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ANALYSIS OF ACIDIC PROPERTIES OF DISTRIBUTION TRANSFORMER OIL INSULATION: A CASE STUDY OF JERICHO (NIGERIA) DISTRIBUTION NETWORK

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ABSTRACT
This paper examined the acidic properties of distribution transformer oil insulation in service at Jericho distribution network Ibadan, Nigeria. Five oil samples each from six distribution transformers (DT1, DT2, DT3, DT4 and DT5) making a total of thirty samples were taken from different installed distribution transformers all from the Jericho distribution network. 10 g of the oil sample were dissolved in 40 ml of solvent ethanol in a ratio of 5 to 4. Then 0.1mol/litre of Potassium hydroxide (KOH) was added as titre with volume increments of 0.001 ml. The system detects when the acid-base-equivalence-point is reached by a voltage measurement in the solution. A transformer insulating oil passes acidity test if the acidity content is not more than 0.2 mg KOH/g oil according to the guideline from the American Society of testing Materials (ASTM). It was observed that twenty test samples of transformer insulating oil from four distribution transformers passed acidity test while ten samples from the remaining two failed the test, showing the later were in conditions. With the acidic content beyond the prescribed minimum value present in the transformer oil, transformer winding is at the risk excessive heat due to internal conduction that could cause explosion or fire outbreak in the transformer

Keywords: *Acidity, Mineral Oil, Oxidation, Transformer, Distribution network.*

1. INTRODUCTION

Distribution transformer is a static device constructed with two or more windings used to transfer alternating current electric power by electromagnetic induction from one circuit to another at the same frequency but with different values of voltage and current. Oxidation of the oil insulation occurs in all equipment where it is in contact with air. Transformers are generally classified by size, insulation, and location. Based on size, transformers rated above 500 kVA are classed as power transformers. Transformers rated at 500 kVA or less is classed as distribution transformers, as they usually have low-tension windings of less than 600 volts [1].Power transformers are high cost important equipment used in the transmission and distribution of the electric energy. Its right performance is important for the electric systems operation, since the loss of a critical unit can generate great impact in safety, reliability and cost of the electric energy supply [2].

The purpose of a distribution transformer is to reduce the primary voltage of the electric distribution system to the utilization voltage serving the customer [3].The distribution transformers available for use for various applications include pole-type, pad-mounted, vault or network type and submersible [4].

Oxidation of the oil is accelerated as operating temperatures of the oil increase or by the presence of catalysts such as metals or metallic compounds. The cumulative effects of oxidation on the oil are to darken the oil, produce water and acids, and in the extreme, produce sludge. The production of water and acids can lead to corrosion of metal surfaces, particularly above the oil surface and can attack cellulose material, resulting in loss of mechanical strength and possible breakdown [5]. More to this is that the presence of acids in transformer oil beyond the maximum allowable quantity often results to internal conduction within transformer oil. The consequence of this is the rise in winding temperature that can lead to the burning of transformer winding.

Experience has shown that there are instances of transformers failing whilst in service, creating significant cost implications for the power supplier and, in extreme cases, explosion with a consequent threat of workers for severe injury or death and significant environmental impacts.

Although a large number of tests can be applied to mineral insulating oil in electrical equipment, the tests are considered sufficient to evaluate the condition of the oil in service and to establish whether the condition of

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the oil is adequate for continued operation. Corrective actions, based on the results are then suggested. Some of the tests among others include [6] dielectric test, acidity test and power factor test. The dielectric breakdown is an indication of oil's ability to withstand stress. Here, the most commonly performed test is ASTM D-877. This test is more readily used as a benchmark value when comparing different results from the test samples.

The power factor (ASTM D-924) is an indication of the amount of energy that is lost as heat impregnates into the oil. When pure oil acts as a dielectric, very little energy is lost to the capacitance charging. Contaminants will increase the energy absorbed by the oil and wasted as heat.

