MANAGING OIP TRANSFORMER BUSHINGS ON ESKOM & NTCSA'S TRANSFORMERS: STANDARDIZATION AND REPLACEMENT CHALLENGES

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ABSTRACT

Oil-impregnated paper (OIP) bushings have been widely used in the Eskom and National Transmission Company South Africa (NTCSA) transformer fleet. Over the years, these bushings have shown varying levels of performance, with certain defects leading to catastrophic failures. The introduction of resin-impregnated paper (RIP) technology in 2007 marked a shift towards safer and more reliable components. This paper examines the history, challenges, and advancements in bushing technologies in Eskom and NTCSA.

INTRODUCTION

A bushing is a device that enables one or several conductors to pass through a grounded barrier, such as a transformer tank. It provides insulation between the high voltage in winding electrical connection and the transformer main tank, which is at earth potential. Bushings are therefore one of the critical components in transformers and reactors. Transformer bushings are designed to last between 20 and 30 years, depending on their operating conditions and the type of technology used. As transformers have an expected lifespan of approximately 40 years, it is anticipated that each transformer will require at least one bushing replacement during its service life.

In South Africa, both Eskom and the National Transmission Company South Africa (NTCSA), previously known as Eskom Transmission, have implemented oil-impregnated paper (OIP) bushings in their transformers. In 2007, resin-impregnated paper (RIP) technology was introduced in all Eskom divisions fleet due to its superior fail-safe features and reduced fire risk. This introduction coincided with the standardization of transformers and their components by Eskom, which was aimed at achieving consistency, compatibility, and optimized spares management. Although network voltages are standardized nationwide, transformers across the network feature different sizes of bushings for the same voltage levels.

This paper explores the history and current state of bushing technologies in South Africa's transformer network. It outlines management of OIP bushings, replacement with dry bushings and challenges encountered during this phase.

MANAGEMENT OF OIL-IMPREGNATED PAPER (OIP) BUSHINGS

There have been several defects experienced on different OIP bushing makes. Some OIP bushings with specific and known defects, which have resulted in severe transmission transformer failures, were replaced through a national project, while others were modified. The modified bushings were at 132kV and 88kV, while 400kV and 275kV bushings were replaced. The remaining OIP bushings are governed by a technical instruction that was originally designed for specific bushing models but has since developed into a comprehensive guide applicable to all OIP bushings. This instruction guide outlines specific measures to be implemented for OIP bushings that have been in operation for over 20 years, providing guidance for the business. The guideline entails assessing the condition of each OIP bushing through testing, visual inspections, and infrared scanning. Based on the bushing's state, a decision is made to either enhance monitoring frequency, replace the bushing, or continue with the standard monitoring routine. This guideline is detailed in Table 1 below.

Table 1
Bushings Condition Assessment Guideline

Test	Frequency	Findings	Action
Visual inspection	As per maintenance documents	Discoloration of gauge glass, no oil level and oil leak is evident from bushing compartment	Remove the bushing from service and scrap it
Tan delta and capacitance test	As per maintenance document	Tan delta < 0.5	Keep in service if no leaks or thermal issues.
		0.5 ≤ tan delta < 0.7	Keep in service, test yearly and plan for replacement
		Tan delta >0.7%	Immediately remove from service and scrap it
Infrared scanning for local overheating check	6 monthly	Overheating detected when comparing phases	Investigate the thermal problem and fix it, if not correctable, replace the bushing.

OIL-IMPREGNATED PAPER (OIP) BUSHINGS HEALTH APPRAISAL

In 2020, an interim OIP bushings health appraisal was conducted on the NTCSA bushings. The test results of 54% of the OIP bushings in service were analyzed and the results are, as indicated below, broken down into different regions. The primary reason for the low number of analyzed results was data management. Although bushing testing is part of routine transformer maintenance, most of the test results are stored on individual computers, making them difficult to retrieve. This study served as the foundation for what has now become a standard practice in managing OIP bushings. It provided operating units with clear guidance on which bushings should be removed from service and which ones required close monitoring. Additionally, it emphasized the importance of analyzing test results before returning transformers to service. Although not all results were available during the study, a significant number of bushings have since been replaced due to their deteriorated condition. As a result, those specific findings are no longer relevant to our records, as the affected bushings have already been replaced.

