Eskom	Standard	Technology

Title: **STANDARD FOR INTRUSIVE WORK AND OIL FILLING OF TRANSFORMERS AND REACTORS ON SITE**

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Content

1. Introduction

The transformer is one of the most important links in the electrical supply network. Transformer failures in service may cause severe supply interruptions and result in high costs. Therefore, transformer reliability requirements are exceedingly high.

Long-term service performance is the result of the combination of activities starting with the specification and ending up with life management including economic considerations. Any of the activities undertaken or not undertaken throughout the lifespan of the unit has the potential to increase the risk to and reduce the lifespan of the unit. The activities which introduce the greatest risk to the unit are intrusive work and oil filling. These activities must be tightly controlled, hence the requirement for this standard. Experience has proven that careful management of the above activities brings great benefits.

2. Supporting clauses

2.1 Scope

This document was developed to reduce the risks of premature failure of transformers and reactors caused by any activity undertaken during intrusive site work and oil filling under vacuum, and to ensure that all Grids and OUs comply with the same requirements.

2.1.1 Purpose

The purpose of this document is to provide steps to be taken when implementing the above scope with the intention to safeguard the equipment.

2.1.2 Applicability

This document shall apply in Transmission Division and Distribution Division.

This standard is applicable to all oil filled power transformers and reactors within the mentioned divisions and shall be used as a minimum requirement at all sites where intrusive site work and oil filling is undertaken.

2.2 Normative/informative references

Parties using this standard shall apply the most recent edition of the documents listed below

2.2.1 Normative

[1] OEM Instructions: Original equipment manufacturers operating and maintenance instructions as provided by the OEM in the manual

[2] IEC60156:1995: Insulating liquids — Determination of the breakdown voltage at power frequency - Test method.

[3] IEC 60422:1989: Supervision and maintenance guide for mineral insulating oils in electrical equipment

[4] IEC 60296: Fluids for electro-technical applications – unused mineral insulating oils for transformers and switchgear

[5] 240-75661431: Mineral Insulating oils (uninhibited and inhibited) Purchase, management maintenance and testing.

[6] 240-146313113: Minimum safety requirements and risks assessment when doing internal inspections on oil filled high voltage equipment.

[7] 240-84908008: Polychlorinated biphenyl phase-out standard.

[8] 240-95118977: Life cycle management plan for power transformers and reactors transmission approved Rotek scope of work and inspection and test plan

[9] EEGE1001: Rotek Engineering — Utilizing Industrial dehumidifiers for intrusive transformer maintenance

[10] EQH — 1008: Rotek Engineering — Work in confined spacers

[11] EC-ST-F-18: Rotek Engineering — Internal inspection of a transformer

[12] 240-94065164: Rotek Engineering — Evacuating transformer and oil filling on site

[13] ORHVS: Operating regulations for high voltage systems

[14] 240-134709285: Oil filing of transformers under vacuum

[15] EC-STF-02: Rotek Engineering- Oil filling of conservator tanks fitted with flexible aircell

[16] Eskom Power series: Volume 5: Theory, design, maintenance and life management of power transformers – chapter 8

[17] 240-65216748 Test procedure for power transformers

2.2.2 Informative

[18] 240-56227424 Rev 1 Standard for commissioning of power transformers — generation

[19] ISO 9001:2000: Quality management systems

[20] ISO 14000: Environmental management systems

2.3 Definitions

2.3.1 General

Definition	Description
Cold commissioning	The tests carried out after the intrusive work, outage or installation work to verify the condition of the transformer.
Commissioning	means the energising of the plant at rated voltage, the taking of load and the on load tests.
Energising	When voltage is applied to the power transformer but prior to placing it on load.
Engineering specialist	A subject matter expert working in the Transformer centre of excellence (High Voltage Engineering Department) at the Head Office.
Impregnation Time	Time period from oil vacuum filling of the power transformer and prior to energisation of the power transformer and it incorporates: a) the time period where oil circulation is taking place and b) the time period where the power transformer is left standing for oil to settle down.
Intrusive work	All transformer and reactor work that requires any draining of oil and/or opening of covers shall be classed as intrusive
Oil degassing	This refers to the processing of the oil with the primary aim of removing the dissolved gasses e.g. when there is a need to re-establish the trend.
Oil filtration	This refers to the processing of the oil with the primary aim of reducing moisture and improving electric strength.
Partial drain	It is the lowering of the oil in the transformer tank below the main tank top cover but above the winding blocks and top yoke.