The dielectric test measures the voltage at which the oil breaks down, which is indicative of the amount of contaminant (usually moisture) in the oil, which is indicative of the amount of contaminant (usually moisture) in the oil[6,7,8]. This mineral oil is not necessarily in good condition even when the dielectric strength is adequate, because this tells nothing about the presence of acid.

The acidity of used oil is due to the formation of acidic oxidation products. Acids and other oxidation products will, in conjunction with water and solid contaminants, affect the dielectric and other properties of the oil[9]. Acids have an impact on the degradation of cellulosic materials and may also be responsible for the corrosion of metal parts in a transformer [10]. The rate of increase of acidity of oil in service is a good indicator of the ageing rate. The acidity level is used as a general guide for determining when the oil should be replaced or reclaimed [11].

Therefore, this paper examined the acidity of distribution transformer oil in service through laboratory tests using a case study of installed distribution transformers at Jericho distribution network comprising of Cocoa house, Onireke, Iyaganku and Odo-Ona Feeders in Ibadan, Nigeria. The study covers part of the commercial place in the city where regular and continuous supply of electricity is desired.

2. MATERIALS AND METHOD

Prior testing of distribution transformer insulation oil, a detailed sampling was carried out on installed distribution transformers at Jericho distribution network to arrive at the selected transformers. Samples were not taken from energized transformers. The transformers have no external sampling valve, hence, the units were first de-energized and the samples were taken internally. The adopted method of obtaining liquid samples follows ASTM D 923 standard. Oil samples were taken from the bottom of the transformers, since less-flammable liquid samples were the ones recommended to be taken from the top. The samples were allowed to stand in tightly sealed containers for 24 hours prior testing.

Five oil samples each from six distribution transformers (DT1, DT2, DT3, DT4 and DT5) making a total of thirty samples were taken from different installed distribution transformers all from the Jericho distribution network, Ibadan. The acid neutralization number is a measure of the amount of acid materials present in the oil. As the transformer ages, the oil will oxidize and increase in acidity. The acid value can also increase from contamination of other foreign material such as paint, varnish, and the likes. An automatic potentiometric titration system Titrino SM 702 was used to measure the acidity of the oil samples as shown in Fig. 1.0

The system involves determination of the Total Acid Number TAN by a volumetric titration with potash to neutralize the carboxylic acids. Ten gramme (10 g) of the oil sample were dissolved in 40 ml of solvent ethanol in a ratio of 5 to 4. Then 0.1mol/litre of Potasium hydroxide (KOH) was added as titre with volume increments of 0.001 ml. The system detects, when the acid-base-equivalence-point EP is reached by a voltage measurement in the solution. The acidity test for each sample was carried out four times and the average total acid number recorded. From the volume of potassium hydroxide at the equivalence point for each experimental run, the total acid number was calculated from equation (1): [12]

$$T_A = \frac{(E_p - C_s)N_{KOH}m_{KOK}}{w} \quad (1)$$

In (1), T_A is the Total acid number, E_P is the Equivalent point, C_s is the Blind value of the solvent ethanol, N_{KOH} is the Concentration of titre (mol/l),m_{KOH} is the Molar mass of titre, = 56,106 g/mol, and w is the Weight of the oil sample.

2.1 Standard Values for Acidity of Transformer Oil

Test Methods by the American Society for Testing of Materials (ASTM) provides that the acidity of oil in a transformer should never be allowed to exceed 0.2mg KOH/g oil. This is the Critical Acid Number and deterioration increases rapidly once this level is exceeded.

3. RESULTS AND DISCUSSION

For the 30 different samples of transformer oil taken from installed distribution transformers at Jericho network (Appendix A-E)in Ibadan, the acidity test for each sample was carried out four times and the average total acid number recorded. From the volume of potassium hydroxide at the equivalence point for each experimental run, the total acidity number was calculated from equation (1). The result obtained for Acidity Test on Distribution Transformer (DT1-DT6) Oil with average values of results for acidity Test on 30 Transformer Oil Specimens on 6 groups of Distribution Transformers is presented in Table 1. Each group was identified by their connections and ratings.

