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Analysis of Insulation Resistance and Oil Test of 3omva Reactor Transformer in Nigeria AGIP Oil Company, Obrikom.

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ABSTRACT
This paper analyzed practical test values of insulation resistance, winding resistance and oil sample obtained from 30MVA/IIKV/1600A Reactor for Nigeria AGIP Oil Company, Obrikom (OB/OB) Gas plant with station tag 4540-X-01B. The practical data obtained were evaluated and compared with theoretical integrity test results or values to meet the customer's specification as well as compliance with electrical standards. The reactor coupled with automated limiter making it a super fault current limiter (SFCL) is interfaced between the two set of generator buses (45-40DGs and 25-40DGs) to reduce system short-circuit level, absorb lagging Vars and to assist in the control of load flow and voltage swell. The practical average winding resistance of 5.506mΩ obtained satisfied the factory test result and the minimum insulation resistance in the research also satisfied the new proposed one giga ohm of insulation resistance is equivalent to one kilovolt of applied Vdc in a medium voltage reactor.

Keywords: *Reactor, SFCL, 50N/51N, IR and DAR CLR*

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I. INTRODUCTION

Reactors are structurally like the power transformer which does not transform voltage or current, they are simply coils that have large number of turns with greater Ohmic resistance. The reactor is coupled with an automated limiter such that once electrical fault is initiated in the system, the limiter introduced high impedance via the reactor making the device Superconducting Fault Current Limiter (SFCL), the SFCL reduced abnormal fault current to more acceptable level.Base on function, reactors types commonly available in the market are: Neutral grounding reactors, thyristor controlled reactors, smoothing reactors, test reactors, damping reactors, filter reactor and current limiting reactors. The 30MVA reactor discussed in this paper which is a limiting reactor that can reduce short-circuit currents which result from 4540 Bus and 2540 Bus at Obrikom as a result of plant expansions and power source addition or introduction of distributed generation [1]. The reactor reduced the three phase short circuit level to the barest minimum.

Various tests are conducted on the reactor to know the integrity, the test are major in Insulation Resistance (IR), winding resistance and oil test. Insulation resistance or leakage current to ground or to other parts of the system/reactoris commonly measured directly in mega-ohms or calculated from measurement of applied voltage and leakage current {2]. The insulating oil is mainly for the purpose of coolant and as well as insulator. Oil as an insulating property should possess high dielectric strength and low viscosity. Common test that concern the testing of insulating oil include dielectric breakdown tests, moisture measurement by the Karl Fisher (KF) method, anddielectric dissipation factor. Megger Oil test equipment (OTS60AF) provides the fundamental characteristics of insulating oil [3]. This paper analyzed practical and theoretical data obtained in field exercise.

1.1 The Aim of this Research Work

The aim of this research work is to evaluate Insulation Resistance (IR), Polarity Index (PI) and Breakdown Voltage (BDV) of the oil of SFCL (current limiting reactor).

1.2 Objective of this Research Work

- Carry out test on 30MVA reactor.
- Obtain practical data from field survey.
- Analyze the effect of poor insulation on the system and the BDV.
- Evaluate practical data obtained with theoretical results.

II. LITERATURE REVIEW

The expansion of energy system in oil and gas sector and the increased in energy demand by the Host Communities have acquired more distributed generations to meet the demand thereby increasing the short-circuit currents levels not considered in the previous long-term planning forecast. The system techniques for short-circuit current limitation commonly used are rating switch gear equipment, splitting the grid and introducing higher impedance transformers and series reactor and using complex strategies such as segmental network tripping. The alternatives of current limiting method introduced power loss, high cost, reliability etc. the adopted solution for most power system is the Gir-core current limiting reactor or the superconducting controller reactor which at steady state operation the coil's impedance is low and under fault condition detect excessive current, automatic recovering and faster limiting fault current action by introduction of high impedance [4]. The line reactor apart from limiting short-circuit current, it filter out spikes out of current [5], [6] and reduce the inflow of Harmonics current into the power supply [7].