Definition	Description
Plant Manager	It means the person the responsible for the maintenance of the transformers, which is the SMS Manager in Distribution and the HV Plant Manager in Transmission
Regenerated oil	Reclaimed used oil that has been reprocessed to comply in all respects with requirements of 240-75661431
Soaking Time	Time period that the power transformer is left standing after energisation but prior to placing the power transformer on load.
Standing Time	Period of time after any disturbance of the oil (filtering/vacuum filling) during which the unit shall not be energised in order to allow for the dissipation of any bubbles and ensure void free impregnation of the paper insulation.
Transformers	This shall include all oil filled equipment, i.e. network transformers, generation transformers, distribution transformers, auxiliary transformers and reactors.
Virgin oil/New Oil	Oil that has never been used in electrical equipment and that complies in all respects with oil specifications (240-75661431)
Works Advisor	An experienced Eskom person who regularly performs specific tasks for which he has been specially educated, trained and appointed and of which he/she has and maintains an in-depth knowledge

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
A	Acid
BIPM	Business Integration and Performance Management
DGA	Dissolved Gas Analysis
DS	Dielectric Strength
HVE	High Voltage Engineering
ITP	Inspection and Test Plan
kPa	kilopascal
MOP	Mobile Oil Plant
OEM	Original Equipment Manufacturer
OU	Operating Unit
ppm	parts per million
PQP	Production (Project) Quality Plan
SMS	Specialized Maintenance and Support
WC	Water Content

2.5 Roles and responsibilities

a) Safety Precautions — Safety precautions shall be observed at all times while activities described in this document are being undertaken, the relevant Plant Manager where the work is undertaken will be responsible to ensure safety. He/She shall ensure that people comply with [6].

b) Site responsibilities and actions — the relevant grids Plant Manager shall ensure that all the relevant work conforms to this standard.

2.6 Implementation date

The implementation date is the date when this document is authorized.

2.7 Process for monitoring

Records must be kept by the worker performing the activities, of the complete process. all stages, readings, pressures, temperatures humidity (ambient) and time durations to enable verification of the process.

The Plant Manager in the relevant area where the work is undertaken is responsible for monitoring that all activities covered by this standard, comply with the requirements of this standard.

Job observations and internal audits can be undertaken by the relevant Grid/OU management if required.

External observations/audits will be undertaken as required by Transmission BIPM staff or engineering specialists.

2.8 Related/supporting documents

240-134709285 – Oil filing of transformers under vacuum

3. Intrusive work and oil filling, under vacuum of transformers and reactor on site

3.1 Activities to be performed

All transformer or reactor work that requires draining of oil and/or opening of covers shall be checked with the engineering specialist through the submission of a relevant scope of work (SOW) and applicable PQPs or ITPs before the works start. Once the engineering specialist has satisfied himself/herself that the work is necessary, the scope is adequate, and that the proper control measures exist, the approval of the activity shall be done only by him/her co-signing the relevant ITP or PQP. No work shall start unless the relevant PQP has been co-signed by the engineering specialist or his/her delegate.

3.1.1 Use of OEM procedure

Whenever the OEM manual is available and the procedure for the required activity is available, then the procedure as prescribed in the OEM manual must be followed. This is especially necessary while units are under guarantee and the OEM must approve any work to take place within the guarantee period. Where Eskom has more stringent requirements, Eskom requirements shall take precedence.

3.1.2 Internal inspection or work to be undertaken while active part is exposed to atmosphere

Even though it is not always possible to avoid opening of transformers, the intention is to limit the exposure of the active part to atmosphere to as short a period as possible. While work is not being undertaken, the inside of the unit must be pressurised with dry air (using bottles) or dry-air generator at all times to 25kPa. Air dryness shall be an equivalent of -40°C dewpoint at ambient of 25°C (this is 0.5% moisture in paper insulation). While work is in progress and covers are opened, a positive pressure must be maintained in the tank using high volume dry air machines or dehumidifiers (flow rate shall be >= 1000 m^3/hour and air dryness shall be an equivalent of -30ºC dewpoint at ambient of 25ºC). All the requirements of the following procedures must be complied with.

- EEGE1001: Rotek Engineering — Utilizing Industrial dehumidifiers for intrusive transformer maintenance
- ET1009: Rotek Engineering — Working in confined spacers

The objective is to take the utmost care of the active part of the unit by restricting access and monitoring and ensuring removal of items and tools prior to energisation. All access into the tank must be controlled by a clean condition procedure whereby all tools, items taken into the unit must be entered into a register and must be checked out after the work is complete or the workers leave the tank, only the necessary skilled personnel, and not more than 2 people at a time, should enter the tank. Personnel entering the tank should wear, lint free disposable overalls and all care must be taken not to introduce any contamination into the tank, and shoes (white gumboots) should be wiped clean before entry. Workers must ensure they do not stand on leads, damage insulation or pull on connections, only the necessary contact should be made with insulation.

