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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 economical considerations. Any of the activities undertaken throughout the lifespan of the unit has the potential to increase the risk to and reduce the lifespan of the unit. The activity which introduces the greatest risk to the unit is the opening up of the unit, site work and oil filling. This activity must be tightly controlled, hence the requirement for this standard.

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

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 comply with the same requirements.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited, Transmission Division, and entities wherein Eskom Transmission has a controlling interest.

This standard is applicable to all oil filled. power transformers and reactors within the Transmission Division and shall be used as a guideline 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] ESP 32-406 – Mineral Insulating oils (uninhibited and inhibited) Purchase, management maintenance and testing.

[6] TPC41 -1088 : Minimum Safety Requirements And Risks Assessment When Doing Internal Inspections On Oil Filled High Voltage Equipment.

[7] ESP 32-136, Construction Safety, Health, and Environmental Management.

[8] SANS 555:1985: Mineral insulating oil for transformers and switchgear (uninhibited).

[9] ESKASAAC2: Management of polychlorinated biphenyls (PCB).

[10] TBP41-3661 Life Cycle Management Plan for Power Transformers and Reactors Transmission approved Rotek Scope of Work and Inspection and Test Plan

[11] NRS 079-2:2006. Application guidelines for the management of insulating oil used in the electrical supply industry

[12] ISO 9001:2000: Quality Management Systems

[13] ISO 14000: Environmental Management Systems

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

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

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

[17] ET-OP-F-01: Rotek Engineering — Evacuating transformer and oil filling on site

[18] ORHVS: Operating regulations for high voltage systems

[19] TPC41 — 140: Secondary plant commissioning of transformers and reactors

[20] EC-ST-F-02: Rotek Engineering- Oil filling of conservator tanks fitted with flexible aircell

2.2.2 Informative

[21] 240-56227424 Rev 1 Standard for commissioning of Power Transformers — Generation

2.3 DEFINITIONS

Definition	Description
Chief Engineer	An appointed person in writing working in the High Voltage Engineering Department Technology Division) at the head office.
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.
Filtered, degassed oil (polishing)	Oil that has been filtered to improve the dielectric strength to 70 kV/2,5 mm gap and water content to less than 10 mg/kg. with a gas content of less than 0.2%.
Impregnation Time	Time period after 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.
Long storage	Storage of a power transformer for a period longer than 3 months.
Major work/intrusive work	refers to maintenance/repair work where the power transformer is drained or dismantled to such an extent that its active part is fully or partly exposed to the atmosphere.
New oil	Virgin oil, shall mean oil, which complies in all respects with ESP 32406 Table 5, SANS 555, IEC 60296 — fluids for Electrotechnical applications. and shall comply with the Cigre Test 2 for low Sulfur content. However, the following tests limits shall apply before filling into clean oil containers for

Definition	Description
	shipment and usage. Dielectric strength (DS) not lower than 70 kV/2,5 mm gap. Water content (WC) not more than 10 mg/kg (or p.p.m.).
Power transformers	Oil filled - Network transformers. coupling transformers, transformers supplying directly to customers, auxiliary transformers. shunt reactors, series reactors
Regenerated oil	Reprocessed used oil, which complies in all respects with SABS 555. However, the following tests limits shall apply before filling into clean oil containers for shipment and usage: Dielectric strength (DS) not lower than 70 kV/2,5 mm gap. Water content (WC) not more than 10 mg/kg (or p.p.m.).
Soaking Time	Time period that the power transformer is left standing after energisation but prior to placing the power transformer on load.
Specialist	An experienced Eskom person who regularly performs specific tasks for which he has been specially educated, trained and appointed and of which he has and maintains an in-depth knowledge

2.3.1 Disclosure Classification

Controlled Disclosure: Controlled Disclosure to External Parties (either enforced by law, or discretionary).

2.4 ABBREVIATIONS

Abbreviation	Description
A:	Acid
DGA:	Dissolved Gas Analysis
DS:	Dielectric Strength
HVE	High Voltage Engineering
ITP	Inspection and Test Plan
kPa	kilopascal
OEM	Original Equipment Manufacturer
ppm	parts per million
PQP	Production (Project) Quality Plan
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 HV Plant Manager for the Grid where the work is undertaken will be responsible to ensure safety. He shall ensure that people comply with TPC41-1088 and ESP32-136.

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

c. Implementation Date

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

2.6 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 HV Plant Managers in the relevant grid 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 management as required.

External observations/audits will be undertaken as required by Transmission PAM staff or Technical Specialists.

2.7 RELATED/SUPPORTING DOCUMENTS

Documents superseded by this document.

