TYPE TEST REPORT

O Plus Dry™ Bushing

25 kV system, 150 kV BIL, 3000 A

1 Abstract

A Design/Type test report for O Plus Dry™ transformer bushing 025N3000AA is presented. The bushing was successfully tested and shown to meet the IEEE requirements for a 25 kV system voltage, 150 kV BIL, with a current rating of 3000 amperes. The bushing also meets IEC voltage requirements for a 24 kV system and 125 kV BIL. The purpose of this report is to certify that this bushing meets the requirements of the applicable standards.

2 Certification

We certify that:

- ABB conducted these tests in the laboratories at the Alamo, Tennessee facility of ABB.
- The data and statements in this report are true and accurate to the best of our knowledge and ability.
- We performed the tests based on our interpretation of the applicable standards.

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3 Introduction

3.1 Description and ratings

This report is a “Design Test” report by the IEEE definition, or a “Type Test” report by the IEC definition. It describes the tests performed on O Plus Dry bushing style number 025N3000AA, and gives the results of these tests.

This bushing is for use in oil-filled transformers, and meets IEEE requirements for a nominal system voltage of 25 kV, a Basic Impulse Level of 150 kV, and a maximum line-to-ground voltage (max L-G) of 16 kV. It is a bottom-connected bushing rated for 3000 A, 60 Hz.

The bushing also meets IEC dielectric requirements for a U_m of 24 kV, a rated lightning impulse withstand (BIL) of 125 kV, and a maximum phase-to-earth voltage of 14 kV.

3.2 Overview of tests

Required tests can be categorized as: dielectric tests, mechanical tests, and thermal tests. Testing was performed with a goal of meeting the IEEE requirements for all three, as well as the dielectric portion of the IEC requirements. The tests prescribed in both IEEE and IEC standards are very similar, but there are minor differences in test levels and acceptance criteria.

All dielectric tests were performed to the more severe level, and acceptance criteria were the most stringent, between the IEEE and IEC standards, such that the requirements of both are met with one series of tests. For example, IEEE requires that power factor be measured only at 10 kV, whereas IEC requires that dissipation factor be measured at two additional, elevated voltages. Explanations for the more important of the differences between the standards, and which level was used, are given in the sections for the particular tests.

Additionally, ABB internal standards are often more stringent than those of either standard. For example, ABB limits for power factor (or dissipation factor) and partial discharge are more stringent than in either industry standard. These more stringent limits were used, even though they may not be explicitly pointed out.

The general sequence of required dielectric tests is as follows: preliminary dielectric tests to demonstrate the bushing is good and to obtain reference measurements, cantilever testing, impulse testing, AC withstand tests with partial discharge measurements, and a repeat of the reference measurements to demonstrate that no damage has occurred.

Both standards provide a de-rating factor that must be applied when operating the bushing at an altitude higher than the standard altitude, but neither tells how this must be demonstrated. To directly demonstrate suitability for use at a higher altitude, a sub-set of the dielectric tests was repeated at elevated voltages determined by applying the de-rating factor, after the sequence of required tests, and the reference measurements were repeated.

The primary mechanical test is the cantilever test, which was performed early on within the sequence of dielectric tests, so that subsequent tests would reveal any possible damage. Remaining mechanical tests (leak tests) were performed independently of the dielectric tests.

Thermal tests were done to demonstrate that the bushing meets the requirements, and to derive thermal constants, which are useful for predicting operating temperatures. Thermal tests were not done to IEC conditions, but the IEEE tests are more severe. Calculations were done, using the method of IEC, to demonstrate thermal suitability for short circuit conditions.

