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ADAPTIVE TECHNOLOGY AND POWER SYSTEMS MANAGEMENT "THE EVOLUTION OF LOCAL TECHNOLOGY"

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1. ABSTRACT

This paper considers the possible use of some local materials as adaptive replicas to some existing materials presently used in power distribution transformers. It considers the roles played by some in the system, source some local materials, treat them (dry, oil impregnation, varnishing as the case may be) and subject them to some known standard tests.

The paper further compares their test result with available standard record and goes further to commission a prototype 10KVA, 11/0.415 KV, distribution transformer using coconut oil as the coolant/insulant and mansonia bushings to enhance external connection of the internal terminals. The results though not very conclusive depicts that these renewable materials may reasonably be used to replace or compliment the presently used mineral (transformer) oil and porcelain bushings.

The Use of Vegetable oils And Wooden Bushings In Power-Distribution Transformers

2. Introduction

Oil and bushings are dielectrics or insulants. Transformer oil[4] a very costly petroleum (mineral) product is used in transformers as insulant and coolant for the magnetic/electric circuits respectively to discourage temperature rise during the course of operation. The transformer oil source is not renewable since oil wells can dry up. Bushings (made primarily of porcelain) serve as a means of externally connecting the leads of the terminals of the various phase of the transformer ready to be interconnected with the entire power system for transmission, distribution or tests without the possibility of any short circuit between the leads and the tank of the transformer. Porcelain bushings are expensive, heavy and easily crack under pressure (electrical or mechanical). The bushings are used in concealed cabinets, in indoor or outdoor substations or exposed.

Vegetable oils (Palm kernel, Palm oil, coconut oil, rubber seed oil etc) might be possibly used to replace transformer oil (from petroleum products) owing to the Cost and the fact that vegetable oil are products of renewable sources. Also, the cost of the implementation of a vegetable oil farm, processing, and treatment plants will be much reasonable than the cost of petroleum oil prospecting and building of an oil refinery and other accessories.

Wood (Timber) is readily available locally, easily machineable, easily reproduced, easily kept in stock as replacement parts, easily treated to meet the standards of a bushing, less expensive than porcelain and very resistant to shock/pressure compared size by size with a porcelain bushing. They can be used as

Table 1: **Basic Characteristics of Insulating Oils[4] (Transformer Oil)**

Characteristics	Unit	Value
Density	Kg/m^3	885-890
Viscosity at 20°C	M^2/S	$30x10^6$
50°C	M^2/S	$8x10^6$
Flash Point (not less than)	°C	135
Volume Resistivity at 20°C		10^{10}
Pour Point (Not higher than)	°C	45
Acid Number	Mg. K0H/g	0.03-0.05
Permitivity	-	2.2-2.4
Tank at 50Kz	-	0.003-0.005
Dielectric Strength at 20°C	MV/m	18

Table 2: Characteristics of Insulating Oils[5] (Experimental Results)

Characteristic Property	Transformer Oil	Coconut Oil	Palm Kernel Oil
Flash Point (°C)	146	334	319
Fire Point (°C)	160	360	359
Melting Point (°C)	-31 (pour point)	19	27
Specific Gravity at 25 (°C)	1.560	0.9364	0.9185
Acid Number (mg)	0.01	1.12	3.10
Smoke Point (°C)	105	210.7	168
Dissipation factor 50Hz	0.00075	0.00075	0.00075
60Hz	0.00090	0.00090	0.00090
Dielectric Constant 50Hz	0.0092	0.0092	0.0092
60Hz	0.0092	0.0092	0.0092
Dielectric Loss Factor at 50Hz	0.06872	0.06872	0.06872
60Hz	0.08246	0.08246	0.08246
Conductivity 50Hz	0.19104	0.19104	0.19104
60Hz	0.27509	0.27509	0.27509
Dielectric Strength at room temperature MV/m	19.32	22.56	21.12

3.2 WOODS[6]

Various samples were procured and shaped to approximately the same surface area/Volume ratio. They were dried to a constant weight (Table 3), their insulation resistance noted impregnated with oil, dried and their insulation resistance measured, their rate of oil and water absorption noted, their insulation resistance on being soaked in water measured. The samples were dried and the rate of water loss/insulation resistance noted. The results were as shown in Table: 3,4,5,6.