NB: Sick people, particularly those sneezing should refrain from entering the transformer. If working under warm conditions which promotes excessive sweating the time spend inside the transformer must be such that no sweat dripping occurs.

3.1.3 Inspections on completion of work

Once the work has been completed inside the tank, a skilled supervisor/specialist, who was not part of the daily activities, must do an internal inspection to ensure no insulation nor leads have been damaged and neither tools nor spare parts have been left inside the tank. The supervisor must also check the clean condition register to ensure that all articles have been checked out. The supervisor/specialist must then approve the closing up of the unit. After the internal inspection by the supervisor/specialist, nobody must open or work inside the tank. After all covers have been closed, the tank of the unit must be equalised to the diverter barrel, selector if in a separate compartment, and the radiators. The unit must then be pressurized to 25 kPa, taking care not to exceed this value and operate the pressure relief valves. All gaskets, valves, diverters, radiators must be inspected for leaks by applying a water and soap mixture to all of these, leaks will show up a bubbling and these must be repaired prior to pulling vacuum.

The tank must be pressurized to 25 kPa with dry air and be left undisturbed for 48 hrs in order to perform the dew point measurements as indicated below. It is an acceptable practice to waiver the dewpoint measurement and extend the vacuum time. This vacuum time extension becomes more important at coastal areas or when humidity levels are elevated (30% – 60%).

3.1.4 Dryness of insulation

Prior to the unit being vacuumed in preparation for oil filling, the dryness of the insulation must be determined. The dryness of the paper can be determined in one of two ways:

a) Taking a paper sample using the Doble method and having the paper analysed at an accredited laboratory to determine the moisture level. Table 1 is to be used as a guide to the moisture limits and criteria to be used when considering the de-hydration of transformer insulation[16]. An Engineering specialist can be contacted to advice on the drying required.

Table 1: Moisture in transformer paper insulation: risk profile[16]

Moisture in paper insulation (%)	Dielectric strength risk	Paper degradation risk	Actions
< 1.7	None	Normal ageing	None
1.7 – 2.2	Low	Increase ageing	Consider on-line drying
2.2 – 3.0	Medium	Accelerated ageing	Consider on-line drying
> 3.0	High	Accelerated ageing	Consider workshop drying

b) Performing the dew point measurement. The moisture in the insulation can be determined by monitoring the moisture in the dry-air. The measurement of the gas moisture content is called the dew point. After undisturbed period of more than 24 hours, some of the moisture in the insulation will migrate into the gas. The moisture in the gas is proportional to the moisture in the insulation and can be used to determine the relative dryness of the transformer insulation, but mostly the insulation surface moisture. The level of moisture is also related to temperature. See Figure 1 for a graph showing the relationship between dew point, ambient temperatures and moisture content on the surface of the insulation.