Furthermore, as highlighted in the previous section, bushing replacement decisions are not solely based on tan delta values. Many other bushings have been replaced due to various conditions, as outlined in Table 1. The most significant achievement of this initiative was the strong emphasis on following the technical instruction, which ultimately yielded positive outcomes.

Table 2
Fleet Condition per Region

Grid	Tested bushings (%)	Bushings for replacement (no.)	Bushings requiring increased monitoring frequency (no.)
Region 1	88%	1	2
Region 2	33%	7	27
Region 3	75%	0	24
Region 4	86%	0	22

Grid	Tested bushings (%)	Bushings for replacement (no.)	Bushings requiring increased monitoring frequency (no.)
Region 5	91%	0	55
Region 6	32%	1	9
Region 7	76%	6	57
Region 8	81%	4	33
Region 9	85%	4	42

This process led to a greater number of transformers being subjected to bushing testing, with a stronger focus on analyzing the results. However, several challenges were encountered during this initiative, including issues related to both testing and replacement, which will be discussed in the following sections.

BUSHING TESTING CHALLENGES

As not all bushings had test results, this led to an increased number of transformers being taken out of service for testing when possible. During this process, testing challenges, such as the ones outlined below, were encountered.

1. **Lack of Nameplates and Reference Values:** Older bushings often lack nameplates or reference capacitance, and power factor values are illegible, making it difficult to assess their condition accurately during testing. In this instance, the test results were evaluated solely based on the criteria outlined in Table 1, which may not be entirely accurate for technologies like resin-bonded paper, as they typically exhibit inherently higher tan delta values.

2. **Absence of Test Taps:** Many older bushings, especially those of lower voltage ratings do not have test taps, which complicates the testing process as these bushings cannot be tested easily without these connections. Additionally, the hot collar test is not a common test that testing technicians are familiar with or equipped to perform. As a result, the alternative is to remove the bushings from the transformer for testing, after which a decision is made to either return them or replace them. This has made bushing testing more cumbersome and time-consuming.

3. **Environmental Factors (Dust, Dirt, Atmospheric Moisture):** In some areas of South Africa, the dusty environment can significantly affect test results. Dirt on the bushing surface often leads to higher power factor readings, requiring the bushings to be cleaned and retested. In coastal regions, where morning moisture levels are high, it is advisable to wait for the sunlight to dry the moisture before performing tests. This has become common practice to ensure the accuracy of test results.

4. **Negative Power Factor Readings:** There have been many instances where negative power factor readings or close to zero readings were observed. Some of these were due to incorrect test connections to grounded apparatus. This can usually be corrected by ensuring proper connection procedures. However, many testers are unfamiliar with interpreting such readings, leading to delays as transformer specialists are often consulted for guidance before testing can proceed.

CHALLENGES DURING REPLACEMENTS

Replacing bushings, especially those in large transformers, has been and continues to be a complex and costly process. The introduction of dry bushings as the new standard, in standardized sizes, in Eskom/NTCSA’s transformer fleet continues to require careful planning and coordination. Transformers need to be taken out of service, either for testing or during the replacement process. This has often led to transformers being out of service for longer than usual outage times. Additionally, replacing bushings on transformers with varying sizes and specifications has added and continues to add an extra layer of complexity to the replacement effort, due to the need for modifications to accommodate the installation of new bushings.