From Table 1, it was observed that all the five transformer oil samples (TOS 01 – TOS 05) from distribution transformers (DT1; 33/0.415 kV type) passed acidity test since all the samples had total acid number less than 0.2 mgKOH/g of the oil. Similarly, the oil samples (TOS 06 – TOS 10) from distribution transformers (DT2; 33/0.415 kV type) passed acidity test since all the samples had total acid number less than 0.2 mgKOH/g of the oil. However, oil samples (TOS 11 – TOS 15) from distribution transformers (DT3; 33/0.415 kV type) failed acidity test since all the samples had total acid number greater than 0.2 mg KOH/g of the oil. It was also observed that all the five transformer oil samples (TOS 16 – TOS 20) from distribution transformers (DT4; 11/0.415 kV type) passed acidity test since all the samples had total acid number less than 0.2 mg KOH/g of the oil.

Similarly, all the five transformer oil samples (TOS 21 – TOS 25) from distribution transformers (DT5; 11/0.415 kV type) passed acidity test since all the samples had total acid number less than 0.2 mg KOH/g of the oil. However, all the five transformer oil samples (TOS 26 – TOS 30) from distribution transformers (DT6; 11/0.415 kV type) failed acidity test. The results showing each specimen of the 30 oil sample tested are presented Table 2.