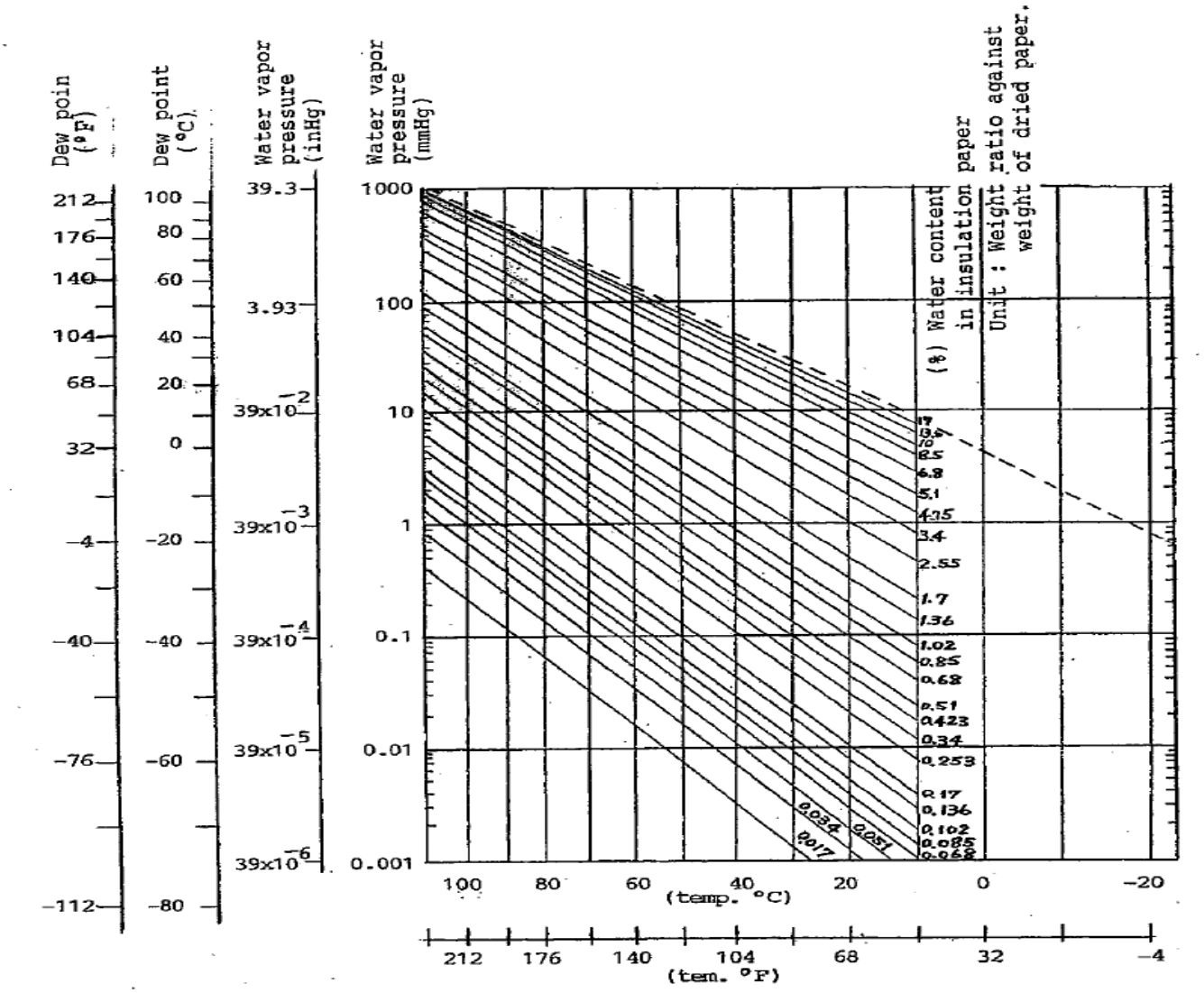

Figure 1: Relationship between the dew point of gas and water content of the winding and element

The surface moisture shall be below 0.8% and 1.5% for units younger than 20 year and for those in service respectively, before final vacuum. If the results are outside these parameters a dry out process must be undertaken. Unit must be evacuated first before pressurizing.

NB: This surface moisture reading must not be confused with the moisture concentration in the solid insulation by ratio to the dry weight.

3.1.5 Vacuum treatment

This section refers to the power transformers (tank, diverter cylinders, radiators, bushings and conservator) that are designed to withstand full vacuum. The connection requirements shall be as laid down in the OEM's manual or the Rotek engineering procedure [12], if no OEM directive is available.

3.1.6 Vacuum procedure

When the leakage test has been satisfactorily completed, the tank is evacuated to a pressure below in accordance with the requirements listed in Table 2 below, and maintained at these levels for the times specified.

Table 2: Minimum evacuation prior to oil filling

Rated Voltage (kV)	Degree Of Vacuum (kPa)	Leak Rate (30 min)	Vacuum Holding Time (hrs)	Vacuum During Filling (kPa)	Hot Oil Circulation (hrs)
≤ 132	< 0.1	< 0.1 kPa	24	Maintain< 0.1	2 full volume passes at 40 ºC
220 and 275	< 0.1	< 0.1 kPa	36	Maintain< 0.1	2 full volume passes at 40 ºC
400 and above	< 0.1	< 0.1 kPa	48	Maintain< 0.1	2 full volume passes at 40 ºC
Oil Temperature for filling: 60 ºC 0.1 kPa = 1 mbar					

Vacuum must be pulled at highest point of transformer which is the top of conservator tank and top of transformer tank.

3.1.7 Oil filling under vacuum

3.1.7.1 Oil quality prior to filling

As per the oil specification [5].

3.1.7.2 Oil filling under vacuum

Before the oil is filled into the transformer, it shall be heated to 65°C and filtered through a vacuum filter with a pore diameter of maximum 5µm. Air and water shall be removed so the oil meets the requirements of 3.1.7.1.

The unit is filled under vacuum, through the bottom valve, up to the correct level in the conservator for the prevailing temperature.

Do not use the vacuum in the transformer tank as a suction medium for oil filling as this creates turbulence and excessive foaming of the oil.