The reactor just like the power transformer possess two insulating materials:thecellulose and the mineral oil, the cellulose used for electrical insulating and mechanical purpose, while the mineral oil is responsible for electrical insulation as well as a coolant [8]. The breakdown voltage of mineral oil when nanoparticles such as Titanium Dioxide (TiO2), Barium Titanate (BaTiO3) and Zinc Oxide (ZnO) were mixed into the mineral oil-based nanofluid were investigated by researchers [9]. Experimentally, nanoparticles addition in the mineral oil, the AC breakdown voltage increased slightly above that of the mineral oil [10], hence, nanoparticles were good substance to develop mineral oil for dielectric applications. In this paper we shall investigate the BDV according to IEC 60156 [11], ASTM D 1816 [12].

The Insulation Resistance (IR) of transformer coil is applicable to that of the reactor coil. IR basically, is the ratio of supplied voltage (V_{dc}) to the resulting current (I_{dc}) at a specified time and temperature after the application of supplied voltage. IR test ensured healthiness of the insulation or dielectric between the two conducting parts and higher the ohmic value better the insulation of the system or equipment [13]. The megger value of equipment voltage ranges is estimated in table 1 [14] and the temperature correction factor [15] used in most calculation as given by equation 1 shall be discussed in later part of this research work.

$$\text{IR (M}\Omega) = \frac{\text{CE}}{\sqrt{(\text{KVA})}} \quad (1)$$

Table 1(a): IR Base on REAL Standard/NETA MTS-1997 (Table 10.1)

Equipment(V_{max})	0.25KV	0.6KV	5KV	8KV	15KV	25KV	35KV	46KV	69KV
Megger Range	0.5KV	1KV	2.5KV	2.5KV	2.5KV	5KV	15KV	15KV	15KV
Min IR Value	25MΩ	100MΩ	1GΩ	2 GΩ	5 GΩ	20 GΩ	100 GΩ	100 GΩ	100GΩ

Table 1(b): IR Base on REAL Standard/NETA MTS-1997 (Table 10.1)

Coil Voltage	(0 – 0.6) KV	(0.6 – 5) KV	(5 – 15) KV	(15 – 69) KV
Megger Size	1 KV	2.5 KV	5 KV	5 KV
Min IR Value (Liquid Filled)	100MΩ	1GΩ	5 GΩ	10 GΩ
Min IR Value (Dry Type)	500 MΩ	5 GΩ	25 GΩ	50 GΩ

Table 1(c): Temperature Correction Factor (Base 20°C)

°C	0	5	10	15	20	30	40	50
°F	32	41	50	59	68	86	104	122
Correction Factor (C)	0.25	0.36	0.50	0.72	1.50	1.98	3.95	7.85

III. MATERIALS AND METHOD

3.1 Materials

The materials used for this research work is detailed; 30MVA reactor; Argo oil tester and sample collectors; 1555 10KV IR tester; AMEC Michrometer /5600/59936 and Fluke Multimeter.

3.2 Test Procedure for Reactor Oil

The gap distance between electrodes Argo oil tester was fixed at 2.5 mm, the test vessel was properly rinsed 2 – 3 times of the reactor oil and the sample bottle was with about 500ml of oil (paraffin oil). Testing was carried out minimum of 3 times for each liquidtest sample according to IEC 60156. The AC breakdown voltages of the top and bottom collection was investigated using oil BDV tester and data obtained are shown in table 2.