3.3 Applicable standards

The standards referenced during testing are:

IEEE Std C57.19.00-2004	IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings
IEEE C57.19.01-1991 IEEE Std C57.19.01-2000	IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings
IEEE Std C57.19.100 - 2012	IEEE Guide for Application of Power Apparatus Bushings
IEC 60137, Edition 6, 2008	Insulated bushings for alternating voltages above 1,000 V
BT009 (ABB, Alamo)	Bushing Test Procedure

3.4 Units tested and test dates

Serial number of unit used for main sequence of tests:	1000095679
Serial numbers of additional units	1000095678, 1000095683, 1000095687, 1000095706
Test dates for dielectric and mechanical tests	December 2 - 6, 2014 and February 9, 2015.
Test dates for thermal tests	January 8 - 9, 2015

4 General test notes

4.1 Power factor versus dissipation factor

Per IEEE standards, dielectric loss measurements are made using power factor. Per IEC standards, dielectric loss measurements are made using dissipation factor. While technically there is a very slight difference based upon the definitions, at low levels of loss the values obtained are the same, except that power factor is expressed as a percentage, while dissipation factor is expressed as a ratio. Therefore, there is a factor of 100 difference between the two stated values (ie, the decimal place is moved two places). For simplicity in comparisons, limits for dissipation factor, as stated in the IEC standard, have been converted to percentages.

4.2 Test sequence

The tests listed in Section 5, and which are directly required by the standards, were performed in the sequence shown. The sequence is important to ensuring that any damage done is detected in later tests. Certain tests (for example, tests done for proof of altitude performance) were done on a different unit, but care was taken to make sure this did not affect the sequence of tests for the main unit.

The tests listed in Section 6 and Section 7 were performed independently, and the sequence of tests is not important.

4.3 Correction of test voltages

When actual test conditions vary from standard test conditions, applied withstand voltages may be corrected to those withstand voltages at standard conditions. If the ambient conditions during the test period were such that the correction resulted in a higher test voltage for a given test, then the higher level was used for that test and the level is noted in the results. If the correction resulted in a test voltage that was less than or equal to the standard voltage, the standard voltage was used (ie, test voltages were never reduced from the standard values).

4.4 Power frequency

Tests performed using AC voltages and currents were done at a power frequency of 60 Hz.

It is a generally accepted conversion that dielectric tests done at different power frequencies are considered equivalent if the number of cycles is the same. In this way, tests performed at 60 Hz include 20% more cycles than would a test performed for the same duration, but at 50 Hz. Therefore, a dielectric test done at 60 Hz is generally slightly more stringent, and can be used to qualify equipment for use at 50 Hz.

Because of the skin effect phenomenon, and if the wall thickness of a conductor is sufficient, more of the cross section of a conductor will effectively carry current at 50 Hz versus at 60 Hz. Therefore, a bushing operated at 50 Hz will have conductor losses that are less than or equal to the losses of the same conductor when operated at 60 Hz. Therefore, a temperature rise test done at 60 Hz is generally more stringent, and can be used to qualify equipment for use at 50 Hz.

5 Dielectric test results (including cantilever tests)

5.1 Preliminary C1 power factor/dissipation factor and capacitance

		Power factor			Capacitance	
Description of test level	**Applied voltage (kV)**	**Measured (%)**	**Limit (%)**	**per**	**Measured (pFds)**	**Limit**
IEEE Level	10	0.30	0.5	ABB	733	Reference
1.05 U_m / √ 3	15	0.30	0.5	ABB	733	Reference
U_m	24	0.30	Δ<+0.1	IEC	733	Reference

Bushing passed

5.2 Test tap withstand

Measurement	Applied voltage (kV)	Duration (minutes)	Acceptance criteria
Tap to flange	2	1 minute	No flashover or breakdown

Bushing passed

5.3 Preliminary dry power-frequency voltage withstand and partial discharge measurements

			Partial discharge at test level			
			Measured (pC)		Limit (pC)	
Description of test level	**Applied Voltage (kV)**	**Duration (minutes)**	**Start**	**Finish**	**Value**	**per**
1.5 max L-G	24	N/A	3	N/A	5	ABB
2.0 max L-G	32	N/A	3	N/A	5	ABB
Withstand	60	5	N/A	N/A	N/A	IEEE, IEC
2.0 max L-G	32	N/A	3	N/A	5	ABB
1.5 max L-G	24	N/A	3	N/A	5	ABB
1.05 U_m / √ 3	15	N/A	3	N/A	5	ABB

Bushing passed

Note: Background partial discharge in the lab was approximately 3 pC.