Do not fill oil from conservator with tank partially drained and vacuumed, this creates turbulence when the oil enters the transformer and creates air pockets in the oil. Also this can damage the Buchholz relay's electrical contacts and mechanics.

3.1.7.3 Filling difficulties

If the prescribed pressure of less than 0.1 kPa cannot be maintained, the filling process must be interrupted. The reason for too high a pressure is either a leak or insufficiently degassed oil. The fault has to be located and rectified.

If at the moment when the filling is interrupted the whole insulation system is submerged in oil, then continue as per the procedure for a partially drained transformer after the fault is remedied.

If parts of the insulation are still above the oil level when the filling is interrupted, the following applies:

a) provided that the product of pressure and time (P*t) during the difficulties is below 5 kPa (50 torr hours), evacuate the tank and continue vacuuming the tank for at least 12 hours after the pressure has reached 0.1 kPa (1 torr) before continuing the filling procedure.

b) if the product of pressure and time (P*t) during the difficulties is above 5 kPa* hours, or the tank was filled with air at atmospheric pressure, then drain all the oil and restart the vacuuming and filling procedure.

3.1.7.4 Impregnation time before energising

To facilitate oil penetration of the insulation and absorption of any gas bubbles, the temperature of transformers with service voltage 400kV and above shall, after the filling has been completed, be increased at least to 40°C by circulating the oil through the MOP. The temperature is measured externally at half the tank height. The oil shall be circulated as per ERI document [12] at least twice through the loop/ filter system until the oil quality conforms to the specification. Once the temperature has been reached and the oil has been tested and has reached the oil quality specified in [5] the vacuum pump must be switched off.

Once oil filling has been completed and the temperature and oil quality has been reached the transformer must not be energised earlier than the times given in Table 3 below, this is to promote complete oil impregnation of the insulation and dissipation of any bubbles.

Table 3: Minimum standing time

Rated voltage kV	Minimum impregnation time before application of voltage (hours)
Below 220	24 (1 day)
220 – 400	48 (2 days)
Above 400	96 (4 days)

3.1.7.5 Transformer venting

After filling the transformer are where applicable running the oil pumps for 24 hours, the following components shall be ventilated at their highest points, to release any air trapped inside the transformer tank.

- Buchholz relay
- LV bushings and turrets
- MV bushings and turrets
- HV bushings and turrets
- Radiators
- Oil pumps
- Tap changers/diverters
- Conservator with air cell

3.1.8 Electrical tests to be performed prior to energising

All cold commissioning electrical tests as specified in procedure [17] shall be performed and evaluated. Once the transformer's condition has complied with the requirements of the above procedure, the unit can be prepared for energisation.

3.1.9 Checks on transformer prior to energising

Prior to the energisation of the transformer the following checks must be undertaken:

- Ensure the correct operating position of all valves, including main valves, conservator's valves, cooler valves, online dryers' valves and online oil monitoring equipment valves, etc.
- Ensure oil levels in main conservator, tap changer conservator, HV bushings, MV bushings, LV bushings, and breathers meet the correct levels for the current temperature condition.
- Ensure tap changer, pumps, fans, online dryers and online oil monitoring equipment are ready for service.
- All bushings test caps are installed.
- Ensure temperature gauges are operating correctly.
- Ensure earthing is correct.
- Fast depressurization system is in service mode.
- No loose objects are left anywhere on the transformer body.

3.1.10 Checks on transformer after energizing

- On load checks.
- After energisation oil samples to be taken as per [5].

3.1.11 Soaking time after energizing

Soaking of a power transformer is recommended (not compulsory) for new units and those installed after being refurbished, when the energizing is for the first time. The soaking requirements must be checked with the OEM (manual). The soaking is done in order to observe any irregularities in the insulation, at service voltage, after unit has been assembled on site. During the soaking time the items listed below are to be monitored.

- Abnormal noise,
- Sharp changes in oil temperature,
- Any alarms coming up,
- Rate of rise of the DGA, using the online monitoring equipment (set at hourly rate during this time).

The recommended time for soaking is 12hrs and this time can be reduced to 1 hour for the other units.

4. Authorisation

This document has been seen and accepted by:

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5. Revisions

Date	Rev	Compiler	Remarks
Dec 2020	2	MM Moabelo	Definitions and abbreviations tables updated. Air-dryness requirement added. Moisture in transformer paper insulation: risk profile table was added. Oil filling under vacuum detailed removed from this procedure and referenced to [12].
Jan 2017	1	MG Moiane	Revised vacuum procedure, vacuum leakage testing procedure, oil filling procedure, vacuum holding times and standing times before energisation

6. Development Team

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7. Acknowledgements

Not applicable.