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TABLES

1. INTRODUCTION

“This document consist of ‘On-site Dry out of Power Transformers within Generation Group”

2. SUPPORTING CLAUSES

2.1 SCOPE

2.1.1 Purpose

The document lays down standard procedure to be adhered to during onsite drying of power transformer insulation (cellulose paper and oil). This standard procedure focuses on the method of circulating hot oil under vacuum and was developed to ensure that adequate steps are taken prior to and during drying process to limit and reduce the ageing rate of the transformer insulation and to prevent disastrous conditions from occurring.

2.1.2 Applicability

This standard is applicable to all oil immersed power transformers (i.e. Generator, Unit, Service and Station transformers) within the Generation Group.

2.2 NORMATIVE/INFORMATIVE REFERENCES

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] 32-406 Rev 0: Mineral Insulation Oils (Uninhibited and Inhibited) Part 1: Purchase, Management, Maintenance and Testing.

[2] 240-56356472 Rev 1.0: Clean Conditions for Power Transformer Outage Standard

[3] 240-56357579 REV 0.1: Pre-commissioning of Large Power Transformers Standard

[4] OPR 6204 Rev 5: operating regulations for high-voltage systems

[5] RES-01-13339: evaluation of moisture measurement

[6] R Moore: low frequency dry out of generator transformer 4 at Arnot Power Station

[7] SABS 555:1985, mineral insulating oil for transformers and switchgear (uninhibited).

2.2.2 Informative

None

2.3 DEFINITIONS

Definition	Description
Filtered oil (polishing)	Oil that has been filtered to improve the dielectric strength to greater than 70 kV/2,5 mm gap and a water content to less than 10 mg/kg (ppm).
New oil	Virgin oil, which compiles in all respects with requirement of ESKASCAAR9 Rev.0
Power transformers	Generator transformers, Unit transformers, Service and Station transformers.
Regenerated oil	Processed or re-refined used oil, which compiles in all respects with SABS 555, 1985. However, the following tests limits shall be met on point of loading/filling and prior to energising: (a) Dielectric strength (DS) greater than 70 kV/2,5 mm gap. (b) Water content (WC) less than 10 mg/kg (ppm).

2.3.1 Classification

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

2.4 ABBREVIATIONS

Abbreviation	Description
	None

2.5 ROLES AND RESPONSIBILITIES

None

2.6 PROCESS FOR MONITORING

None

2.7 RELATED/SUPPORTING DOCUMENTS

None

3. ON-SITE DRY OUT OF POWER TRANSFORMERS WITHIN GENERATION

3.1 REQUIREMENTS

3.1.1 Safety precautions

The power station HV operating procedure, OPR 6204 Rev 5, shall be adopted when entering the power transformer yard

The transformer shall be isolated from all sources of supply and a permit shall be issued as per HV regulation.

3.1.2 Station responsibilities and actions

The details of power station-specific responsibilities and actions will depend on the management instructions in place at each power station; however the power station management is responsible to ensure that the moisture in both the paper and oil insulation is within the Eskom moisture content limits. Power stations are required to have a detailed document entailing responsibilities of different persons.

3.1.3 Operational

3.1.3.1 Site pressing and reclamping

The majority of the Generator Transformer designs at the power stations do not accommodate pressing and reclamping of the transformer windings and structures at site should over drying be experienced. Refer to Eskom Generation report of 1996 by R Moore: Low Frequency Dry out of Generator Transformer 4 at Arnot Power Station.

Therefore site drying shall be conducted with caution and accuracy to eliminate pressing and reclamping of the windings and transformer structures on site.

Therefore site drying shall be conducted with caution and accuracy to eliminate pressing and reclamping of the windings and transformer structures on site.

3.1.3.2 Moisture measurement

The transformer system engineer is obliged to take part in determining the moisture contents in transformer oil and paper insulation prior to applying any power transformer dehydration system. Determining the amount of moisture contents in the paper insulation can be achieved by utilisation of various **online insulation moisture measurement systems** described in Eskom Research Report: **RES/RR/01/13339.**

The equilibrium curve method can be utilised on condition that the transformer loading (operating temperature) is kept fairly constant for a certain period of time (at least 2 days) to achieve quasi-equilibrium state.

All these methods used to determine the moisture contents in power transformer insulation only give an indication of the amount of moisture present in the oil and cellulose insulation. Hence, all the relevant factors like the weight of cellulose paper in the transformer and its DP should be considered when determining the amount of moisture to be removed from the transformer insulation (oil and cellulose paper) as miscalculation may result in uneconomical and transformer service life threatening situations.

3.1.3.3 Moisture limits

The Eskom research report **RES/RR/01/13339** details some of the moisture limits that serves as guides that are utilised by various utilities worldwide in ascertaining the wetness of the transformer cellulose paper insulation, refer to Table 1. Since these limits only serve as guidelines, it is encouraged to adopt a more conservative approach to reduce risks of over drying, see **guide 1 and 2**.