Table 3: **DATA FOR TREATED AND UNTREATED WOOD SAMPLES[9]**

S/N	SAMPLE	WEIGHT (g) OF SAMPLE		INSULATION RESISTANCE (MΩ) AT 2.5KV	
		Untreated	Treated	Untreated	Treated
1	Obeche	18.5/18	17/17	100	4000
2	Black Afara	23/25	22/24	100	4000
3	Obobo	41/40	39/39	100	4000
4	Opepe	41/43	40/41	100	4000
5	Apa	60/70	55/65	100	4000
6	Danta	80/80	80/80	100	4000
7	Ekimi	50/44.5	49/43	100	4000

The samples were introduced into containers with equal volumes of tap water and transformer oil respectively. Their percentage water absorption and insulation resistance were as shown in Table 4.

Table 4: **SAMPLES IN WATER AND OIL, INSULATION RESISTANCE[9] AND PERCENTAGE WATER ABSORPTION**

S/N	SAMPLES	WEIGHT (g)	INSULATION RESISTANCE (MΩ) AT 2.5KV	PERCENTAGE ABSORPTION (%)
1.	Obeche	17 - 80	4000 - 0 - 4000	0 - 370.6
		17 - 37	4000 - 1200 - 4000	0 - 145.3
2.	Black Afara	22 - 29	4000 - 0 - 4000	0 - 77.3
		24 - 31	4000 - 1200 - 2000	0 - 29.2
3.	Obobo	39 - 70	4000 - 0 - 4000	0 - 79.5
		39 - 50	4000 - 1400 - 2000	0 - 28.2
4.	Opepe	40 - 80	4000 - 0 - 4000	0 - 100
		41 - 60	4000 - 1400 - 2000	0 - 46.3
5.	Apa	55 - 80	4000 - 0 - 4000	0 - 45.45
		65 - 80	4000 - 14000 - 4000	0 - 23.08
6.	Danta	80 - 100	4000 - 0 - 4000	0 - 25
		80 - 100	4000 - 1200 - 1700	0 - 25
7.	Ekimi	49 - 90	4000 - 0 - 4000	0 - 83.7
		43 - 60	4000 - 1200 - 1000	0 - 39.5

Note: The First Reading is for samples in water and the second reading is for samples in oil.

The samples in water were removed from the containers and heat treated until the weight of each sample was constant. The weights, insulation resistance and water loss percent was noted and were as shown in Table 5.

Table 5 HEAT TREATED SAMPLES - WEIGHT, INSULATION RESISTANCE, WATER LOSS PERCENT.

S/N.	SAMPLE	WEIGHT (g)	INSULATION RESISTANCE Ω AT (2.5kV)	PERCENTAGE WATER LOSS (%)
1.	Obeche	69 - 33	0 - 4000	321.1 - 0.0
2.	B. Afara	44 - 23	0 - 4000	92.3 - 0.0
3.	Obobo	70 - 39	0 - 4000	79.5 - 0.0
4.	Opepe	80 - 42	0 - 4000	90.5 - 0.0
5.	Apa	70 - 55	0 - 4000	27.3 - 0.0
6.	Danta	90 - 70	0 - 4000	28.6 - 0.0
7.	Ekimi	80 - 42	0 - 4000	90.5 - 0.0

To see the effect of moisture on the insulation resistance of the wood, the samples in oil were introduced in a medium of oil-water mixture, the mixing being done in various proportions. The results were as shown in Table 6.

