINATED FROM ACID and WATER .BOTH FACTORS MUST BE TAKEN INTO ACCOUNT WHILE ESTIMATING LOSS OF LIFE**

- **OXYGEN IS THE MAIN FACTOR OF OIL AGING**

- **FURANS FORMATION IS CONNECTED WITH WATER GENERATION :3 MOLCULES PER ACT**

- **ONE CAN EXPECT SOME CORRELATION BETWEEN INITIAL FURANIC FORMATION AND DP,**

REQUIREMENTS;

- *THEORETICAL MODEL OF THE PROCESS*
- *VELOCITY CONSTANTS CONSIDERING*
- *TEMPERATURE HUMIDITY AND ACIDITY*
- *GUIDE FOR ASSESSING RESIDUAL LIFE CONSIDERING ASSESSMENT OF THE 'HOT SPOT' TEMPERATURE*

:WATER – WHAT IS THE NEWS

THE MAIN SOURCE IS ATMOSPHERIC WATER.

THE MAIN MECHANISM IS VISCOUS FLOW OF WET AIR OR FREE WATER VIA POOR SEALING

SOLID INSULATION IS WATER ACCUMULATOR. MOST OF WATER IS STORED IN THE "COLD THIN STRUCTURE- 20….30.% OF THE TOTAL MASS

PARAMETERS OF EQUILIBRIUM DEPEND ON STRUCTURE OF CELLULOSE, TEMPERATURE, PRE-SENCE OF GASES AND WATER-IN OIL SOLUBILITY. EMPIRICAL APPROXIMATION (PIPER, FESSLER,..) MAY BE USED ONLY FOR ROUGH ESTIMATION.

INFLUENCE OF TEMPERATURE MAKES NON-UNIFORM DISTRIBUTION OF WATER IN THE TURN AND COIL INSULATION

THE MOVING FORCE OF WATER TRANSFER IS MOISTURE POTENTIAL $\varphi = P \sqrt{T}$ WHICH IS DIFFERENT FOR TURN INSULATION (GREATER) AND MAJOR INSULATION (ESSENTIALLY WEAKER) .

BUBBLE EVOLUTION DEPENDS ON CELLULOSIC STRUCTURE, INTERFACIAL TENSION OF OIL AND PRESENCE OF GASES

ADVANCING EXISTING MAINTANACE PROGRAM

- ***Definition of the probable defects or"sensitive points" in the particular transformer on the base of design review and in-field experience.***

- ***Utilization of group of methods, which characterize the particular defect. Correlation between relevant methods is considered.***

- ***Application of multi-step diagnostic procedures:***

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    - **Detection** – basically **in-service** procedures
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    - **Confirmation** of abnormality – some complementary e tests
    - ;
    - **Identification** of the problem – typically off-line tests;
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    - **Prediction** of the future condition – **functional-mode tests** (typically, life assessment program);
    -
    - **Verification** – tests and checks after draining of the oil.

TRADITIONAL APPROACH

(CHARACTERISTICS MONITORING)

- **Periodical tests of the parameters, which are recognized as characteristics of the equipment.**
- **Selection of some preferential characteristics.**
- **Measure of a set of characteristics cyclically or when some questionable event occurs:**
- **Looking for some new (more effective) tool**
- **In terms of interpretation – looking for trend:**
- **Definition of limited and critical values for each tested parameter**

Disadvantages of this approach are:

- **Questionable correlation between tested parameters and defective condition.**
- **Uncertain or false diagnosis is possible.**
- **Unnecessary tests are often carried out.**
- **Misunderstanding in interpretation is possible**

MOVE TO CONDITION BASED MONITORING

***Life Management of transformers** shall follow the same process for the resolution of problems as for the management of human health: **symptoms of illness – anamnesis – focused examination – diagnosis – cure**.*