Voltage	Guide 1	Guide 2	Guide 3
< 110 kV	3.0 %	3.2 %	2.0 %
< 220 kV	2.8 %	3.0 %	1.5 %
> 220 kV	2.6 %	2.8 %	1.0 %

Table 1: Transformer paper insulation moisture limits

Note: Considering the presumed moisture contents in the fleet of power transformers within the Generation Group, **guide 3** seems to be more stringent and may result in over drying of the power transformers. However, this may be considered on new, repaired and refurbished power transformers that are equipped with on-line dehydration systems.

Table 2 shows the IEC Guide that provides a more risk incline approach to activating drying of the cellulose insulation.

Moisture in paper insulation	Risk
<1.7 %	None
1.7 to 2.2 %	Low – accelerated ageing
2.2 to 3.0 %	High – accelerated ageing
> 3.0%	High – corrective action required

Table 2: Transformer Paper Insulation Moisture Risk

3.1.3.4 Determining the paper condition

The system engineer shall strive to determine the condition of the power transformer paper insulation prior to dehydration process. Determination of the strength of the paper insulation assists in determining by the extent to which the power transformer must be dried and/or how much negative effect does the dehydration process have on the paper condition. The paper condition can be ascertained either through:

(a) Taking paper samples to perform degree of polymerisation analysis or

(b) Taking oil sample to perform 2-furfural analysis

N.B: Previous filtering or processing of the power transformer oil must be taken into consideration when analysing the 2-furfural results as they may lead astray if the oil was polished or filtered before. The 2-furfural analysis shall be done before and after dehydration process whereby the results obtained after dehydration process shall only be used for future reference.

Should it be possible to take paper samples for DP analysis, this shall be done before and after dehydration process. The paper sampling for DP analysis shall be done using the Doble method.

3.1.3.5 Moisture dehydration

Once the condition of the paper insulation and the amount of moisture present in the oil and paper insulation is determined, the percentage amount of moisture to be dried from the paper insulation shall be determined to reduce the risks of over-drying the power transformer.

Furthermore, the dehydration process shall be monitored and tests shall be performed on continuous

basis to ensure that over drying is avoided.

N.B: Over drying may trigger costly exercise of transporting the transformer to the workshop for pressing and re-clamping. Over-drying may also result in paper deformation or shrinkage that in the future may result in inter-turn and/or inter-layer failure of the power transformer.

3.1.3.6 Hot oil circulation dry out method under vacuum

This type of dehydration is common at Eskom generation power stations and is considered to be rigorous and can have negative effect on the transformer paper insulation. Therefore it is important to reiterate that this type of dehydration system shall only be used on power transformer with DP > 400. Otherwise, other less disruptive and less rigorous processes shall be utilised.

The following shall be undertaken prior to utilisation of this dehydration process:

(a) Determine the moisture contents, oxidation stability, dissolved gas analysis, acidity and dielectric strength

(b) Determine the paper condition either using 2-Furfural analysis or use paper samples for DP analysis

(c) Ensure that no bubble or foreign particle are introduced into the power transformer

(d) Ensure that the transformer oil storage bags are not contaminated prior to utilising them

Table 3 shows the tests that shall be performed on completion of the dehydration process.

Within 2 days of completion	After 3 months of completion
Moisture contents	Moisture contents
Oxidation stability	2-Furfural
Acidity level	Acidity level
Dielectric strength	Dissolved gas analysis
DP where possible	Dielectric strength

Table 3: Post dehydration tests

Procedure to be followed

This procedure describes the method whereby oil filled transformers shall be dried out by circulating hot oil under vacuum.

N.B: During the dehydration process, ensure that there is continuous monitoring of the moisture removed from the transformer to prevent over drying of the insulation.

1. Drain the transformer insulating oil into the oil storage bags.
2. Prepare the drying out plant in accordance with the manufacturer's instructions.
3. Fit an oil level indicator between the top and bottom of the transformer tank. Reinforced clear plastic pipe shall be utilised.
4. Isolate the conservator tank and the Buchholz relays.

5. Refer to the transformer nameplate data to determine if the cooling system should be isolated when drawing vacuum. Then isolate or do not isolate the cooling system accordingly.
6. Draw cold vacuum on the transformer tank until the internal vacuum is below 0.25 kPa (1.875 Torr) or the vacuum remains constant for four hours.
7. Isolate the mobile oil plant vacuum pump from the transformer and allow the internal pressure to stabilise for a period of at least one hour.
8. After the stabilisation period, check the leakage rate as follows:

   (i) Immediately after the stabilisation period elapses, record the vacuum pressure reading (P1) directly on the vacuum gauge

   (ii) After time period of 30 minutes (or 1800 seconds), record another vacuum pressure reading (P2) directly on the vacuum gauge

   (iii) Calculate the leakage rate factor according to the formula:

$$L = \frac{(P2 - P1) \times V}{t} \quad Pa\ l/s$$

Where

T = time in second between readings (usually 1800 seconds)

V = total internal oil volume of transformer main tank in litres.
If the conservator and the radiators are isolated, volume of oil in the transformer main tank will be total transformer oil volume less 5% of oil in the conservator tank and 5% of oil in the radiators

   (iv) The leakage rate shall not exceed 3 000 Pa l/s. If the leakage rate exceeds this value, the leak shall be located and rectified. The leakage rate test shall then be repeated until satisfactory results are obtained.