Table 6 RESULTS FOR SAMPLES IN CONTAMINATED[9] TRANSFORMER OIL

S/N	SAMPLE	WEIGHT (g)	INSULATION RESISTANCE (MΩ) AT 2.5KV
1.	Obeche	37 - 42	4000 - 1100
2.	B. Afara	31 - 32	4000 - 800
3.	Obobo	50 - 60	2000 - 800
4.	Opepe	60 - 60	2000 - 5
5.	Apapa	80 - 90	4000 - 1000
6.	Danta	100 - 105	1700 - 400
7.	Ekimi	60 - 60	1000 - 260

4. APPLICATION - THE SOURCING/USING OF LOCAL RAW MATERIALS IN TRANSFORMER MANUFACTURING.

The standard materials in question are transformer oil and porcelain bushings. The basic property of a dielectric is that it shall insulate, the insulation level is a function of resistivity, electric strength, surface breakdown, flash over, tracking, permitivity and dielectric loss. Also, the higher the permitivity, the lower the voltage at which flashover is likely to occur. Permitivity reveals the conductivity of the insulating materials, that is, it is a measure of quality. The dielectric strength is a measure of the suitability of the insulating materials is service. For oils, it signify the degree of freedom from contamination.

The local materials to be sourced and used are vegetable oils (Coconut, Palm Kernel, Rubber seed etc) and wood/wooden bushings. Their mechanical, electrical and chemical properties were borne in mind though the tests concentrated on electrical properties.

4.1 Characteristics of an ideal Insulant

These includes the following:

(a) High dielectric strength, sustained at elevated temperatures.

(b) Good thermal conductivity.

(c) Permanence, non deteriorating at high temperature;

(d) Good mechanical properties such as ease of working and application, non-hygroscopic, high-resistance to vibration, abrasion and bending.

4.2 The Use of Vegetable Oils As An Alternative to Transformer[4,5]

Certain tests were performed to ascertain the usability of this oil vis-a-vis the transformer oil. Information on the ideal standard for the transformer oil was used as a reference. Transformer oil was procured as well as coconut and palm kernel oil respectively. They were after heat treatment tested for dielectric strength (MV/m), dielectric conductivity (℧), dielectric constant (F/m) dielectric loss factors (F/m) and loss tangent ($\tan\delta$). These values were compared with the reference as shown in Tables 1 & 2.

(All the measured values were at room temperature 28-30^{0}C).

Table 7. **Insulating Oils: Some Basic Characteristics[4]**

Characteristic	Dielectric Strength MV/m		Loss Tangent		Permitivity	
Transformer Oil	18	20	0.003 - 0,005	0.043	2.2-2.4	4.19
Coconut Oil	-	27.2	-	0.006	-	2.97
Palm Kernel Oil	-	22.8	-	0.015	-	3.26

* The First column are the reference for standard transformer oil.

* From the Tabulated results, coconut oil was further used in an oil cooled transformer and the transformer oil too in a control model to determine and compare the performance characteristics.

4.3 The Use of Wooden Bushings As Alternatives to Porcelain Bushings in Power-Distribution transformers.

From the results of the treated wood samples mansonia an easily machineable timber was formed into an identical shape as an 11/0.41KV porcelain bushings. The weight of the shaped wooden bushing were noted and their insulation resistance measured using a scale balance and megger respectively. They were heated to a level of constant weight, this weight and the insulation resistance noted. The samples were immersed in oil for 24 hours, the weight and insulation resistance was again noted. For a glossy/water proof finish, the samples were soaked in vanish and sprayed then dried in an oven, the final weights and insulation resistances were noted. Tables 8 & 9, show the insulation resistance of the bushing under various conditions.

Table 8 High Voltage Bushings[9]

Test Voltage (V)	Porcelain Bushing (M)	Wooden Treated (M)	Heat Treated (M)	Heat/Oil Treated (M)
625 2500	3000 1000	500 400	3000 1000	00 00

Table 9 Low Voltage Bushings[9]

Test Voltage (V)	Porcelain Bushing (M)	Wooden Treated (M)	Heat Treated (M)	Heat/Oil Treated (M)
625 2500	4000 1000	500 160	4000 1000	00 00

The Wooden Bushings (11/0.415KV) were now used on a transformer to determine and compare its performance characteristic with an identical control model using standard porcelain bushings of the same dimensions.

