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EVOLVING COMPREHENSIVE TESTING METHOD TO EVALUATE THE PERFORMANCE OF OIP BUSHINGS ON ESTER OIL FILLED TANKS.

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Abstract

With the increasing shift towards environmentally sustainable and more efficient insulating fluids, natural ester and synthetic ester oils are being considered as viable and preferred alternatives to conventional mineral oil in power transformers. The Transformer Bushings used for such Ester Filled Transformers are hermetically sealed Oil- impregnated Paper (OIP) Bushings or resin-impregnated paper (RIP) bushings. The OIP bushings are hermetically sealed and are filled with mineral oil. The impact of the ester oils [either natural ester oil (NEO) or synthetic ester oil (SEO) filled in the transformer], on the high voltage performance of the transformer bushings requires comprehensive testing & investigation. The technical paper elaborates on the study to investigate the dielectric performance of OIP transformer bushings (Rating: 72.5 kV 800 A 300 BCT, with Dimensions confirming to IS12676) when mounted on the test tanks filled with NEO and SEO Oils.

A series of dielectric routine and type tests have been performed in line with requirements specified in IEC 60137, including Capacitance, Tan Delta, power frequency withstand voltage, partial discharge test, and lightning impulse voltage etc. In addition, extensive negative impulse voltage tests have been performed at the rated lightning impulse withstand voltage & also up to 410 kV_p to evaluate insulation strength and overvoltage stress withstand capability. This guided us to determine the margin beyond the impulse voltage rating. The results provide critical insights into performance of conventional OIP Bushing, when mounted on NEO/SEO filled transformers.

1. Introduction

The shift towards sustainable and fire-safe transformer insulation technologies has sparked significant interest in alternative insulating fluids. Conventional mineral oil, which has been widely used in power transformers, is now being reconsidered due to environmental concerns and fire risks. In response, natural ester and synthetic ester oils have emerged as potential alternatives, offering better biodegradability, higher flash points, and improved moisture tolerance. While these benefits are widely acknowledged, their effects on critical transformer components, such as bushings, remains a key area of technical investigation.

Bushings connect the transformer winding lead to external transmission / distribution network by providing high voltage insulation to earth. OIP and RIP are the two most common bushing technologies used for power transformers. OIP bushings are filled with mineral oil, while RIP bushings rely on a solid insulation system free from oil. Since ester oils exhibit different dielectric and thermal properties compared to mineral oil, it is essential to thoroughly investigate their impact on bushing performance to ensure long-term reliability.

Recent studies have highlighted the potential impacts of alternative insulating fluids on electrical insulation configuration, particularly changes in dielectric characteristics. However, there have been limited technical studies focused specifically on the high-voltage performance of OIP bushings as mounted on ester-filled test tank. Therefore, this study aims to systematically assess the dielectric behaviour of 72.5 kV 800 A 300 BCT OIP and RIP bushings mounted on test tanks filled with NEO and SEO oil. The investigation includes a series of conventional dielectric tests according to IEC 60137, as well as extensive impulse voltage testing

to evaluate insulation withstand capabilities and overvoltage endurance. It is to be noted that each series of standard dielectric tests was conducted for three consecutive cycles at an interval of seven days to assess the repeatability and stability of the insulation performance. This research offers essential insights into the effectiveness of conventional OIP bushings when used in ester-filled transformers. By examining important performance parameters such as capacitance and Tan Delta & potential compatibility issues, this study enhances understanding of insulation performance in alternative fluid environments.

The NEO & SEO Oils for the tests were sourced from M/s Savita Oil – Mumbai. The Brand Name of Savita’s NEO Oil used is BIOTRANSOL HR & the Brand Name of Savita’s SEO Oil used is TRANSOL SYNTH 100. Their main properties are summarised below, as compared with MO,

Property	MO	NEO	SEO
Density	0.86	0.92	0.95
Viscosity 40°C	16.5	50	35
Flash Point	140	250	250
Pour Point	-30	-10	-45
Tan Delta	0.002	0.05	0.03
Acidity	0.01	0.06	0.03

2. Test Procedure: High Voltage Tests (routine tests and type tests)

The bushings have been tested for the routine tests and type tests in line with the requirements of IEC 60137 when mounted on NEO and SEO filled test tanks.

