GE

Grid Solutions

Mid-life Condition Assessment

For Critical Oil-Immersed Power Transformers

Introduction

Non-intrusive inspection helps determine the best maintenance strategy for aging and critical oil immersed transformers. It can be carried out at any time and methods include dissolved gas analysis, visual inspections and electrical tests. If the results identify any abnormalities or the transformer has reached mid-life, then an internal conditional assessment is recommended to ensure accurate diagnostics of the asset.

The internal assessment of the physical, electrical and internal conditions helps to:

- Avoid major failure
- Estimate the remaining time of aging insulation
- Prioritize the maintenance actions
- Define the scope of upgrade or identify the asset to be replaced

This assessment helps asset managers to make the best use of reduced capital and operational expenditure budgets while taking into account residual lifetime and criticality of the assets.

Applications

The internal condition assessment is recommended to be performed from the midlife of a transformer, which is approximately after 20 years of operation or following non-standard results from a non-intrusive inspection, tests and oil analysis. It can also be required before a major asset upgrade. The assessment is applicable for critical medium and large oil immersed power transformers including:

- Power generation transformers including generator step up transformers
- Transmission and distribution transformers including large autotransformers
- Special industrial transformers

Risk of Failure

As transformers age, the risk of failure increases. Aging of a transformer can be accelerated by the nature of operation, the maintenance practices and the design.

As mentioned in the CIGRE technical guide on "Economics of Transformer Management", average yearly major failure rates can be multiplied by up to a factor of 3 between the first 15 years and from 25 to 35 years.

Average yearly major failure rates can reach 1.5% for transmission transformers and 2% for generator transformers after 25 years in operation and continue to increase after 35 years (Figure 1).

The CIGRE reliability survey shows that the main contributors towards a transformer failure are the internal active parts including: core, coils, OLTC, bushings and leads (Figure 2).

Transformer age	Substation units	Generator units
<15 years	0.5%	0.8%
16-24 years	1.0%	1.5%
25-34 years	1.5%	2.0%
35-50 years	2.0%	2.5%
>50 years	3.0%	3.5%

Figure 1: *Failure Rate Change by Age of Unit as shown in CIGRE guide 248. WG A2-20_June 2004*

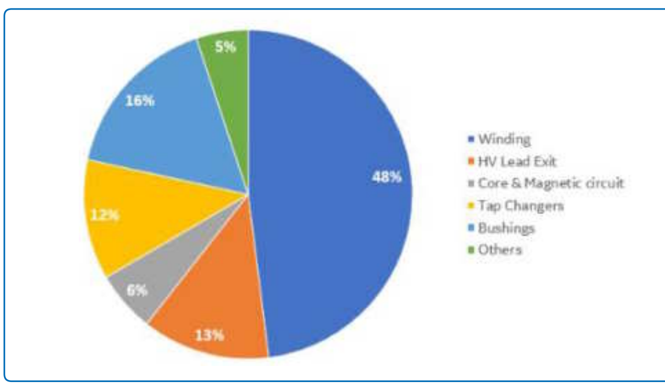


Figure 2: *Major failures location for HV generator transformer > 100 kV, acc. CIGRE WG 2.37 - Transformer Reliability survey 2015*

Method

Prior to the onsite inspection and in addition to the systematic non-intrusive inspections, the transformer expert reviews the historical maintenance and operation records for the transformer to identify areas where potential incipient fault or impact of aging could be expected. A special focus will be put on these areas during the internal assessment.

To perform a comprehensive and intrusive assessment of internal components, the transformer is taken out of service, preferably while other maintenance activities are in progress during a planned outage.

The internal inspection, assessment and diagnostics, which are critical activities on high value assets, should be undertaken by a transformer expert with a deep understanding of aging mechanisms. The goal of the assessment is to provide customized recommendations for remedial actions, maintenance plan updates, upgrades or medium term planning for replacement.

When the asset is de-energized, the oil is drained from the tank to get free access into the transformer for detailed visual analysis. In most cases the expert accesses in a confined space. For inaccessible areas the inspection is be done remotely with a camera.

Component Inspection

The internal inspection of an oil-immersed transformer starts with a systematic and structured inspection of the design and construction parts. It includes:

- Windings, with special focus on spacer lanes, block alignment and lead-outs
- Cooling ducts
- Oil directing structure
- End insulation of coil assembly
- Bolted and crimped connections at lead exits, low voltage busbar
- Leads, lead exit structures and supports between windings, bushings and tap changers
- Coil clamping including a residual clamping survey based on detailed visual and mechanical checks
- Core position, alignment and clamping/frame structure
- Core and frame earthing
- Bushings stems, leads and in oil conical part of the bushing
- Current transformers, mounting and connections
- On load tap changers

Paper sampling at relevant locations (Figure 3) can complement the internal inspection.