Fig. 1. Shows the basic configuration and dimensions of the wooden bushings used for this exercise.

4.4 The Use of Coconut Oil and Mansonia Wooden Bushings in a 10KVA, 11/0.415KV, 50HZ, ONAN Power Distribution Transformer[9]

In order to determine the performance characteristics and suitability of the models, the fully tanked transformers were tested separately and when connected in series. The tests performed were: the open circuit or no load test, the short circuit test and the load test. The results as shown in Tables 10-15 were then compared to ascertain the performance characteristics. The test circuit diagrams were as shown in Fig. 2, 3,4.

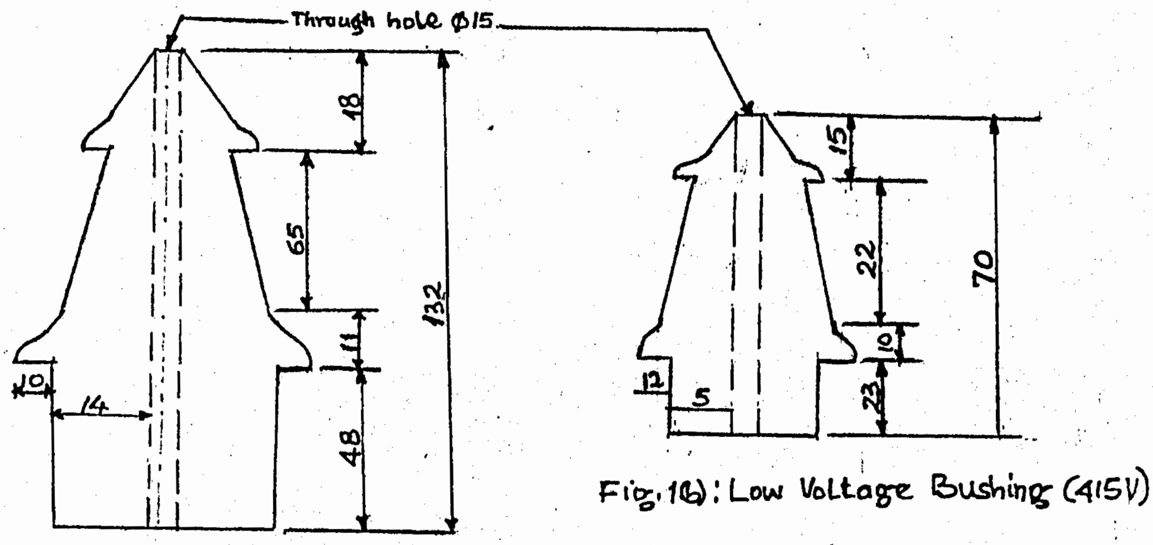

Fig. 1(a): High Voltage Wooden Bushing (11KV)

Fig. 1(b): Low Voltage Bushing (415V)

*Notes: All Dimensions in mm

Fig. 1. : Wooden Bushings

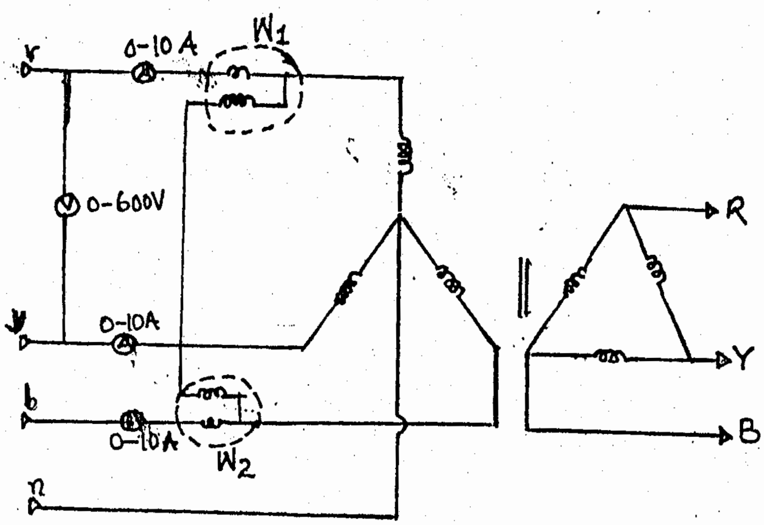

Fig. 2: Circuit Diagram For Open Circuit Test.