9. Draw cold vacuum on the transformer main tank for 24 to 48 hours. The internal vacuum to be less than 0.13 kPa (0.975 Torr). Isolate the vacuum pumps on the mobile oil plant but do not break the vacuum on the transformer main tank.
10. Thoroughly lag the transformer main tank with thermal insulating blankets/sails to retain the heat.
11. Whilst the transformer is still under vacuum feed the oil from the oil storage bags through the mobile oil plant (dry out plant) into the transformer main tank at a high level connection.

    (i) The temperature of oil shall not exceed 60 °C for the first filling only. However, the temperature of oil for the subsequent fillings and cycles shall be 75°C ± 5°C and not more than 80°C.

    (ii) A minimum vacuum of 0.13 kPa shall be maintained throughout the filling stage of the transformer. Should the vacuum of 0.13 kPa not be maintained, the oil feed rate shall be reduced accordingly.

    (iii) Take the oil samples for Dielectric Strength, Water Contents, Acidity and Oxidation stability.

12. When the oil level has risen to a point 500 mm below the vacuum connection of the transformer, the vacuum pump to the transformer shall be isolated and stopped.

13. The oil in the transformer main tank shall be circulated through the mobile oil plant to build up the heat within the transformer main tank:
    (i) Oil shall be removed from the bottom main tank, pass via the mobile oil plant and be returned to the transformer through the top valve of the main tank
    (ii) The oil shall be heated by passing it through the mobile oil plant until the incoming oil to the heated bank reaches 75°C ± 5°C. The temperature of the oil leaving the heaters shall not exceed 80°C.
    (iii) The circulation period is normally 48 hours (see 3.1.3.6-14)
14. The hot oil shall then be circulated through the active parts of the transformer for a period of 48 hours maintaining these temperatures.
15. When circulation period is complete, drain the oil completely from the transformer through the mobile oil plant at a maximum capacity of the mobile oil plant to the storage bags
16. When draining is complete, apply vacuum to the transformer. Immediately after the vacuum start, the vacuum readings shall be recorded as follows:
    (a) 6 readings x 1 minute interval
    (b) 3 readings x 3 minute interval
    (c) 3 readings x 5 minute interval
    (d) 3 readings x 10 minute interval
    (e) 2 readings x 15 minute interval
    (f) 2 readings x 30 minute interval
    (g) Thereafter record hourly readings until the vacuum stabilises for 4 hours

    Note: A typical vacuum drawing period is 24 to 48 hours and vacuum normally stabilises at 0.13 kPa.
17. Plot the graph of vacuum in (Pa) on the Y–axis to time (t) on the X–axis.
18. Repeat steps in paragraph 3.1.3.6-11(ensuring that temperature of the oil is75°C ± 5°C), to 3.1.3.6-17 until a vacuum of 0.02 kPa is achieved or until the last two graphs co-inside. Usually 3 or 4 drying cycles are sufficient
19. Fill the transformer with hot oil as in paragraph 3.1.3.6.12. Take oil samples for DS, A, WC and Oxidation Stability. Remove the lagging blankets and cool down the continuously monitor the Water Contents in oil, Oxidation Stability, and Dielectric Strength during or after each cycle. Active parts by circulating oil cold through the mobile oil plant until the oil temperature at the transformer exit is 30°C maximum.
20. Break the vacuum with dry nitrogen. If the atmospheric humidity is less than20 %, break the vacuum with dry air.
21. Remove vacuum pipework and fill the transformer to the specified level in the conservator tank. Note that both the conservator tank and the cooling system are not isolated at this stage.
22. Bleed the transformer from all bleeding points to remove air pockets that maybe trapped in the transformer.
23. Circulate the total quantity of oil hot through the mobile oil plant for 48 hours at temperature above 60°C and below 80°C. Then circulate the total quantity of oil through the plant for 48 hours with the heating system being switched off to achieve temperature of 30°C and below. Take the final oil sample to test for WC, DS, A and Oxidation Stability.
24. Keep a record of the following data:

(a) The number of drying circles completed

(b) Total amount of water content removed

(c) Final analysis of the oil showing A, DS, WC, DGA and Oxidation stability

(d) Graph of each cycle completed

4. AUTHORISATION

This document has been seen and accepted by:

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5. REVISIONS

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6. DEVELOPMENT TEAM

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