The analysis of the Degree of Polymerization (DP) performed at the oil laboratory gives insights to evaluating the aging of the insulation, to identify any accelerated aging issue and estimate the remaining life time of the insulation for given operating conditions.

Figure 3: *Paper sampling locations must be chosen according to the accessibility and rebuilt feasibility. Locations should be reasonably representative of winding temperature conditions or hot spot conditions.*

Identification of Critical Conditions

The mid-life condition assessment allows the identification of critical conditions, impacts of aging (see page 3) and gap analysis of initial or expected status of the transformer. It includes:

- The detection of the presence of byproducts such as corrosive sulphur, copper sulphide, silver sulphide and precipitable sludge
- The identification of evidence of fault activity such as thermal fault, partial discharge and arcing
- The investigation related to mechanical displacements, loss of tightness and impacts, clamping condition of the windings

Experts' Diagnostics and Recommendations

Based on the findings from the internal inspection, the transformer expert delivers an advanced condition assessment report composed of an asset diagnostics and recommendations for immediate and long term actions. Recommendations include curative and preventive maintenance, upgrade or replacement of the inspected transformer.

When the operators owns a fleet of transformers, recommendations provided following the internal inspection can be extended to other transformers that have not been inspected but have similar operating conditions and design arrangement.

In addition, as the transformer has been opened for the internal inspection, maintenance teams can take the opportunity of the scheduled outage to perform some immediate actions such as re-clamping (further detail on page 4), minor repair and cleansing.

Experts' Diagnostics and Recommendations

Asset management recommendations

Based on the detailed diagnostics, the transformer expert will provide the maintenance and upgrade recommendations that will help to guide the asset owner decisions.

Recommendations can include the following activities:

- Fault rectification including parts or subassembly replacement
- Re-clamping of windings
- Drying of cellulose insulation - on site
- Defining the oil management strategy:
  - Passive online oil filtration when compliant with local regulation
  - Offline oil filtration for moisture reduction
  - Degassing and removal of particles
  - Reclamation through a fullers earth type treatment to improve oil quality
- Sludge removal
- OLTC selector cleaning, preventive limitation on tap changer
- Bushing replacement
- Customized life extension solutions deferring capital expenditure for replacement
- Customized upgrade solutions:
  - To increase cooling efficiency
  - To improve oil preservation system and avoid moisture with conservator bags or drycol retrofit
  - To update technologies (Resin Impregnated Paper, composite external insulation) with new bushing retrofit
- Retrofit of online monitoring to control key components such as oil, bushings and OLTC and increase reliability by following the trend of critical parameters.

Immediate action : re-clamping

Re-clamping the winding can be performed on medium and large transformers with the supervision of the transformer design engineer using an hydraulic press.

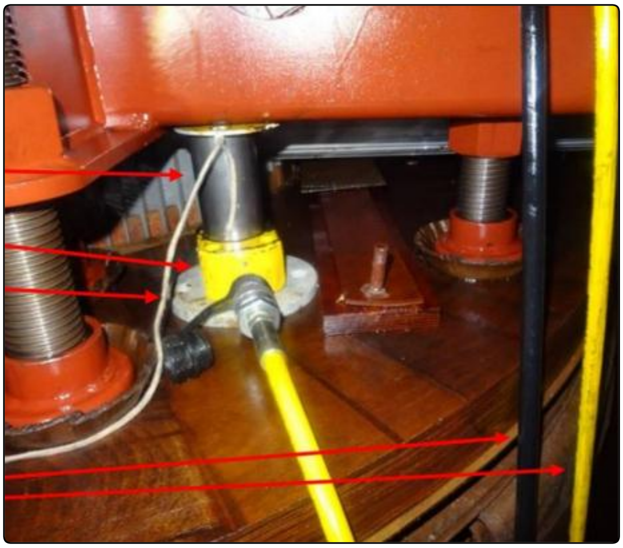


Figure 5: *Example with one of the four hydraulic jacks in position between the clamping beam and the top winding platform, with load spreader to distribute the pressure. All four hydraulic lines were brought in through the HV turret.*

A- *Solid steel spacer*
B- *Hydraulic cylinder*
C- *Load Spreader*

D- *Two hydraulic lines were fed up over the top of the top yoke and to the jacks at the LV side*