OBJECTIVES OF FUTURE PROGRAM
:
DEFINITION OF PARAMETERS OF DEFECT

FINDINGN CORRELATION BETWEEN PARAMETERS OF DEFECT AND RELEVANNT DIAGNOSTIC CHARACTERISTICS OF A TRANSFORMER

DEFINITION OF IMAGE OF DEFECT

DETERMINATION OF THE CHARACTERISTICS OF DEFECTIVE CONDITION CONSIDERING ITS POSSIBLE EVOLVING TO FAILURE

- ***One may assume the architecture of the condition monitoring as a system of inquiry about probable defective conditions: is there excessive moisture, localized overheating, winding distortion..***

WHAT DIAGNOSTIC TOOLS ARE REALLY EFFECTIVE.IN-SERVICE TESTS

OIL SCREEN TESTS–

DETECTING 60-65 % OF LATENT DEFECTS
Denomination of oil tests on four groups is expedient

- ***Identification*** **– parameters, which specify the oil and remain practically unchangeable in the course of life**
- ***Aging status*** **- parameters relevant to aging process;**
- ***Dielectric status*** **– parameters, which affect to the dielectric safety margin (water, particle et al);**
- ***Diagnostic tests*** **– utilization of oil as diagnostic medium.**

DGA is indisputably the best detector of abnormalities.

However, there is still a number of problems:

- **Difference in the rate of gas generation in different oils**
- **Migration of gases between the oil and cellulose**
- **Unusual sources of gas generation**
- **Location of the source of gas generation.**

ASSESSING THE LEVEL OF WATER CONTAMINATION“WATER HEAT RUN TEST

ON-LINE BUSHING MONITORING

PARTIAL DISCHARGE MEASUREMENT

WHAT DIAGNOSTIC TOOLS ARE REALLY EFFECTIVE.OFF-LINE TECHNIQUE.

PREDOMINANT TOOLS TO DETECT 30-35 % of the problems

DETECTION AND QUANTIFICATION OF RADIAL MODE WINDING DISTORTION USING LEAKAGE REACTANCE TEST.

OVER 40 CASES DOCUMENTED

- ***FREQUENCY RESPONSE OF LEAKAGE REACTANCE IS A GOOD OUTLOOK TO IDENTIFY POSSIBLE FAILURE MODES***

ESTIMATION OF WATER CONTENT AND OIL AND INSULATION CONTAMINATION USING TEMPERATURE RESPONSE OF PF AND DC INSULATION RESISTANCE CONSIDERING VALUE OF RELATIVE PORTION OF OIL AND SOLID INSULATION IN THE SPACE

FREQUENCY RESPONSE OF POLARIZATION CURRENT IS GOOD OUTLOOK TO INCREASE EFFECTIVENESS OF THE TECHNIQUE

TEMPERATURE RESPONSE OF DIELECTRIC CHARACTERISTICS OF DEFECTIVE BUSHING

IDENTIFICATION OF CONTACS DETERIORATION

PROBLEMS OF DETECTING DEFECTIVE CONDITION

- **DETERIORATION OF COIL AND TURNS INSULATION**
- **WATER CONTAMINATION**
- **IMPREGNATION WITH OIL AGING RPODUCT**
- **DEPOLIMERIZATION WITNIH NORMAL AGING**
- **OVERHEATING A SMALL AMOUNT OF CELLULOSE**
- **UNEVEN CONTAMINATION OF BARRIERS AND WINDING AND SURFICE**
- **TRACES OF CREEPING DISCHARCHES**
- **LOCALIZED HOT SPOT WITH LOW RATE OF GAS GENERATION**
- **WINDING TWISTING**
- **NONUNIFORM LOOSENING THE WINDING PRESSURE FORCES**

PROBLEMS OF IDENTIFICATION

- **LOCALIZED WATER CONTAMINATION**

- **WINDING INSULATION OVERHEATING**

- **LOCALIZED HOT-SPOT OR DISCHARGES IN MAGNETIC CIRCUIT**

- **REGULATING WINDING OR PARTIAL AXIAL MODE DISTORTION**

- **CONTAMINATION OF BUSHING INTERNAL PORCELAIN**
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- **LOCALIZED HOT SPOT IN LTC DEVERTER COMPARTMENT**