240-56062726: Requirements for oil filling, testing and energisation of power transformers and reactors

240-56062726: Dew point measurement, vacuum treatment, leak integrity, and oil circulation for power transformers and reactors

3. INTRUSIVE WORK AND OIL FILLING, UNDER VACUUM OF TRANSFORMERS AND REACTOR ON SITE

3.1 SAFETY PRECAUTIONS

The HV Plant Manager responsible for the work in the relevant grid is responsible to ensure that all work is carried out safely in terms of the ORHVS, as well ensuring risk assessments are undertaken prior to work being carried out as per the TPC41 — 1088 procedure for internal activities on transformers.

3.2 ACTIVITIES TO BE PERFORMED

All transformer or reactor work that requires draining of oil and/or opening of covers shall be checked with the HVE Transformer Chief Engineer or his/her delegate through submission of a relevant scope of work (SOW) and applicable POPs or ITPs before the works start. Once the Transformer Chief Engineer 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 POP No work shall start unless the relevant PQP has been co-signed by the Chief Engineer or his/her delegate.

3.2.1 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.

3.2.2 Internal Inspection or work to be undertaken while active part is exposed to atmosphere

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) at all times to 10kPa. While work is in progress and covers are opened a positive pressure must be maintained in the tank using dry air machines/ dehumidities continuously and 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 and high voltage part of the unit by restricting access and monitoring and ensuring removal of parts 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 workmen leave the tank, only the necessary skilled personnel 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 should be wiped clean before entry. Workers must ensure they do not stand on leads or damage insulation nor pull on connections, only the necessary contact should be made with insulation_

3.2.3 Inspection on completion of work

Once the work has been completed inside the tank, a skilled supervisor/specialist must do an internal inspection inside the tank 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 inspect by HVE, nobody must open or work inside the tank. After all covers have been replaced, 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 25kPa. 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 dry air must be left pressurized in the tank for 48hrs, in order to perform the dew point measurements as indicated below.

3.2.4 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. If the moisture level is above 0.8% a drying out process must be undertaken, a specialist can be contacted to advice on the drying required.

Taking the dew point measurement. Larger transformers are shipped in dry-gas (air or nitrogen). The moisture in the insulation can be determined by monitoring the moisture in the gas. The measurement of measurement of the gas moisture content is called the dew point. After an equilibrium period of 36-48 48 hours of constant temperature, some of the moisture in the insulation will migrate into the gas. The The moisture in the gas is proportional to the moisture in the insulation and can be used to determine the determine the relative dryness of the transformer insulation. The level of moisture is also related to temperature. See

b. Figure 1 for a graph showing the relationship between dew point, temperature and % moisture content on the surface of the insulation.