Table 2(a): Insulating Oil Breakdown Voltage (BDV) Testing @ 34^{o}C

Level	Test 1 (KV)	Test 2 (KV)	Test 3 (KV)	AV (KV)
Top Sample	66.0	67.5	68.0	67.2
Bottom Sample	59.5	64.5	66.4	63.5

Table 2(b): Insulating Oil Breakdown Voltage (BDV) Testing @ 38.4^{o}C

Level	Test 1 (KV)	Test 2 (KV)	Test 3 (KV)	AV (KV)
Top Sample	56.5	66.0	66.5	63.0
Bottom Sample	50.6	60.8	62.4	57.9

3.3 Test Procedure for Reactor Winding Resistance

With the aid of Amec Micrometer 5600/59936, DC current was injected through the winding of the reactor and then the voltage drop across the winding was read and recorded.The steps is as follows:

- Connect the current/voltage measurement props to the reactor winding: 1U-2U or 1V-2V or 1W-2W.
- Select the micrometer test current to 0.1% – 10% of the rated current of the reactor winding within the required time for the core saturation and the reading stabilization as shown in table 3.
- Start test and wait for measurement stabilization and then stop measurement/store result, immediately discharging starts automatically.
- At the completion of discharge, disconnect props/cables and start next test.
- At the end of test; demagnetize.

It is important to note that if the equipment indicates input voltage overload, then you have selected a range greater than 10%. Select next accommodating range and start the test.
When stability is reached, the formula given in equation (2) is applicable:

$$Vdc = I * R + (Ldi/dt) \quad (2).$$

Where, Vdc = Voltage supply across the reactor winding
I = DC current through reactor winding
R = Resistance of the reactor winding
L = Inductance of the transformer winding
di/dt = Changing value of current (ripple)
Assume that the test set introduced no ripples (di/dt = 0), then Ldi/dt is zero.

Table 3: Reactor Winding Resistance Testing @ 38.4^{o}C (Rph HV = 5.506mΩ)

1U – 2U (mΩ)	1U – 2U (mΩ)	1U – 2U (mΩ)	Amps	Secs To Stabilize
5.501	5.537	5.4789	10	100

3.4 Test Procedure for Reactor Insulation Resistance

The positive terminal of Fluke 1555 10KV insulation tester (IR - Megger) is applied to the primary/secondary (1U/2U or 1V/2V or 1W/2W) side of the reactor and the negative terminal of the megger to ground/earth of the reactor as shown in figure 1. The readings are recorded as shown in table 4 after the application of respective voltages. This process is carried out for other terminals. Base on one Meg Ohm Rule for IR value of equipment, at pressure of 1KV applied between conductor and earth for a minute the IR shall be at 1 mega ohm or as specified by the Bureau of Indian standard of as per IE Rules – 1956.But in this research 1KV application between conductor and earth for a minute of the reactor (11KV 30MVA) the IR of 1GΩ is proposed.

Figure 1: Megger test on 11KV 30MVA reactor in Nigeria Agip Oil Company, Obrikom.

Table 4(a): Reactor Insulation Resistance Testing with 5KV Megger/ Fluke 1556 (50Hz, 5000V/minute)

Terminals	GΩ	W/VOLTS	C/μF	DAR	LIKAGE/ηA
1U-2U/Earth	20.2	5260	0.00	1.06	260
1V-2V/Earth	18.0	5269	0.00	1.06	292
1W-2W/Earth	16.4	5259	0.00	1.06	320

Table 4(b): Reactor Insulation Resistance Testing with 10KV Megger/Fluke 1556 (50Hz, 10KV, PI)

Terminals	GΩ	W/VOLTS	C/μF	DAR	LIKAGE/ηA	Polarity Index	Cal $IR_{M\Omega}$ C @ 3.95
1U-2U/E	38.9	10489	0.00	1.06	270	1.65	250.86
1V-2V/E	34.3	10488	0.00	1.09	306	1.78	245.71
1W-2W/E	31.0	10487	0.00	1.08	338	1.76	242.53

Table 4(c): Insulation Resistance Test on Incomer Feeder to the Reactor Transformer – IC x 300mm^2 XLPE x 4/Phase (PI = Polarity Index, V_w = With holding Voltage)