5.4 Cantilever load withstand

Both IEEE and IEC standards require that pressure be applied internal to the bushing during the cantilever tests. However, the construction of these dry bushings is such that they are mostly solid, with very little “internal” enclosed volume, and there is no liquid to leak out. The largest concern with regard to leaks is that oil from the transformer could leak through the bushing somehow. The most likely path is that oil could leak past the O-rings that seal the flange to condenser joint. Another possibility is that a cracked condenser could allow oil to leak through. Because of the presence of the silicone rubber, which overlaps the flange and forms a secondary seal, detection of any such leaks would be improbable. Therefore, the cantilever tests were performed on two different bushings. The tests presented here were performed on a complete bushing, including the silicone rubber, and were done within the sequence of required dielectric tests, such that any hidden damage would be detected during those tests. But these tests did not include pressure tests. The cantilever tests were repeated separately on another bushing built without silicone rubber applied, so that the probability of leak detection would be greater, and pressure tests were done on that unit. The bushings passed the cantilever load withstand tests applied to both the upper (air) and lower (oil) ends.

5.4.1 Upper (air) end cantilever load withstand

Load (lbf | N)	Hold time (minutes)	Deflection (in | mm)	Criteria
708 | 3150	1	0.139 | 3.53	No damage, pass repeat of routine tests
0 | 0	10	0.021 | 0.53	

5.4.2 Lower (oil) end cantilever load withstand

Load (lbf | N)	Hold time (minutes)	Deflection (in | mm)	Criteria
300 | 1335	1	0.228 | 5.79	No damage, pass repeat of routine tests, permanent deflection ≤0.06 in | 1.52 mm
0 | 0	10	0.035 | 0.89	

5.5 Dry full-wave and chopped-wave lightning impulse voltage withstand			
Impulse quantity	**Applied voltage (kV)**	**Acceptance criteria**	**Result**
	Negative polarity reduced wave impulse at 50%-70% of BIL		
1	99.7	0 flashovers, no puncture	OK, reference for other tests
	Positive polarity reduced wave impulse at 50%-70% of BIL		
1	100.4	0 flashovers, no puncture	OK, reference for other tests
	Positive polarity 1.2/50 µs full-wave impulses at 150 kV (150 kV corrected)		
15	151.5-153.8	≤2 flashovers, no puncture	0 flashovers, no puncture
	Negative 1.2/50 µs full-wave impulses at 165 kV (165 kV corrected)		
1	166.4	0 flashovers, no puncture	0 flashovers, no puncture
	Positive 3 µs chopped-wave impulses at 175 kV (175 kV corrected)		
3	178.0-178.6	0 flashovers, no puncture	0 flashovers, no puncture
	Negative 3 µs chopped-wave impulses at 182 kV (182 kV corrected)		
5	186.0-186.4	0 flashovers, no puncture	0 flashovers, no puncture
	Negative 1.2/50 µs full-wave impulses at 165 kV (165 kV corrected)		
14	166.6-168.6	0 flashovers, no puncture	0 flashovers, no puncture
	Bushing passed		

Notes:

- Flashover means in air; flashovers in oil are not allowed.
- For bushings with U_m greater than 72.5 kV, IEC now requires that negative polarity impulse tests are performed at 110% of rated BIL for full-wave, and 121% of rated BIL for chopped wave. For extra assurance of performance, and commonality in testing, this requirement has been applied at all ratings.
- Wave shapes were compared with those of the appropriate reduced wave impulse.