Sr. No.	Test Particulars	Voltage Levels (kV)
1	Capacitance & Tan Delta	10 kV, 72.5 kV
2	AC withstand + PD test	154 kV, 50 Hz (1 min)
3	Capacitance & Tan Delta	10 kV, 72.5 kV
4a	Lightning Impulse Test (+ve)	15 applications @ 325 kV _p
4b	Lightning Impulse Test (-ve)	1 application @ 358 kV _p

4c	Chopped Lightning Impulse Test (-ve)	5 applications @ 393 kV _p
4d	Lightning Impulse Test (-ve)	14 applications @ 358 kV _p
5	Capacitance & Tan Delta	10 kV, 72.5 kV
6	AC Withstand + PD Test	154 kV, 50 Hz (1 min)
7	Capacitance & Tan Delta	10 kV, 72.5 kV

Table 1. High voltage test sequence for bushings mounted on NEO and SEO filled test tanks.

For each cycle of series of dielectric tests in line with requirements of IEC 60137, the bushings withstood 154 kV dry power frequency voltage for 1 minute with partial discharge (PD) < 10 pC at 154kV. Capacitance and Tan Delta measurement (before and after HV tests) – C1 (Between HV Terminal and Test Tap) are tabulated in Table 2.

At 10 kV & 72.5 kV, for NEO & SEO Filled Test Tanks, the change in the capacitance and Tan Delta is negligible that suggests stable dielectric behaviour and consistent insulation performance. As a next step, the impulse voltage withstand tests were carried out across three cycles to evaluate the dielectric strength of the OIP bushings under impulse overvoltage conditions.

Bushings-Oil Test Tank	Test Voltage (kV)	Cycle 1	
		C (pF)	Tan Delta (%)
OIP-NEO	10	245.1	0.182
	72.5	245.1	0.183
OIP-SEO	10	247.5	0.183
	72.5	247.5	0.185

Bushings-Oil Test Tank	Test Voltage (kV)	Cycle 2	
		C (pF)	Tan Delta (%)
OIP-NEO	10	244.9	0.202
	72.5	244.9	0.203
OIP-SEO	10	247.2	0.189
	72.5	247.2	0.190

Bushings-Oil Test Tank	Test Voltage (kV)	Cycle 3	
		C (pF)	Tan Delta (%)
OIP-NEO	10	244.9	0.202
	72.5	244.9	0.203
OIP-SEO	10	247.2	0.189
	72.5	247.2	0.190

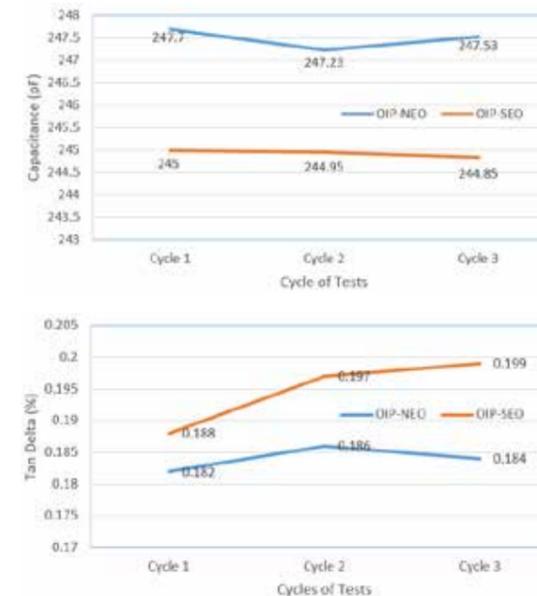
OIP-NEO	10	245.2	0.205
	72.5	245.3	0.198
OIP-SEO	10	247.3	0.184
	72.5	247.4	0.184

The bushings withstood all positive and negative impulse voltage applications without flashover or breakdown, i.e., it exhibits stable impulse withstand behaviour. The details of impulse voltage tests are compiled in Table 3.