Terminals	G Ω	V_w	C/UF	DAR	Leakage (I) µA
R_1-E	1.43	10501	0.03	1.35	7.34
R_1-E	3.44	10498	0.03	1.00	3.05
R_3-E	2.12	10499	0.03	1.08	4.46
R_4-E	1.59	10501	0.03	1.25	6.61
Y_1-E	2.83	10500	0.03	1.07	3.71
Y_2-E	3.72	10497	0.03	1.12	2.82
Y_3-E	4.02	10498	0.03	0.93*	2.61
Y_4-E	4.17	10498	0.03	1.10	2.52
B_1-E	1.46	10498	0.03	1.07	7.18
B_2-E	1.52	10495	0.03	1.02	6.91
B_3-E	1.46	10496	0.03	1.03	7.71
B_4-E	1.37	10497	0.03	1.12	7.67

Table 4(d): IR Testing on Outgoing Feeder from Reactor Transformer

Terminals	G Ω	V_w	C/UF	DAR	Leakage (I)µA
R_1-E	6.13	10497	0.04	1.54	1.71
R_2-E	6.33	10498	0.04	1.22	1.16
R_3-E	5.82	10495	0.04	1.06	1.80
R_4-E	6.02	10496	0.04	1.08	1.08
Y_1-E	13.0	10496	0.04	1.11	807
Y_2-E	13.0	10496	0.04	1.08	810
Y_3-E	10.6	10498	0.04	1.17	993
Y_4-E	12.5	10497	0.04	1.12	840
B_1-E	6.31	10495	0.04	1.42	1.66
B_2-E	9.89	10497	0.04	1.18	1.06
B_3-E	5.11	10495	0.04	1.05	2.06
B_4-E	2.36	10494	0.04	1.01	4.45

ηA

Table 4(e): IR Testing on all Cables connected with Reactor Transformer

Terminals	$M\Omega$	V_w	C/UF	DAR	Leakage 1. μA	P.I
R_1-4/U-E	125	10497	-	1.19	84.2	N/A
V_1-4/V-E	82	10495	-	1.06	128	"
B_1-4/W-E	176	10497	-	1.06	59.5	"
R_1-4/U-Y_1-4/N	134	10498	-	1.18	78.6	"
R_1-4/U-B_1-U/W	236	10498	-	1.10	44.4	"
Y_1-4/V-B_1-4/W	199	10497	-	0.99	52.9	"
R_1-4/U-E	219	10492	-	1.20	47.9	1.81
Y_1-4/V-E	145	10489	-	1.16	72.4	1.39
B_1-4/W-E	409	10490	-	1.14	25.8	1.48

IV. RESULTS AND DISCUSSION

4.1 Results

The graph in figure 2 shows that as the temperature of the reactor oil increases the dielectric strength decreases and after certain period, the arc flashes indicating the breakdown voltage of insulation level of the oil. This is relative to rise in oil temperature lead to decrease of oil resistivity.The average BDV of the oil obtained considering both temperature is ≥63KV which satisfied standard before filtration otherwise 70KV is excellent after filtration. Average winding resistance (per phase Rph-HV = 5.506mΩ) test result can be compared with previous field measurement but since the 30MVA reactor is new, it is compared with factory measurements, and this result permits a maximum difference of 0.5% at 38.4^{o}C.

The effect of leakage current in the reactor system was analyzed using 10KV Megger at 50Hz, 38.4^{o}C. The result obtained in practical analysis satisfied the theoretical calculation and factory data of insulation resistance (IR). The condition for insulation of DAR-dielectric absorption ratio (=IR_{60sec}/IR_{30sec}) given in table 5 [16] is compared with the result obtained in this research.

Table 5: Condition of Insulation Indicated by Dielectric Absorption Ratio (PEARL Standard/NETA MTS-1997)

DAR = 60Sec/30Sec	< 1.25	≤ 1.6	>1.6
Insulation Condition	Questionable	Adequate	Good

The practical minimum DAR = 1.06 is questionable based on table 6 guide.
The polarization index (10mins IR-test/1min IR-test) obtained in table 4 is also compared with table 6.