5.6 Wet power-frequency voltage withstand

5.6.1 Specified wet conditions		
Parameter	**Measured condition**	**Requirement**
Water temperature	18 °C (22 °C ambient)	Ambient ± 15 °C
Angle of precipitation	Approximately 45°	45°
Precipitation rate	1.7 mm/min	1.0-2.0 mm/min
Water resistivity	95 Ω-m	100 Ω-m ± 15 Ω-m
Pre-wet time	>15 minutes	>15 minutes

5.6.2 Test results			
Test	**Applied Voltage (kV)**	**Duration (seconds)**	**Acceptance Criteria**
Wet Withstand	53	60	No flashovers
	Bushing passed		

5.7 Dry power frequency voltage withstand and long duration withstand with partial discharge

			Partial discharge at test level													
			Measured value at time indicated (pC)													
Description of test level	**Applied voltage (kV)**	**Duration (minutes)**	**Start**						**Finish**							**Limit (pC)**
1.1 $U_m / \sqrt{3}$	16	5	3						3							5
1.5 max L-G	24	5	3						3							5
2.0 max L-G	32	5	3						3							5
Withstand	60	5	N/A						N/A							N/A
2.0 max L-G	32	5	3						3							5
1.5 max L-G U_m	24	Measured every 5 for 60	0	5	10	15	20	25	30	35	40	45	50	55	60	
			3	3	3	3	3	3	3	3	3	3	3	3	3	5
1.1 $U_m / \sqrt{3}$	16	5	3						3							5

Note: Background partial discharge in the lab was approximately 3 pC.

5.8 Repeat of power factor/dissipation factor and capacitance after required tests

		Power factor			Capacitance	
Description of test level	**Applied voltage (kV)**	**Measured (%)**	**Limit (%)**	**per**	**Measured (pFds)**	**Limit**
IEEE Level	10	0.31	0.5	ABB	732	Δ< ± 1%
1.05 $U_m / \sqrt{3}$	15	0.31	0.5	ABB	732	Δ< ± 1%
U_m	24	0.30	Δ<+0.1	IEC	733	Δ< ± 1%
		Bushing passed				

Note: The algebraic difference in power factor (expressed in percent) measured at 10 kV before and after the dielectric withstand voltage tests must be within ±0.04. For capacitance, the acceptable change is ± 1.0%

5.9 Repeat of certain tests at elevated levels for proof of altitude performance

Due to decreased air density as altitude increases, the air end of a bushing will not withstand as high a voltage at a high altitude as it would at a low altitude. Both IEEE and IEC standards provide a method to calculate altitude correction/de-rating factors, but neither tells how to demonstrate this. To directly demonstrate suitability for use at a higher altitude, a sub-set of the dielectric tests was repeated, but at higher voltages determined by applying the correction factor. The IEC correction factor was used because it is more conservative. The calculated IEC altitude correction factor for 10,000 ft. | 3,048 m calculates to 1.286.

However, this correction factor applies only to the air-end length of the bushing – insulation internal to the bushing or at the oil end of the bushing is not affected by altitude. So, while the bushing was tested at elevated voltage levels for proof of altitude performance, the internal insulation of the bushing was not designed for these higher voltages, and there was some risk that the bushing would not survive the elevated voltage tests. Because of this risk, these tests were performed after the required tests, or on the same style bushings of different serial numbers.

While the bushing did survive the tests, this is absolutely not to be taken that the bushing is rated for these levels – it is not.

5.9.1 Dry full-wave lightning impulse voltage withstand for proof of altitude

The rated BIL was multiplied by the calculated IEC altitude correction factor to obtain the new level for the positive and negative full-wave impulses. Because of the risk of puncture at the elevated voltage, only full-wave impulses, and only five of each polarity were applied. The bushing passed each tier of impulse testing.

Impulse quantity	Applied voltage (kV)	Acceptance criteria	Result
Negative polarity reduced wave impulse at 50%-70% of BIL			
1	115.7	0 flashovers, no puncture	OK, reference for other tests
Positive polarity reduced wave impulse at 50%-70% of BIL			
1	125.1	0 flashovers, no puncture	OK, reference for other tests
Negative polarity 1.2/50 µs full-wave impulses at 193 kV (193 kV corrected)			
5	196.6-198.5	0 flashovers, no puncture	0 flashovers, no puncture
Positive polarity 1.2/50 µs full-wave impulses at 193 kV (193 kV corrected)			
5	195.5-196.7	0 flashovers, no puncture	0 flashovers, no puncture

Notes:

- Flashover means in air; flashovers in oil are not allowed.
- Because these test were performed at significantly elevated voltages, for which the bushing was not designed, these impulse tests did not apply the extra 10%.
- Wave shapes were compared with those of the appropriate reduced wave impulse.