1. Variation in Bushing Sizes

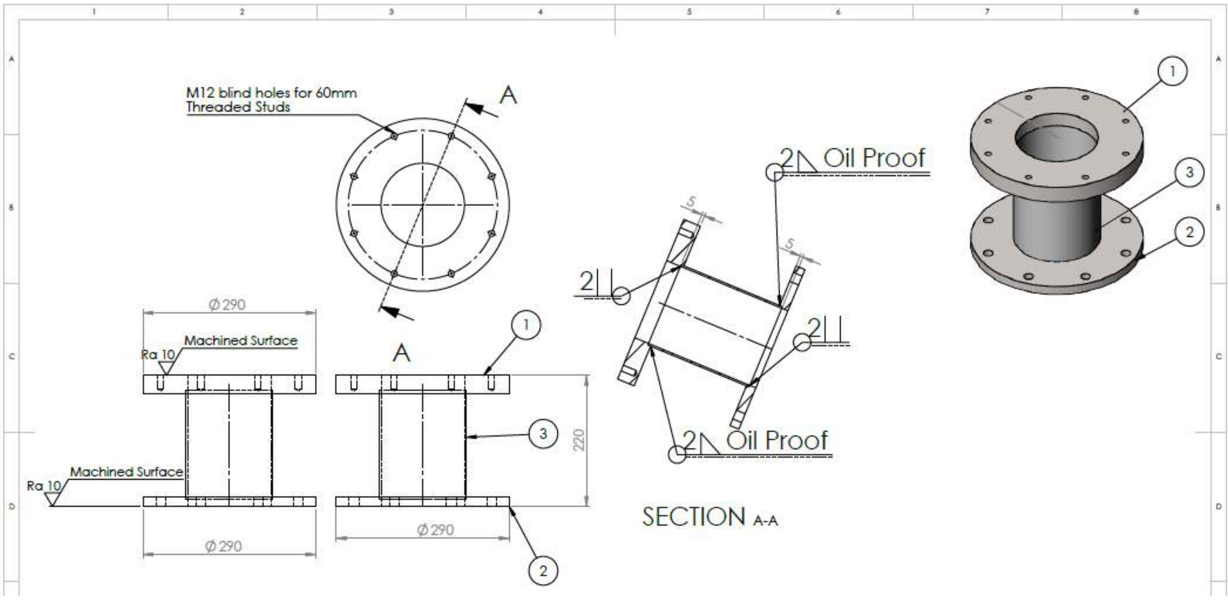
The differing sizes of bushings installed in Eskom/NTCSA transformers, even for those with comparable voltage ratings, reflect a historical issue within the network. As a result, despite uniform network voltage levels, there is no consistent standard for bushing sizes across the fleet. An example of this variation is shown in Table 3 below in a 132kV 1250A bushing from the same manufacturer. Some of these variations could be identified from drawings, while for others, where drawings are unavailable, the measurements are taken when the bushing is removed from the transformer. This has resulted in longer outage durations. Some bushing drawings were unclear, showing multiple possible conductor connections without specifying which one applied to a particular transformer. This ambiguity often leaves field engineers uncertain about the correct configuration for a specific unit. This further complicates the modification process as conductor modifications can only be confirmed once the bushing has been pulled out of a transformer.

Table 3
Variation in Size of 132kV 1250A Bushings

	Bushing A1	Bushing A2	Bushings A3	Bushing A4	Standardized Bushing
Oil Side Length (mm)	580	740	940	1130	660
Flange diameter(mm)	335	335	335	520	290
PCD (mm)	290	290	290	470	250
Fixing bolts (no. x mm)	12 x 16 (Ø)	12 x 16(Ø)	12 x 16(Ø)	12 x 20(Ø)	8 x 16(Ø)
CT extension length	150	300	480	600	300
CT Ext diameter	200	160	190	325	160

Typical design modifications include

- manufacturing of adaptor flanges to be rewelded on existing flanges,
- manufacturing new solid rods (conductors), or machining replacement conductor to required lengths,
- cutting of exit leads to be connected into shortened conductor,
- manufacturing an adaptor turret where the replacement bushing is longer than an existing bushing.