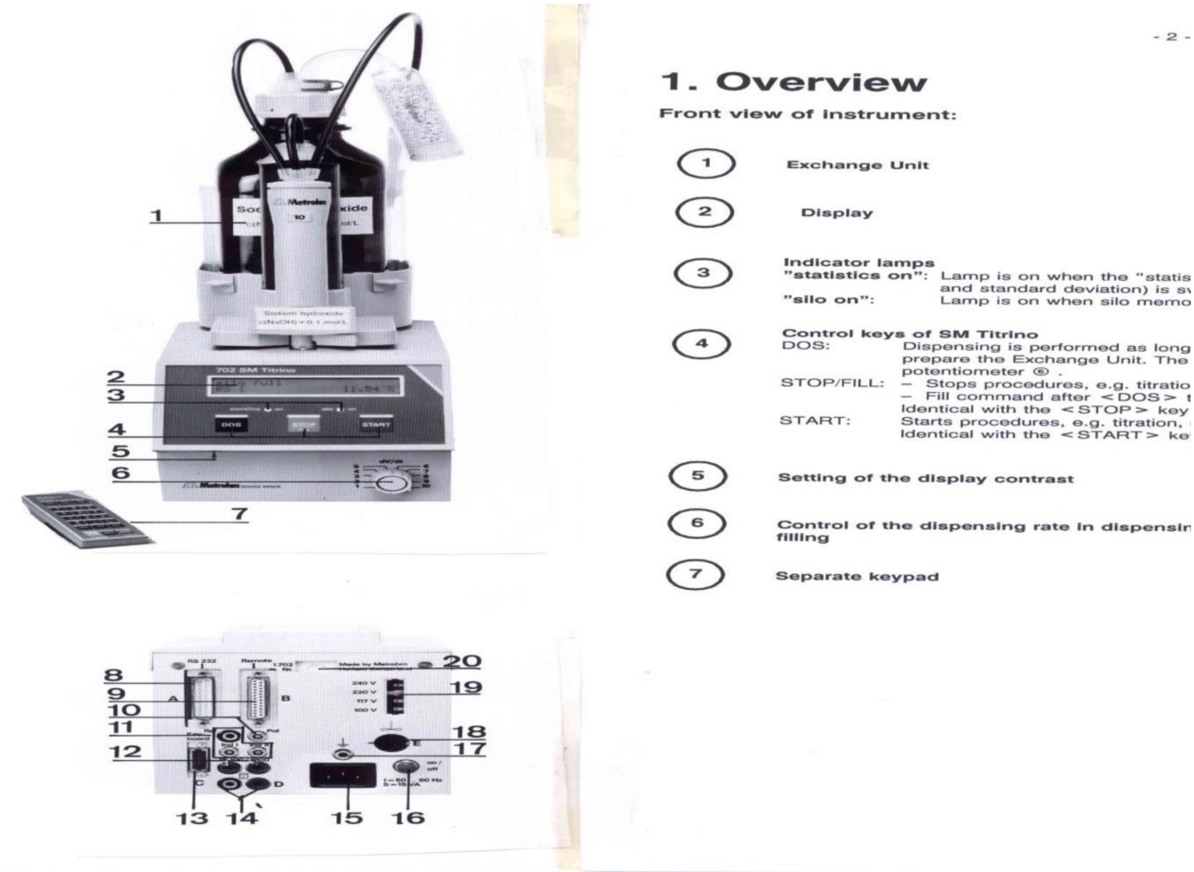

Figure. 1: Volumetric titration system (Source: www.astm.org/standards)

Table 1: Results for Acidity Test on 30 Transformer Oil Specimen on 6 kinds of Distribution Transformers

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Avarage total Acidity mgKOH/g of oil
TOS 1-5	DT1	33/0.415	250	0.09
TOS 6-10	DT2	33/0.415	300	0.10
TOS 11-15	DT3	33/0.415	500	0.25
TOS16-20	DT4	11/0.415	300	0.08
TOS 21-25	DT5	11/0.415	200	0.09
TOS 26-30	DT6	11/0.415	500	0.27

Table 2: Interpretation of Results for Acidity Tests conducted on the 30 Samples of Distribution Transformer Oil showing total acidity of each oil specimen

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Total Acidity mg KOH/g of oil	Remarks
TOS 01	DT1	33/0.415	0.10	Passed test
TOS 02	DT1	33/0.415	0.06	Passed test
TOS 03	DT1	33/0.415	0.08	Passed test
TOS 04	DT1	33/0.415	0.12	Passed test
TOS 05	DT1	33/0.415	0.08	Passed test
TOS 06	DT2	33/0.415	0.10	Passed test
TOS 07	DT2	33/0.415	0.08	Passed test
TOS 08	DT2	33/0.415	0.08	Passed test
TOS 09	DT2	33/0.415	0.12	Passed test
TOS 10	DT2	33/0.415	0.10	Passed test
TOS 11	DT3	33/0.415	0.22	Failed test
TOS 12	DT3	33/0.415	0.25	Failed test
TOS 13	DT3	33/0.415	0.24	Failed test
TOS 14	DT3	33/0.415	0.32	Failed test
TOS 15	DT3	33/0.415	0.21	Failed test
TOS 16	DT4	11/0.415	0.08	Passed test
TOS 17	DT4	11/0.415	0.06	Passed test
TOS 18	DT4	11/0.415	0.06	Passed test
TOS 19	DT4	11/0.415	0.08	Passed test
TOS 20	DT4	11/0.415	0.12	Passed test
TOS 21	DT5	11/0.415	0.10	Passed test
TOS 22	DT5	11/0.415	0.12	Passed test
TOS 23	DT5	11/0.415	0.08	Passed test
TOS 24	DT5	11/0.415	0.08	Passed test
TOS 25	DT5	11/0.415	0.06	Passed test
TOS 26	DT6	11/0.415	0.25	Failed test
TOS 27	DT6	11/0.415	0.30	Failed test
TOS 28	DT6	11/0.415	0.26	Failed test
TOS 29	DT6	11/0.415	0.21	Failed test
TOS 30	DT6	11/0.415	0.31	Failed test

Acids in the oil have been reported to originate from oil decomposition/oxidation products. Acids can also come from external sources such as atmospheric contamination. These organic acids are detrimental to the insulation system and can induce corrosion inside the transformer when water is present. An increase in the acidity is an indication of the rate of deterioration of the oil with sludge as the inevitable by-product of an acid situation which is neglected.