5.9.2 Dry power frequency voltage withstand for proof of altitude

The rated dry power frequency withstand voltage was multiplied by the calculated IEC altitude correction factor to obtain the new level for the dry withstand test. The bushing passed each tier of dry power frequency voltage withstand testing.

Description of test level	Applied Voltage (kV)	Duration (minutes)	Partial discharge at test level			
			Measured (pC)		Limit (pC)	
			Start	Finish	Value	per
2.0 max L-G	32	N/A	3	N/A	5	ABB
Withstand	78	1	N/A	N/A	N/A	IEEE, IEC
2.0 max L-G	32	N/A	3	N/A	5	ABB
1.5 max L-G U_m	24	1	3	3	5	ABB
Bushing passed						

Note: Background partial discharge in the lab was approximately 3 pC.

5.9.3 Wet power frequency voltage withstand for proof of altitude

The rated wet power frequency withstand voltage was multiplied by the calculated IEC altitude correction factor to obtain the new level for the wet withstand test. The bushing passed the wet power frequency voltage withstand testing.

Test	Applied voltage (kV)	Duration (seconds)	Acceptance criteria
Wet withstand	65	60	No flashovers

5.9.4 Repeat of power/dissipation factor and capacitance after proof of altitude tests

Description of test level	Applied voltage (kV)	Power factor			Capacitance	
		Measured (%)	Limit (%)	per	Measured (pFds)	Limit
IEEE Level	10	0.30	0.5	ABB	732	Δ< ± 1%
1.05 U_m / √ 3	15	0.30	0.5	ABB	732	Δ< ± 1%
U_m	24	0.30	Δ<+0.1	IEC	733	Δ< ± 1%
Bushing passed						

Note: The algebraic difference in power factor (expressed in percent) measured at 10 kV before and after the dielectric withstand voltage tests must be within ±0.04. For capacitance, the acceptable change is ± 1.0%

6 Mechanical test results

6.1 Repeat cantilever load withstand with pressure test

In order to increase the probability of leak detection, a second bushing, built without silicone rubber applied, was cantilever tested, including the pressure tests. This is the unit reported in this section. Air pressure was applied to the void between the two O-rings that seal the flange to the condenser, the valve was closed and the pressure gauge monitored. The requirement is that no pressure is lost during, or for 10 minutes after, the test. The bushing again passed each of the cantilever load withstand tests.

6.1.1 Upper (air) end cantilever load withstand

Load (lbf | N)	Hold time (minutes)	Deflection (in | mm)	Criteria
800 | 3558	1	0.100 | 2.54	10 psig | 70 kPa internal pressure, no leaks, no damage
0 | 0	10	Not measured	

6.1.2 Lower (oil) end cantilever load withstand with pressure test

Load (lbf | N)	Hold time (minutes)	Deflection (in | mm)	Criteria
300 | 1335	1	Not measured	10 psig | 70 kPa, no leaks, no damage
0 | 0	10	Not measured	

6.2 Production leak test

The requirements concerning leak testing in the IEEE standard imply an internal volume, such as with an oil-impregnated bushing, but do not work well as specified with a dry bushing. In lieu of the IEEE test, all O Plus Dry bushings receive a production leak test using Helium leak detection, which is more suitable given the construction. The test is performed before application of the silicone rubber, because the silicone rubber forms a secondary seal, which could conceal a leak of the primary seals. There are two main joints that could leak. One is between the conductor and the condenser body, and the other is between the condenser body and the flange. These joints are leak tested. A fitting is attached to the flange, and a fixture is attached to one end of the condenser, such that it seals to the conductor and to the condenser body. These are connected to a vacuum pump and Helium detection system. The voids are evacuated to less than 1 mbar of pressure. Helium is applied around both ends of the condenser body-to-flange interface, and also to the opposite end of the condenser, where the conductor protrudes from it. Any Helium leaking past the seals and into the evacuated voids is automatically detected, and would be cause for rejection.