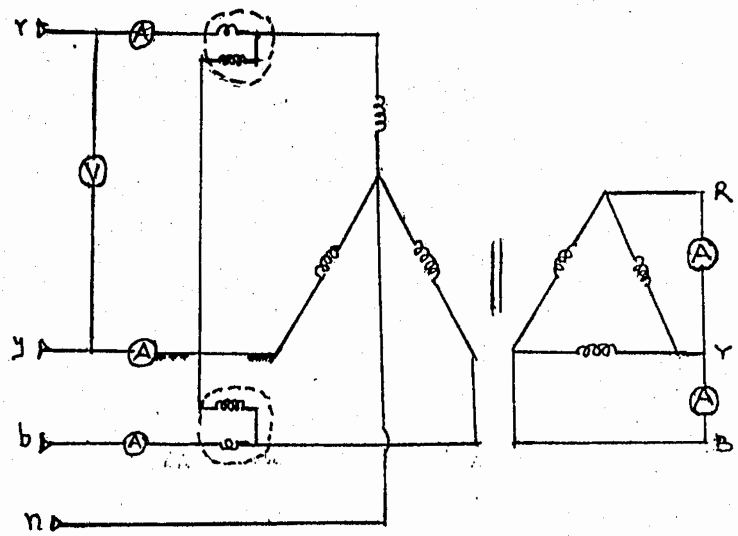

Fig. 3: Circuit Diagram For Short Circuit Test

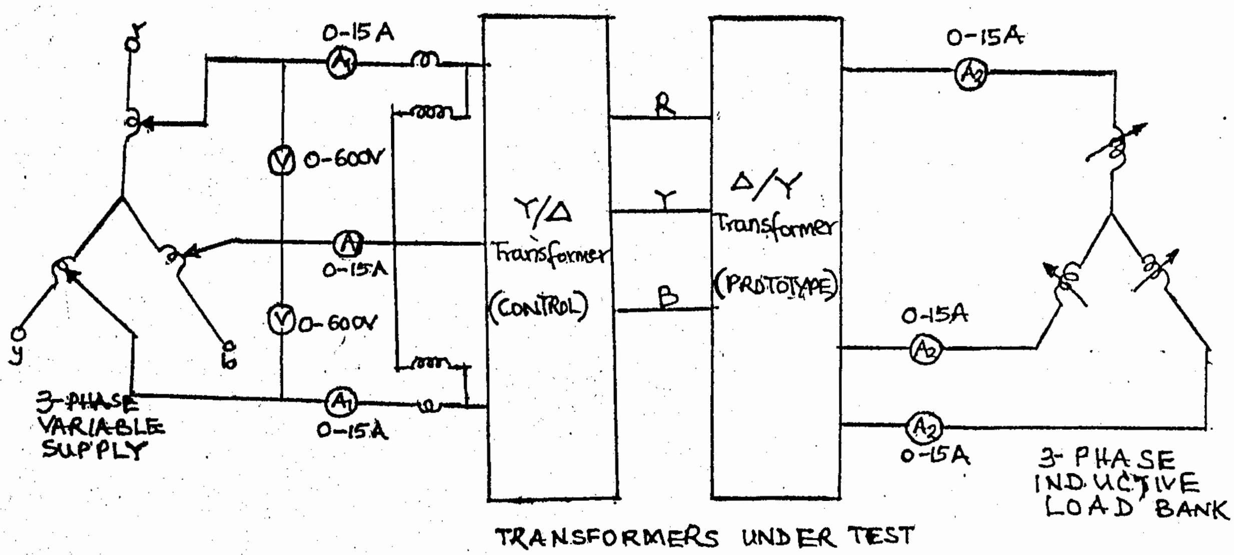

Fig. 4: Circuit Diagram For Load Test.