It has been reported that the acidity of oil in a transformer should never be allowed to exceed 0.20mg KOH/g oil. This is the critical acid number and deterioration increases rapidly once this level is exceeded. The acid neutralization number, or acid number, is the amount of potassium hydroxide (KOH in mg) required to neutralize the acid in one gram of oil. It is indicative of the acid content in the oil. With service-aged oils, it is also indicative of the presence of contaminants, like sludge. It should be recognized that the acidity test alone determines conditions under which sludge may form but does not necessarily indicated that actual sludging conditions exit. New transformer oils contain practically no acids. The acidity test measures the content of acids formed by oxidation. The oxidation products polymerize to form sludge which then precipitates out. Acids react with metals on the surfaces inside the tank and form metallic soaps, another form of sludge.

For mineral oil, sludging has been found to begin when the acid number reaches or exceeds 0.4 mg KOH/gram. New oil has an acid number of less than 0.05 mg KOH/gram. Oil showing an acid number of 0.15 or larger can be expected to show accelerated acid formation. Typically, results of 0.10 mg KOH/gram of oil or less are considered good. Higher values are indicative of a problem.

From the results obtained for the tests conducted, some of the samples failed the test while some passed the test. All those samples who marginally failed or passed the acidity test can be reconditioning while those transformers oils with acidic values more than 0.02 mg KOH/gram need complete replacement of the new insulating oil.

If the test indicates that an insulating liquid is not in satisfactory condition, it may be restored by reconditioning, reclaiming, or it can be completely replaced. Reconditioning is the removal of moisture and solid materials by mechanical means such as filter presses, centrifuges, or vacuum dehydrators. Reclaiming is the removal of acidic and colloidal contaminants, and products of oxidation, by chemical and absorbent means. Replacing the liquid involves draining, flushing, testing, and proper disposal of materials removed.

4. CONCLUSION

From the tests results, it can be seen that twenty test samples of transformer insulating oil passed acidity test. These oil test samples are TOS 01 – TOS 10 and TOS 16 – TOS 25. This indicates that the transformer insulating oil from distribution transformers DT1, DT2, DT4 and DT5 are in good condition, which implies that oxidation leading to acidity of the oil has not commenced in the transformers. Therefore, no reconditioning or replacement of the insulating oil is necessary for these sets of transformers. The results obtained for ten oil test samples (TOS 11 – TOS 15 and TOS 26 – TOS 30) indicates that the transformer insulating oil from distribution transformers DT3 and DT6 were not in good condition. The samples failed acidity test. This shows that contaminants, like sludge, were present in the oil from these transformers and reconditioning or replacement of the insulating oil is necessary for these sets of transformers.

Therefore, the condition of oil in service, even, the new one should be checked regularly so that it will not result to transformer breakdown. The presence of acidic content beyond the prescribed minimum value in the transformer oil can lead to internal conduction, resulting to excessive heat and hence eventual explosion or fire outbreak in the transformer. Hence, the need for periodic tests on transformer insulating oil if a quality and continuous service are to be maintained.