The bushing passed the leak test.

7 Thermal performance test results

7.1 Temperature rise tests

Temperature rise tests, including overload testing, were performed on the 025N3000AA bushing in accordance with IEEE C57.19.00-2004 and C57.19.100-2012. The bushing was manufactured with thermocouples imbedded in the conductor, and additional thermocouples attached at various external positions as required to determine the hottest spot of the bushing. The lower end of the bushing was immersed in oil to a level below the flange mounting surface as specified in the results table below, and the oil was heated to a nominal rise above ambient as specified in the results table. Rated current was passed through the bushing until a stable operating temperature was reached. The temperature rise of the upper end bus, approximately 1 meter away, was specified to be at least 30 K above ambient air temperature. The test was performed at the rated current, and at a second current as shown in the table below. In addition, readings were taken with zero current flowing through the bushing, but all other conditions unchanged. The reason for the three different tests is so that the thermal constants may be derived from the test data. Measurements for ambient temperatures were taken as the average of three thermocouples. The results were as follows:

Description of current	Zero	Rated	Overload
Current (A)	0	3000	3900
Ambient Temperature (°C)	20.3	20.3	20.7
Test oil level (in | mm)	0 | 0	0 | 0	0 | 0
Test oil rise (K)	63.5	64.9	65.5
Upper bus rise (K)	N/A	43.2	60.4
Hot spot rise (K)	N/A	81.6	97.5
Nominal oil rise(K)	65	65	65
Corrected hot spot rise (K)	N/A	81.7	97.1

Note: The corrected hottest-spot rise is the hottest-spot rise adjusted for the difference between nominal and actual test oil rises, using the factor K_2, shown in section 7.2.

With regard to temperature limits, the IEEE standard assumes the insulating material has a temperature index of 105 °C (Class A), and the limits given in the standard were based on this assumption. However, O Plus Dry bushings are constructed of an epoxy-based material with a temperature index of 120 °C (Class E). While the IEEE standard does not directly give limits for other materials, it does allow for their use with the following statement, “For insulating materials with temperature index greater than 105, the hottest spot temperature rise should be chosen accordingly…” Therefore, instead of a temperature rise limit of 75 K, the limit is taken to be 90 K.

This agrees with the temperature rise limit directly given in the IEC standard for Class E insulation material, which is 90 K. Since the temperature rise of the tested bushing is less than the specified limit, the bushing passed the test.

The temperature rise test was done according to the IEEE standard. However, the only significant difference is that the IEEE standard requires the temperature rise of the immersion oil to be 65 K, whereas the IEC standard only requires a rise of 60 K. Therefore, the bushing is considered to have comfortably met the limits of the IEC standard as well.

7.2 Thermal constants

The thermal constants were calculated based on the temperature data from the thermal tests. The values of the thermal constants for this bushing are:

Constant	Value
K_1	22.1
K_2	0.92
n	2.02
τ (minutes)	45

The thermal constants can be used to estimate the bushing hottest-spot temperature under various conditions of loading, oil immersion temperature, and ambient temperature. For information regarding thermal constants and their usage, see the O Plus Dry Bushings Technical guide and IEEE C57.19.100-2012.

7.3 Verification of thermal short-time current withstand

IEC provides a method for estimating the final temperature attained during a severe shorttime overload, such as a short circuit. This method is a calculation, which assumes that all heat generated during the overload is stored within the conductor. IEEE does not provide such a method, but this is similar to calculations that have been done within the industry. As such, the IEC method was used. The calculated values indicate that the bushings passed the thermal short-time current withstand testing.

Overload current	Duration (seconds)	Ambient (°C)	Final temperature (°C)	Temperature limit (°C)
25 x rated	2	40	138.5	180

8 Conclusion

This concludes the test program and data. The bushing passed all applicable tests.

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1ZUA2751-272 EN REV 0, 13.11.2017