Table 6: PI Guide to IR Test [16]

PI	< 1	< 2	<4	>4
Insulation Condition	Dangerous	Questionable	Good	Excellent

The practical minimum PI = 1.65 is questionable based on table 6 guide.
Minimum insulation resistance is ≥ 16.4GΩ/min at the application 5KV and average leakage current is 290.7ηA.

Minimum insulation resistance is ≥ 31.0GΩ/min at the application 10KV and average leakage current is 304.7ηA.

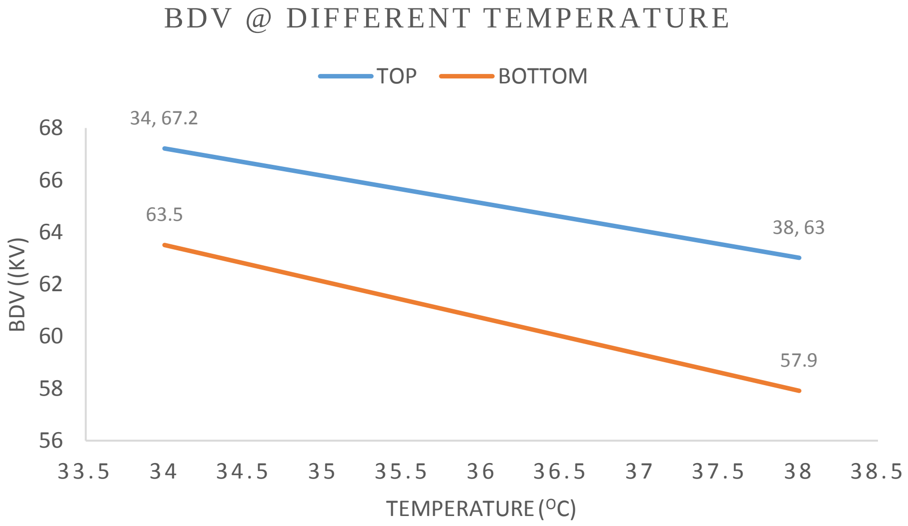

Figure 2: Graph of breakdown voltage of reactor oil with rise in temperature.

From field work analysis, winding resistance R_{ph} HV = 5.506 $m\Omega$, insulation resistance > 16.4G Ω /minute and average leakage current = 304.7 ηA show that the 25MVA Transformer integrity is unquestionable. However, several factor like DAR (average of DAR = 1.08) associated with low insulation resistance of the power cable and other accessories such as CTS/VTS reduced the overall insulation resistance level of the equipment. From table 4(c) DAR value of 0.93 show the questionable condition of the system which may improve after oil filtration or soaking the reactor for 48hrs. The minimum insulation value by 'Hand rule' as stated; one mega – ohm for each 1,000volts $(1KV = 1M\Omega)$ of operating voltage i.e. 2400 volts motor should have minimum of 2.4MΩ

The field study shows that for every 10^0C increase in temperature halve the resistance, or for every 10^0C decrease double the resistance. In the absence of more reliable data the formula $R = CE/\sqrt{KVA}$ is suggested, where, R is one minute measured (Earth – winding or winding with other minding, C is a constant for measurement depending on temperature, E the voltage rating of the winding and KVA the rated capacity under test. The temperature corrector factor is shown in the Table 1(c).

V. CONCLUSION AND RECOMMENDATIONS

5.1Conclusion

The practical average winding resistance test value and the minimum insulation resistance test results show that the 30MVA, 11KV reactor transformer is unquestionable, though the DAR and PI results are questionable when compared with stated insulation resistance guide. The minimum insulation resistance of 16GΩ @ 5KV and 31GΩ @ 10KV satisfied 1KV = 2GΩ insulation condition. Hence, the proposed 1KV = 1GΩ minimum insulation condition is obtainable.

5.2 Recommendation.

➢ Base on the DAR and PI results obtained, I hereby recommend that the reactor oil should undergo oil filtration as to achieve oil BDV$\geq 70KV$.

➢ Routine test and reactor performance should be evaluated in every five years to ascertain functionality. 100% sufficient redundancy should be provided depending on the criticality of the electrical power system network.

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