OIP-NEO	OIP-SEO
Impulse voltage (kV _p)	Impulse voltage (kV _p)
325 (+ve) (15 applications)	325 (+ve) (15 applications)
-358 (-ve) (1 application)	-358 (-ve) (1 application)
393 (-ve) (5 applications)	393 (-ve) (5 applications)
358 (-ve) (14 applications)	358 (-ve) (14 applications)

Table-3 Impulse Applications

The trends of Capacitance and Tan Delta values (at 72.5 kV) are shown in Figure.1.



The Tan Delta values showed negligible changes, which are within acceptance limits. The observed minor variations can be attributed to dielectric relaxation effects and minor charge accumulation during successive impulse applications. The consistency of the capacitance and Tan Delta values before & after the impulse test suggests

that no significant changes in insulation. These results confirm the reliability of OIP bushings under impulse conditions.

After assessing Capacitance and Tan Delta variations, both the OIP bushings (mounted on NEO and SEO oil-filled test tanks) successfully withstood the HV AC application at 154 kV for one minute, with partial discharge (PD) < 10 pC. Since PD remained within the limits even at One Minute Withstand Level, this confirms insulation integrity.

Capacitance and Tan Delta measurements were repeated & the results are presented in Table-4.

Bushings-Oil Test Tank	Test Voltage (kV)	Capacitance (pF)	Tan Delta (%)
OIP-NEO	10	245.3	0.195
	72.5	246.3	0.195
OIP-SEO	10	247.2	0.184
	72.5	247.3	0.184

Table-4 Test Results after Impulse Application

It is concluded that the OIP bushings mounted on NEO & SEO filled test tanks successfully withstood all three test cycles (routine tests and type tests).

3. NEG Impulse Margin Evaluation Test

The negative impulse margin test was carried out to evaluate the withstand capability of the OIP bushings at higher negative lightning impulse voltages. The test sequence involved stepwise application of impulses followed by dielectric parameter measurements. During the tests, the bushing’s HV terminal was shorted to earth for 15 minutes between two cycles of negative impulse voltage applications.

Sr.	Test	Voltage Levels (kV)
1	Steps of 50kVp	100 kV to 325 kV _p
2	Full -ve	15 Shots at 325 kV _p
3	Full -ve	5 Shots at 350 kV _p
4	Full -ve	5 Shots at 370 kV _p
5	Full -ve	5 Shots at 390 kV _p
6	Full -ve	5 Shots at 410 kV _p
7	Extended Margin	30 Shots at 410 kV _p
8	AC withstand test	154 kV-1Minute

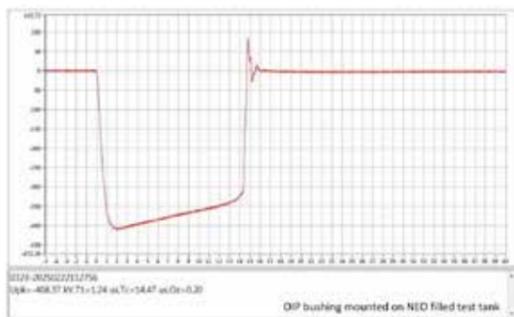
Table 5. -ve impulse margin evaluation test sequence

Capacitance and Tan Delta measurements were carried out at 10kV, between two impulse applications & Capacitance and Tan Delta measurements were carried out at 10kV and 72.5kV, after the concluding AC Withstand Test,. Table 6 contains Capacitance and Tan Delta values measured at 10kV After application of 5 Impulses at 390kVp.