An Example of an Adaptor Design
Figure 1

CASE STUDY - A TRANSFORMER ON FIRE DURING BUSHING REPLACEMENT

Bushing replacement was carried out to prevent a catastrophic transformer failure. However, at NTCSA, an incident occurred when a healthy 27-year-old 250MVA 400/132/22kV transformer was taken out of service to replace OIP bushings with deteriorated insulation. During the scope of work execution, modifications were made to the bushing turrets and flanges, which involved some welding activities. Unfortunately, a welding spark made its way into the active part of the transformer, resulting in a fire. The internal damage and contamination of the active part rendered the transformer unserviceable. This was an unfortunate incident that could have been avoided by adhering to proper procedures.

Burned Top Yoke Covered in Fire Soot
Figure 2a

Burned LV Lead, and Core Clamping Structure
Figure 2b

The Turret Where Welding Was Taking Place
Figure 2c

CONCLUSIONS

Oil-impregnated paper (OIP) bushings have played a significant role in the history of Eskom and NTCSA's transformer networks. However, various defects and failures have led to the introduction of more reliable and safer alternatives, such as Resin-impregnated paper (RIP) bushings. The paper highlighted various issues related to OIP bushing performance, how Eskom/NTCSA manages the OIP fleet and the challenges experienced while replacing these with alternative technologies, such as RIP bushings.

Key findings include:

Bushing Management: OIP bushings are being actively managed through regular testing, visual inspections, and infrared scanning. Bushing replacement and condition assessments are carried out based on the age and condition of the bushings, with recommendations for replacement or increased monitoring when necessary.

Testing Challenges: Several challenges were identified during the bushing testing process, including the lack of nameplates or reference values on older bushings, the absence of test taps on many bushings, environmental factors affecting test results, and instances of negative power factor readings due to improper connections. Moreover, the issue of record management was identified, which led to many test results unavailable for analysis, thus calling for retesting of bushings.

Replacement Challenges: The replacement of bushings, especially in large transformers, remains a complex and costly process. Issues such as variations in bushing sizes across transformers, even with the same voltage ratings, lead to longer outage durations and additional modifications. The need for remanufacturing of some bushing parts, such as adapter flanges and turret modifications, further complicates the replacement process.

The goal of managing OIP bushings was to prevent catastrophic transformer failures, typically resulting in fires. However, an unfortunate incident occurred during a replacement in which a transformer caught fire. This incident serves as an example of human error, which is an inevitable aspect of fieldwork. It underscores the importance of strictly following proper procedures during bushing replacements to avoid such catastrophic failures.

In summary, the paper underscores the importance of understanding the assets in place, assessing their condition, providing clear guidelines for monitoring and testing, meticulously planning testing and replacements, and implementing proper procedures. These steps are crucial to ensuring the reliability and safety of bushing replacements within Eskom and NTCSA's transformer network, ultimately contributing to the overall reliability of the entire transformer fleet.

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BIOGRAPHY

Ms. Khayakazi Dioka is a Corporate Specialist for Transformers and Reactors at Eskom NTCSA. She holds a BSc in Electrical Engineering and an MSc in Engineering, both from the University of Cape Town. Khayakazi's expertise lies in transformer specifications, design reviews, factory capability assessments, factory acceptance testing, failure investigations, asset health appraisals, and providing technical support throughout the lifespan of transformers until the end of their service life. Additionally, she develops and offers training on transformers to other employees.

Khayakazi is a member of CIGRE SC A2, the convener of the Transformer Technology Advisory Group, and served as the International Chair for CIGRE Women in Engineering (WiE) from 2019 to 2022. She has contributed chapters to two CIGRE Green Books, one on Transformer Procurement and the other on Transformer Life Management. Throughout her career, she has made significant contributions to various technical bodies. Furthermore, Khayakazi is deeply passionate about women's empowerment and mentors many engineers.

Mr. Sandile Ngubane, has been employed at Doble Engineering since 2011, and has worked as Field Service Engineer and currently works as a Technical Services Manager in the Client Service Department. There he was primarily involved in testing and diagnostics of High Voltage Plant, interpretation of data and research into new technologies and practices. He is currently a member of Cigre working groups A2 and D1. Mr. Ngubane received his Bachelor of Technology degree in Electrical Engineering from the Durban University of Technology and he is currently pursuing a master's degree in electrical engineering from the Electrical Institute of Technology