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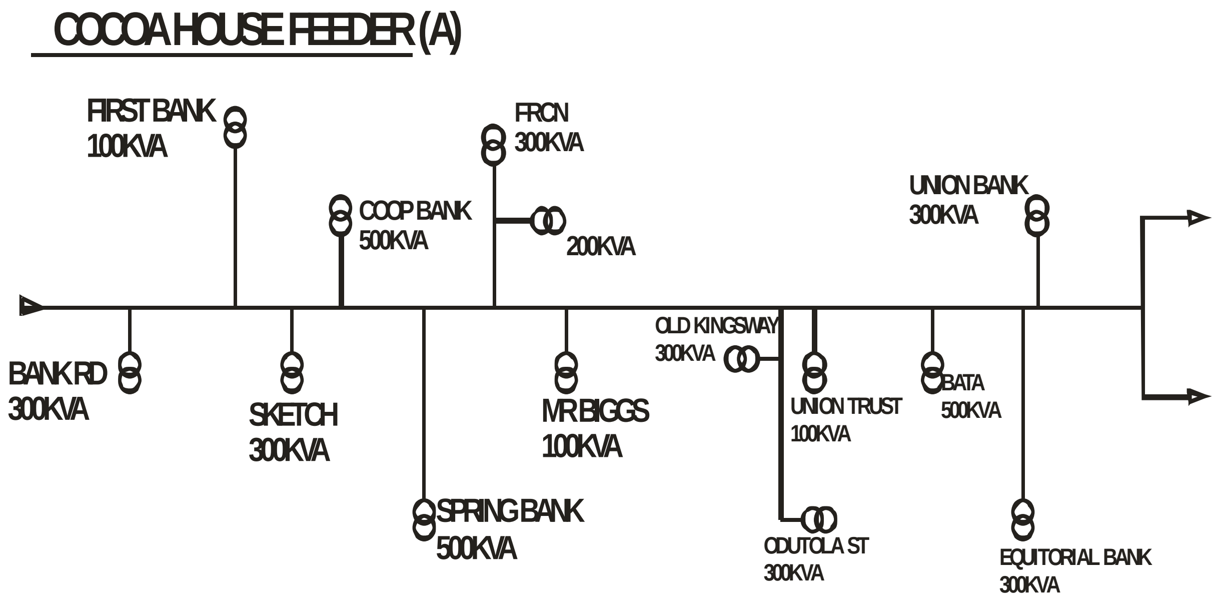