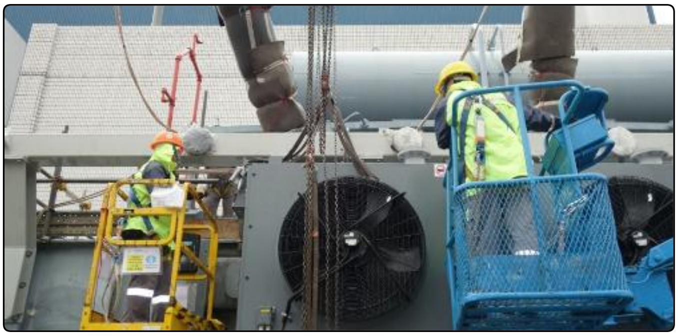


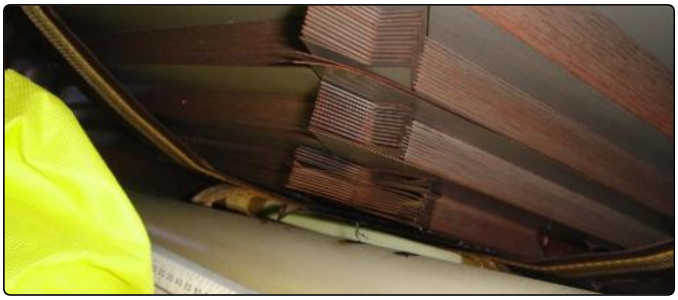
Figure 4: *Improving cooling efficiency with upgrade of coolers and control cubicles on a 23 kV/435 kV three phases 420 MVA generator step up transformer.*

Figure 6: *View of clamping brackets on LV side of one phase after the winding re-clamp. The photo shows how cable ties were used to secure blocks and shims.*

Typical Issues Detected During Internal Inspections

Bellow are some examples of typical issues detected during internal inspections performed by GE experts on transformers from various manufacturers.

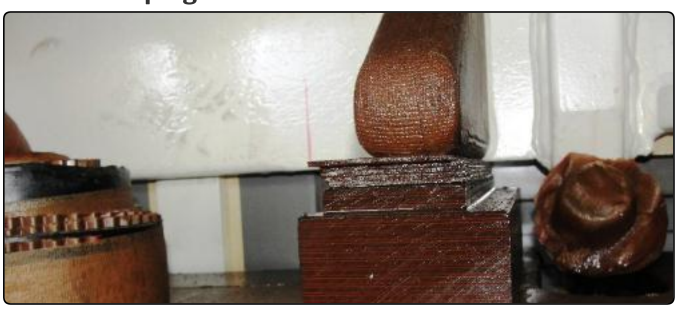
Short circuit and circulating current damages



Findings: Short circuit and circulating current damages identified on core and core frame of a 19 year old large step down transformer 230 kV/10,5 kV.

Recommendation: Fault rectification with core and frame insulation and components repositioning.

Loose clamping



Findings: The clamping on one phase was found to be loose. The group of shims and thin block was so loose that it could be pulled out by hand.

Recommendation: Winding re-clamping.

Copper sulphide formation

Findings: Copper sulphide formed on copper busbar and in the wraps of the paper insulation on copper conductors.

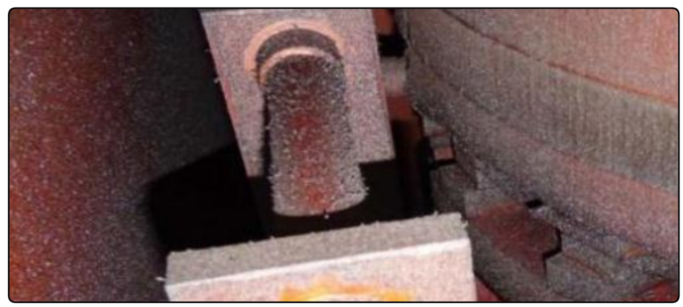
Recommendation: Cleaning of copper busbars and replacement of paper impacted by deposit where accessible. Rinse of the transformer active parts to eliminate residual corrosive oil, oil reclamation and chemical treatment or oil change according to the transformer history of maintenance.

Corrosive sulphur formation

Findings: Silver sulphide on de-energized tap changer of a large 35 year old 330 kV/138 kV/11 kV auto-transformer.

Recommendation: Cleaning, treatment, passivation, change of oil reclamation process or replacement according to extent of damage and history.

Sludge formation



Findings: Sludge formation and aggregated particles aligned in a direction perpendicular to the surface, following the localized electrical field gradient.

Recommendation: First recommendation is for a sludge removal to mitigate winding pollution risks and to protect the dielectric strength. Second recommendation is for the amendment of the oil management strategy based on the condition assessment of the oil and insulations. Operations that could be performed according to condition, implementation constraints and local regulation include: oil replacement, oil reclamation, online or offline oil filtration.

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