Figure 1: Surface moisture as function of dew point

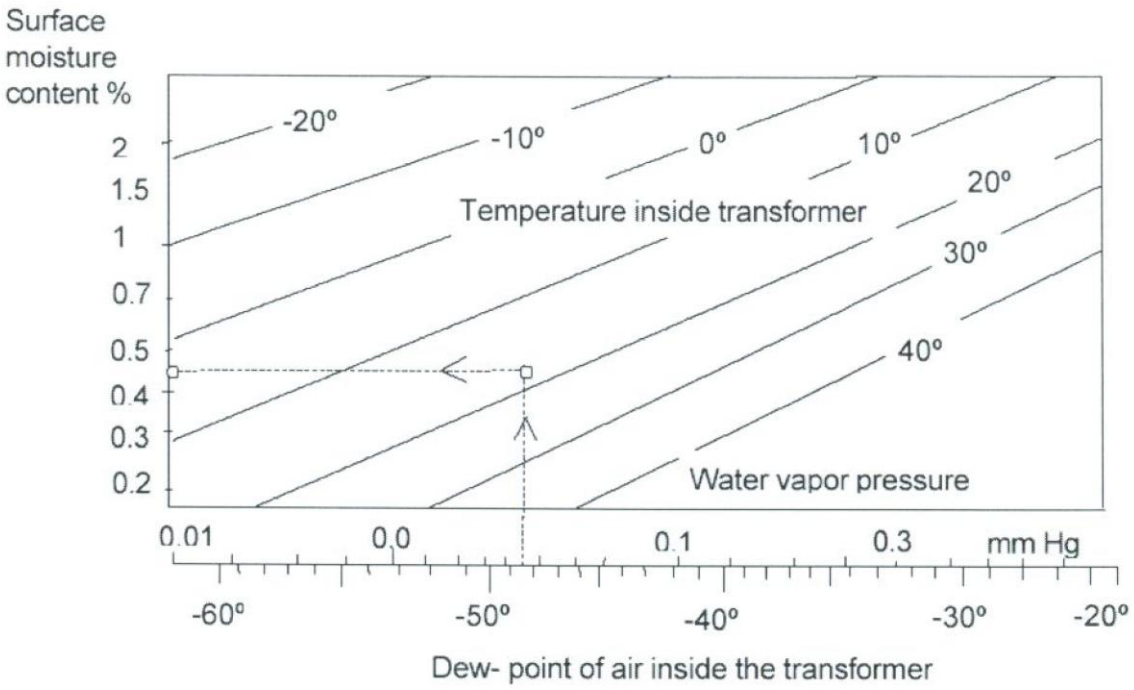

Figure 1 shows how the surface moisture content of the insulation can be read from the moisture content of the gas in the tank, expressed by its dew point temperature. A low moisture content correlates to a low dew point The surface moisture shall be below 0.8%, before final vacuum or a dry out process must be undertaken.

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

3.2.5 Vacuum Treatment

Note: 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 ET-OP-F-01 — Evacuating Transformers and oil filling on site, if no OEM directive is available.

Before filling the transformer with oil, the insulation must be degassed (vacuum treated), before drawing vacuum, do the following:

a. the highest point on the transformer, i.e. top of the conservator tank, is used to draw vacuum from the transformer tank and refer to Table 2 for the applicable data. Ensure that the diverter switch is included when drawing vacuum on power transformers fitted with onload tap changer, and in cases where the conservator is not vacuum-proof, the valve between the conservator and the main tank shall be closed and the drain valve of the conservator opened. If the valve between the main tank and the conservator is not vacuum-proof, the connection between the surfaces shall be disconnected and the connection to the tank shall be blanked off.

b. conservator, cooler, tapchanger, tapchanger barrel/cylinder, and other components resistant to vacuum are evacuated simultaneously. Components which are not vacuum proof shall be protected in a suitable way_ Ensure that balance pipes are fitted to the tapchanger/diverter/selectors and the transformer tank to ensure pressure equilibrium on both sides of barrier boards and diverter barrels to prevent damage

c. ensure that the on-line gas analyser sensors, for example Hydran/Kelman, and on-power dehydration sensors, for example. Dry-keep, installed have been removed before any vacuum is applied on the power transformer.

d. ensure that a final check is conducted on the power transformer with its cooling system to ensure that there are no leaks. If the specified vacuum does not hold. the leak in the power transformer system shall be located and corrected.

3.2.5.2 Leak Test Procedure

During the application of vacuum before oil filling, a leakage test should be made to ensure that the assembled transformer is tight enough to ensure trouble free filling and operation. For the leakage test under vacuum, proceed as follows:

a. Evacuate the transformer until the pressure is below 0,3kPa (3 torr) which should be reached within about 4 hours.

b. Close the valve to the vacuum pump

c. Read off the pressure P1 on the pressure guage after about 1 hour

d. Read off the pressure P2 again, after exactly a further 30 minutes

The leakage L is then calculated according to the formula

L = (P2 — P 1)*V/ t +60

Where

t = time in minutes between the two readings

V = volume of the transformer tank in litres (dm^3)

P2 and P1 are measured in kPa (ton^-)

If the leakage exceeds 3kPa litres/sec (30 torr litres/sec) the leak must be located and repaired before proceeding.

3.2.5.3 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 1 below, and maintained at these levels for the times specified.

Table 1: Minimum evacuation prior to oil filling

Nominal HV system	Minimum degree of vacuum **before oil filling**	Leakage rate **(Max. permitted)**	Vacuum holding time **(min. hours)**
400kV and above	0.5 mm Hg/0.07 kPa/ 0.5torr	3 kPa.litres/second	48 hrs
220kV and < 400kV	1.0nnmHg /0.1 kPa /1 torr	3 kPa.litres/second	36hrs
Below 220kV	1.0mmHg / 0.1 kPa /1 torr	3 kPa.litres/second	15hrs

If the transformer or reactor has been stored (at any time) without oil for a period of more than 3 months, the vacuum holding times should be doubled. If the unit has been stored for longer than 6 months without oil the unit should be oil filled under vacuum (impregnation) for at least 48 hrs before it can be opened to reduce the risk of fast moisture absorption by the solid insulation.

3.2.6 Oil Filling Under Vacuum

3.2.6.1 Oil Quality prior to filling

The oil tanker or holding tank, all hoses, pumping equipment. valves and filters must be for the exclusive use of the power transformer oil or must have been meticulously cleaned and rinsed. Failure to ensure pristine oil and equipment puts at risk the viability of the power transformer operation.