4.5 FINAL TEST RESULTS[6]

Table 10. SHORT CIRCUIT TEST RESULTS (HV. SIDE SHORT CIRCUITED).

Short circuit Voltage	Prototype	Control
Vsc(V) Short Circuit Current (A)	0.525	0.525
Short Circuit Power, Psc (W).	178	189.4

Table 11. OPEN CIRCUIT TEST RESULT. (HV SIDE O/C)

Test Voltage	Prototype		Control	
Vol (V)	Current(o)	Power (AV)	Current (A)	Power (W)
300	1.11	280	1.07	316
360	2.38	420	2.47	420
380	2.80	400	3.33	428
400	3.98	520	3.98	540
415	4.55	612	4.93	596

Table 12. INDUCTIVE LOAD TEST RESULTS

Input	Side			Output	Side
V_1 (V)	I_1(A)	W(W)	V_2(V)	I_2(A)	Current From Bank
300	2	620	299	0	0
300	9.7	1260	286	8.2	30
415	9	1180	390	0	0
415	14.1	1900	383	6.0	15

Table 13: VOLTAGE RADIO TEST (SEPARATE UNITS)

Input Voltage (V)	Output Voltage (V)	Prototype
5	273	294
10	400	644
20	610	619
25	718	729
30	829	857
35	910	831

Table 14: VOLTAGE RADIO (CASCADED UNIT)

Input Voltage (V)	Output Voltage (V) Control to Prototype	Output Voltage Prototype To Control
50	48	50
150	149	148
300	288.7	287
400	399.7	400

Table 15: INDUCTIVE LOADING OF SERIES CASCADED[6] TRANSFORMERS.

(Performance Characteristics Table)

Parameters	SOURCE (*Input*)					LOAD (*Out Put*)				
Analyzed Data for 300V	V_S	I_S	P_S	S_S	$\varnothing_S$	V_R	I_R	P_R	S_R	$\varnothing_R$
	300	2	620	1039.23	0.60	299	0	0	0	0
	300	9.7	1260	504027	0.25	286	8.3	475	4062	0.12
η(VA)	<---------------- 0.806					<----------------------------				
η(W) = P_R/P_s										
Reg = $\frac{V_{RNL}-V_{RE}}{VRNL}$	<---------------- 0.377					<----------------------------				
	<---------------- 0.044					<----------------------------				
Analyzed Data for 415V	415	9	1180	6469.21	0.18	390	0	0	0	0
415V	415	14.1	1900	101351	0.19	390	6	513	980.3	0.13
η(VA) = S_R/S_s	<--			0.393	<----					
η(W) = P_R/P_s	<--			0.270	<----					
Regulation	<--			0.018	<----					

At 300V, the system drop at full possible loading is 14V (i.e 300 - 286 = 14V) and the current required for magnetization is 2A (14.4% of rated load current and 24.1% of a maximum experimental current value) of 8.3A). The load current, I_R differ from that at the input side by 1.4A hence the KVA transfer from source to load is reasonably good and leading to an efficiency of about 81%.

* At 415V, the system drop at full possible loading is 32V and the current required for magnetization is 9A (64.7% of designed rated value and 150% of experimental maximum value). This manifestation on the KVA transfer is reasonably obvious leading to an efficiency of only 39.3%.

* Surprisingly, the voltage regulation appears to be better than at 300V (1.8% versus 4.4% at 415 and 300V respectively).

* The power factor for the source and load are reasonably low and becomes a little better with loading.

3.6 Conclusion:

The results from the tables are self revealing and confirm reasonably that with further research and development vegetable oil can be used in place of transformer oil and wooden bushings wholly or partly in power-distribution transformer. These innovations would be of great help if improved and used in our power system.

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