" Transformer Life Management and Life Extension
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Cigre published brochure № 227 **"**GUIDE for Life Management Techniques for Power Transformers," prepared by CIGRE WG A2.18. This document of guidelines follows basically the two branches of transformer life: 1) Condition monitoring and assessment and 2) Operations and correction. The contribution in the first branch has been in condition classification, definition of aging factors, recommendations on failure identification and on monitoring methodology, and monitoring techniques and assessment of typical problems based on a Catalogue of Defects and Faults. In the second branch a Catalogue of Operations has been introduced along with concepts and methodology of insulation rehabilitation and life extension and methods and support for insulation processing**.**

This presentation discusses several specific subtopics, which are important from both technical and economic points of view, namely: Consideration in many faces of transformer life; Typical failures mode and cause; More realistic state of aged equipment with nonuniform insulation aging and contamination; Functional –based diagnostic methodology and condition – based ranking the transformer population; Transformer design review as diagnostic tool; Novel diagnostic methods; Repair in field ; Effective procedures to extend transformer life

The basic traditional philosophy declaring, "the life of the transformer is the mechanical life of aged paper" is appeared to be rather questionable.

The latest CIGRE studies suggest better understanding the mechanism of insulation deterioration. Particularly it was found a critical effect of aging by-products on insulation degradation, which would be even more significant than relevant effect of temperature and time. Therefore removing by-product could be a powerful means to extend the life.

On the other hand, both of transformer service experience and transformer models Life Tests have suggested that transformer life is more complex category that just mechanical life of paper. Service experiences and particularly failure analysis give grounds to deduce that many failures occur just due to aging phenomena. However "Dielectric life" could be shorter than "Thermal life" due to critical effect of oil aging products resulting in critical reduction of dielectric withstands strength of oil and degradation of surface strength. There has been really a new trend in failure causes, associated with reduction of impulse strength and over flashing across windings due to surface contamination

Service aged transformer retains complex moisture and aging profiles. To understand and model moisture behavior in transformers, the insulation structures should be divided by physical categories by temperature zones, and possibly by concentration gradients.

Temperature migration of water across winding conductor insulation has to be considered as well. There is a little information about rate of generation and migration process of aging water. One can expect substantial generation of aging water when polymerization degree (DP) is below 400 Aging water migrates from the hot spot area to coolest zone.

Particles (including of those aging mode) are migrating in oil under impact of gravity, oil flow, and particularly electrical field. The latter attracts the conductive particles and simultaneously deposits them on the winding surfaces, pressboard barriers, and bushing porcelain causing a critical reduction of dielectric strength across the surface

Traditional approach to transformer involves periodically carrying out a series of tests suggesting the limited and critical values for each tested parameter, and look for change against nameplate/previous test data. The principal disadvantages of traditional methodology are: Questionable correlation between tested parameters and transformer defective condition; possible uncertain or false diagnosis; often unnecessary test procedures; possible

misunderstanding in interpretation; neglecting defects ,which can not be detected by specified test scope; practical impossibility to anticipate future state of equipment, particularly remnant life span.

A functional-based methodology is suggested as an attempt to provide a complete coverage of the key deterioration processes. Concepts of the methodology include definition of the functional subsystems of a transformer, development of a functional failure model and utilizing several (not one) diagnostic procedures that relate to the particular fault. Functional-based diagnostics is centered on the prediction of the substantial drop in the dielectric safety margin under impact of moisture, oil by-products, contaminating particles, partial discharge activity, tracking and creeping discharges, and oil-and-paper aging. Critical defective and faulty conditions could be determined in terms of PD activity

In fact all large transformers are individuals and two units of the same style number can have a totally different "service health and age». Design Review can be the only effective means to identify peculiarities available. CIGRE A2 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 A2.18 Life Management has highlighted the Design Review as a diagnostic tool.

Design review is a key procedure to answer the questions: Where are sensitive points in the core and coil assembly and transformer components and their likely failure modes? What defects and faults can be expected in particular transformer component relating to the particular functional subsystem? What is the possible path of defect evolution into the malfunction, and then into failure? Variability of the design (diagnostic accessibility) is considered.

Precise diagnosis of the equipment condition is a key factor to take a proper decision about on-site operation. The SCA2 Colloquium in Merida (2003) highlighted substantial progress in diagnostic techniques particularly in interpretation of test data and evaluation of thermal, electrical and mechanical transformer properties.

28 countries contributed to the CIGRE survey reporting successful experiences with wide application of PD measurements for diagnostic, monitoring and quality assurance. Achieved sensitivity of electrical PD detection (better than 50 pC) shows a new opportunity particularly in verification of in-field repair quality.

Experience has shown that fluid can serve as a powerful diagnostic media retaining about 70% of the diagnostic information available for transformers. In-depth by-products analysis and new analytical techniques, especially analysis of particles morphology, dissolved sulphur and dissolved metals are recommended as a complementary diagnostic tool.