Ensure that the insulating oil (regenerated or/and virgin from the Approved List) conforms to the oil requirements specified. All oil to be filled in transmission transformers must meet the requirements of and IEC 60296 including the requirements for non-corrosive oil and the Cigre 2 test for corrosive sulphur.

Table 2: Oil quality prior to filling

HV	DS	Moisture content	Gas content
All voltages	≥70kV/2.5mm gap	≤10ppm @ 20°C	<0.2%

The requirements of Table 2 are to be demonstrated with a sample taken from the last container before the transformer and at the site of use.

All the transformers and reactors must be filled with only new oil after vapour phasing. The oil to be used for vacuum filling or topping up must be tested before being inserted in the transformer and must comply with the limits listed in the above Table 2. Should the required limits not be met. the oil

shall be filtered in its separate storage container until the results are satisfactory. Only once the required test results are obtained may the oil be transferred, via filtration plant, to the unit to be filled.

3.2.6.2 Oil Filling Under Vacuum

Before the oil is filled into the transformer, it shall be heated to between 40°C and 50°C and filtered through a vacuum filter with a pore diameter of maximum 5pm. Air and water shall be removed so the oil meets the requirements of Table 2 above. The most effective and safest method to purify and dry oil is by circulation through a vacuum filter a few times before it is filled into the transformer. During oil handling, static electricity may be generated in certain types of oil hose. The oil hoses shall therefore be built up around an earthed core or have a built in earth conductor to prevent static electricity from generating a high potential. The filter plant, oil tanker, transformer and all terminals shall also be grounded.

The unit is filled under vacuum, through the bottom valve, up to the correct level in the conservator for the prevailing temperature. The pressure in the tank during the filling shall **not exceed 0.1kPa** (1 **torr)** and the temperature of the oil during filling shall be between 40°C and 50°C.

On load tapchangers and diverter switch housings must be filled according to the OEM instruction for each type.

Separate vacuum proof coolers are evacuated for 1 — 2 hours and filtered separately with purified, degassed oil. The oil is then circulated through the vacuum filter at least twice. When the circulation is completed, open the valve between the coolers and main tank.

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 vacuum filter. The temperature is measured externally at half the tank height.

3.2.6.3 Filling Difficulties

If the prescribed pressure of less than 0,1kPa 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 above 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 5kPa (50 torr hours), evacuate the tank and continue vacuuming the tank for at least 12 hours after the pressure has reached 0,1kPa **(1** torr) before continuing the filling procedure.

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

3.2.6.4 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 vacuum filter. The temperature is measured externally at half the tank height. The oil shall be circulated at least twice through the loop/ filter system until the oil quality conforms to the specification in Table 2 above. Once the temperature has

been reached and the oil has been tested and has reached the oil quality specified in Table 2 above the vacuum pump must be switched off.

To guarantee complete oil impregnation of possible gas bubbles in the insulation, the transformer must not be energised earlier than the times given in Table 3 below, once oil filling has been completed and the temperature and oil quality has been reached.

Table 3: Minimum impregnation time

Rated voltage kV	Minimum impregnation time before application of voltage (hours)
Below 220	12 (0.5 days)
220 – 400	48 (2 days)
Above 400	120 (5 days)

3.2.6.5 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

3.2.7 Electrical Tests to be performed prior to energising

All electrical tests as specified in Transmission procedure

240-56062810: Secondary plant commissioning of transformers and reactors

shall be performed and evaluated. Once the transformers condition has complied with the requirements of the above procedure, the unit can be prepared for energisation.

3.2.8 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, Drykeep valves and on line oil monitor valves, etc.
- Ensure oil levels in main conservator, tapchanger conservator, HV bushings, MV bushings, LV bushings, and breathers meet the correct levels for the current temperature condition
- Ensure tapchanger, pumps, fans, dry keep and oil line oil monitors are ready for service.
- All bushings test caps are installed
- Ensure temperature gauges are operating correctly

- Ensure earthing is correct
- SERGI system is a service , where applicable all flengens
- No loose objects are left anywhere in the transformer body.

3.2.9 Checks on Transformer after energizing

- On load checks
- After energisation oil samples to be taken as per procedure ESP32-406 Application guidelines for the management of insulating oil used in the electrical supply industry

3.2.10 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:

Name & Surname	Designation
	Document Approved by TDAC ROD 13 February 2013

5. REVISIONS

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November 2012	0	S Mtetwa	Draft document for Review created from TST 41-545
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