Bushings-Oil Test Tank	Test Voltage (kV)	Capacitance (pF)	Tan Delta (%)
OIP-NEO	10	244.9	0.194
OIP-SEO	10	247.6	0.177

Table 6 – Capacitance & Tan Delta after 390kVp

During the first application of 410 kV_p, the OIP bushing mounted on NEO filled test tank, there was a flashover inside the test tank.



Capacitance and Tan Delta measurements were carried out at 10 kV and were 244.08 pF and 0.192 %, this confirmed absence of abnormality. In the next step, 154kV was applied for duration of 1 Minute, to ascertain the health of Bushing. The bushing successfully withstood the voltage, and the PD observed was 2.46 pC at 154kV. In addition, the bushing was taken out of NEO Filled Test Tanks for visual inspection it was found that there were no flashover marks on the bushing surface (air end side and oil end side). Subsequently, Oil Sample was taken out from Bushing and evaluated for Moisture Content and DGA & the results are in Table-7

Moisture Content	2.4 ppm
Dissolved gases	Gas Content (ppm)
Hydrogen (H ₂)	16

Methane (CH ₄)	BDL
Acetylene (C ₂ H ₂)	BDL
Ethylene (C ₂ H ₄)	BDL
Ethane (C ₂ H ₆)	BDL
Carbon Monoxide (CO)	71
Carbon Dioxide (CO ₂)	292

Table 7 – Moisture and DGA results of oil sample

The Moisture Content and Gas contents in the Oil Samples indicate that the Bushing itself is healthy and the flashover in the first impulse at 410kVp appears to be external to the bushing and at the interface between Oil End Insulator of Bushing & NEO filled in Test Tank.

On the other hand, OIP-SEO withstood the first impulse at 410 kV_p & subsequent impulse applications of 5 plus 30 without any flashover. Capacitance (247.67 pF) and Tan Delta (0.178 %) measured at 10 kV after the negative impulse margin evaluation test, confirmed the health of the bushing. After the Impulse margin test, the bushing also withstood 154 kV for 1 minute with PD ~ 7.83 pC at 154kV. After the HV test Capacitance and Tan Delta were 247.35 pF & 0.178% and confirmed the health of the bushing & also confirmed the successful withstand of Impulse Margin Test at 410kVp & subsequent 154kV-1Min AC Test.

Subsequently, Oil Sample was taken out from Bushing and evaluated for Moisture Content and DGA & the results are in Table 8

Moisture Content	4.2 ppm
Dissolved gases	Dissolved gases contents (ppm)
Hydrogen (H ₂)	BDL
Methane (CH ₄)	BDL
Acetylene (C ₂ H ₂)	BDL
Ethylene (C ₂ H ₄)	BDL
Ethane (C ₂ H ₆)	BDL
Carbon Monoxide (CO)	96
Carbon Dioxide (CO ₂)	141

Table-8 Moisture Content & DGA of Oil Sample from Bushing tested on SEO Filled Test Tank

The Moisture & Gas contents in the Oil Samples indicate that the Bushing is healthy after all margin evaluation tests.

4. Summary

In order to evaluate & confirm the suitability of OIP Bushings with dimensions confirming to IS 12676, an extensive & systematic testing procedure including margin testing has been evolved. This systematic evaluation procedure consisted of carrying out 3 cycles of One Minute AC Test followed by Impulse application method same as Type Test and subsequent One Minute AC Test. After the successful withstand of three cycles, a unique procedure has been evolved to establish the Margin on Impulse Voltage Withstand. The OIP Bushing mounted on NEO Filled Test Tank withstood -390kVp, whereas OIP Bushing mounted on SEO Filled Test Tank Withstood 410kVp. As is mentioned in the details of results, this evaluation has proved and confirmed the suitability of OIP Bushings with Dimensions confirming to IS 12676 ,for use on the NEO / SEO ester oil filled transformers.

5. References

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