Diagnostic accessibility of aged transformer is still rather limited. The difference in insulation temperature predetermined nonuniform decomposition of insulation. The amount of heated insulation subjected to accelerate wear makes sometimes less than 2-4 % of total insulation mass, and hot spot area is not typically accessible for sampling. It might be a questionable interpretation of DP value in hot spot through DP of samples taken from accessible outside members. For a given level of paper degradation, the furanic content could be different for different types of paper. Novel methods based on direct extraction of furans and acids or by means of analysis extracted by-products e.g. from vacuum condensate during transformer treatment can be a powerful contribution to proper assessment of aging state.

Novel PDC and FDS (Frequency Domain Spectroscopy) give opportunities to extend diagnostic accessibility of aged insulation detecting also localized non-uniformities e.g. surface contamination. However deterioration of turn-to-turn insulation with aging water and oil by-products can hardly be detected by dielectric methods because minor insulation and major insulation are tested being connected in series and the capacitance of turn insulation is well more than the capacitance of major insulation.

There has been a significant progress in development and implementation of on-line monitoring techniques. Moisture in wet insulation zones can be determined on-line by measuring the moisture in oil with a humidity sensor. There is a positive experience with automated on-line monitoring of 8 individual gases. Besides traditional diagnostic purpose automated DGA monitoring allows to identify a transformer personality on certain operation condition and to understand better from dynamic behaviour of gases considering effect of load, temperature and design features.

Recently complete repair of large transformers have been reported including replacement of winding and insulation parts.

Advanced diagnostic methods are important for the reliable and economic repair-decision process. Analysis of pre-failure operation condition and failure recorder data, and especially comprehensive test program would require determining scope of repair and relevant repair facilities.

Experience has shown that in many instances some old transformer designs are not adequate to modern requirements. Hence modification of design would be necessary especially in case of post-failure repair in order to avoid a similar failure in future, and to ensure reliable service after repair . A failed transformer can serve as a source of valuable information about the design features and real state of insulation, which is in most cases inaccessible unless the core and coil assembly is dismantled

Preservation of insulation from moisture, dust and other contaminants is one of the most important repair procedures. Preservation is, in many respects, much more efficient than drying out because subsequent drying process would take much longer time than time of exposure to the ambient air.

Processing includes a wide range of operations from removing residual oil out of active part and especially out of the core, preliminary cleaning to remove all debris, particles, etc. up to final filling with oil and bubbles removing. A well-controlled drying and regeneration process is essential for successful repair of large active part on site as well as fully impregnation with oil and final winding compressing.

On-side repair needs particularly intensive quality assurance program. Processing complexity and high costs to perform a complete scope of factory tests have been one of the obstacles in taking decision in field repair. The repair scope does not make a substantial change in voltage distribution. Possible changes in insulation dimensions can be well controlled. Hence, the state of insulation, namely level of moisture, particles contamination, quality of impregnation and degassing, and possible defects due to improper assembly have to be the main objectives of high voltage tests. On the other hand sensitivity of short duration tests to insulation contamination is limited. Correspondingly post-repair high voltage tests, especially of reduced magnitudes might not contribute substantially to insulation condition verification whereas a long duration test with PD measurement could be most effective procedures

Technical life extension program should consider a complex of economic based procedures including: Mitigation of abnormal operation conditions On-line processing (maintaining the proper level of dielectric margin, and aging degradation level; reconditioning) Comprehensive program of insulation rehabilitation and refurbishment of a transformer including correction of revealed and potential faults, restoration of mechanical state of the core and coil.

Aging brings accumulation of latent defects that result in reduction of dielectric strength and acceleration of Insulation degradation.Traditionally insulation drying out is considered as most important procedure to improve insulation condition and extend the life. However removing of moisture is only a part of insulation restoration program, which as a whole should include also degassing, cleaning (filtering) and especially regeneration insulation structure and active part in integrity.Changing of oil and flushing insulation with oil are not sufficient procedures because they do not allow removing by-products out-of cellulose macrospores. Retained by-products would accelerate further degradation.

LFH Drying out technique allows removing some by-products (in a company with water) out of winding minor insulation however hardly out of pressboard.

Complex treatment including dissolving by-products and regeneration of insulation integrity would be the most appropriate solution to extend the Life.

There have been experienced several techniques of removing oil-aging products out of insulation: 1. Use special cleaning fluid during complex treatment of insulation (drying, regeneration and cleaning). 2. Improve the detergency of operating oil:

by means of some special cleaning additives by means of establishment of special condition, namely, maintaining a low concentration of oil decay by reclaiming and a high temperature of oil to improve its solubility. Removing aging by-products and moisture would restore dielectric margin and slow down rate of deterioration. Cleaning fluid can serve as effective tool to regenerate and renovate Insulation.