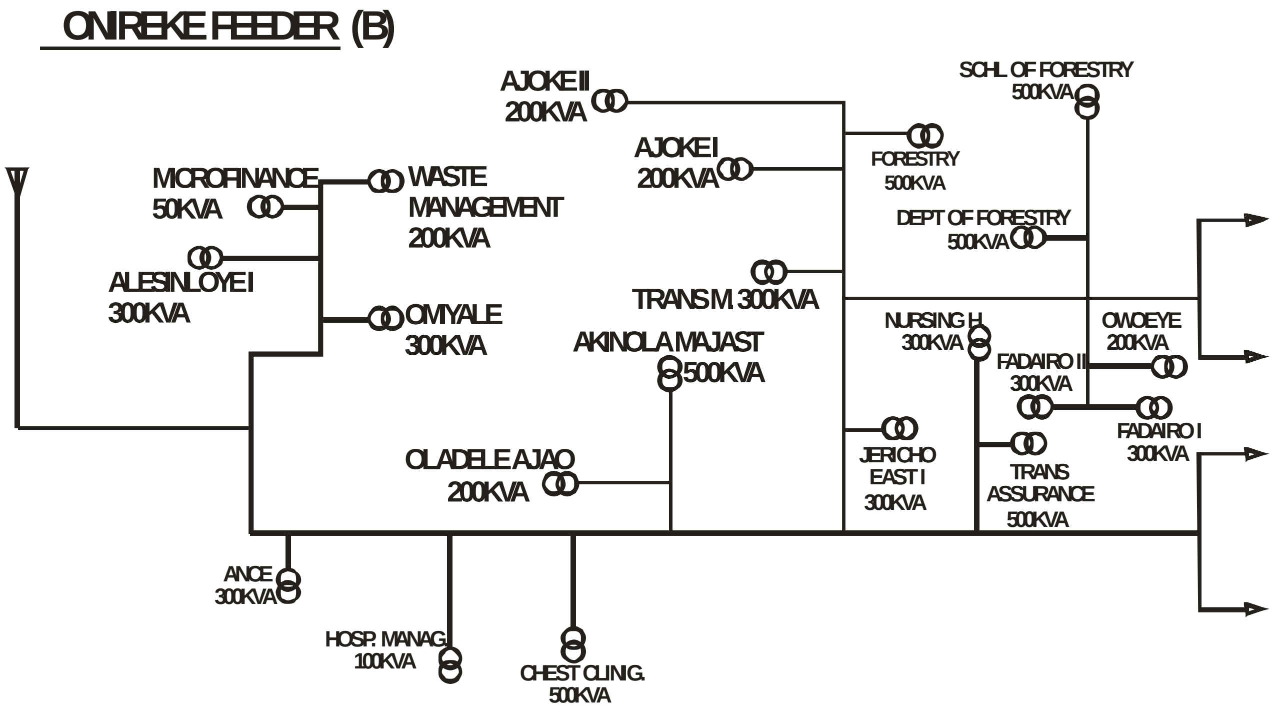
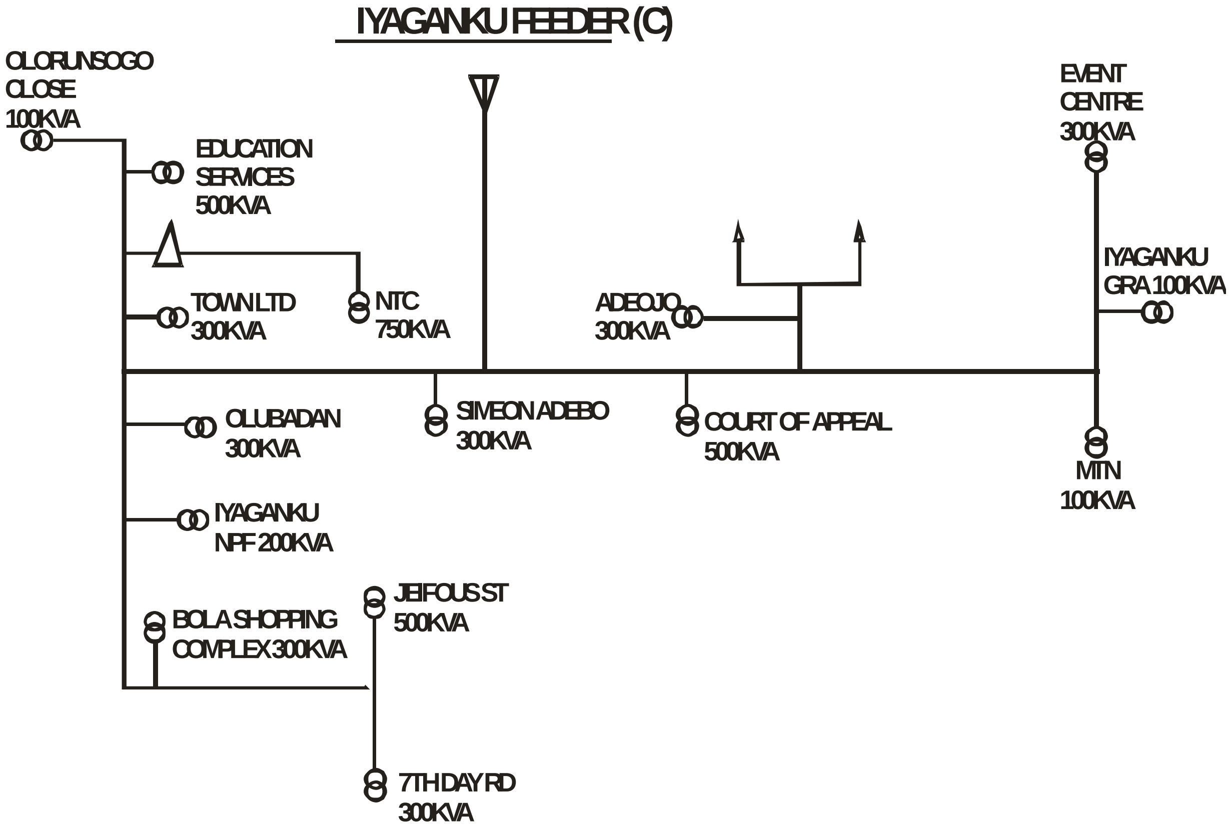
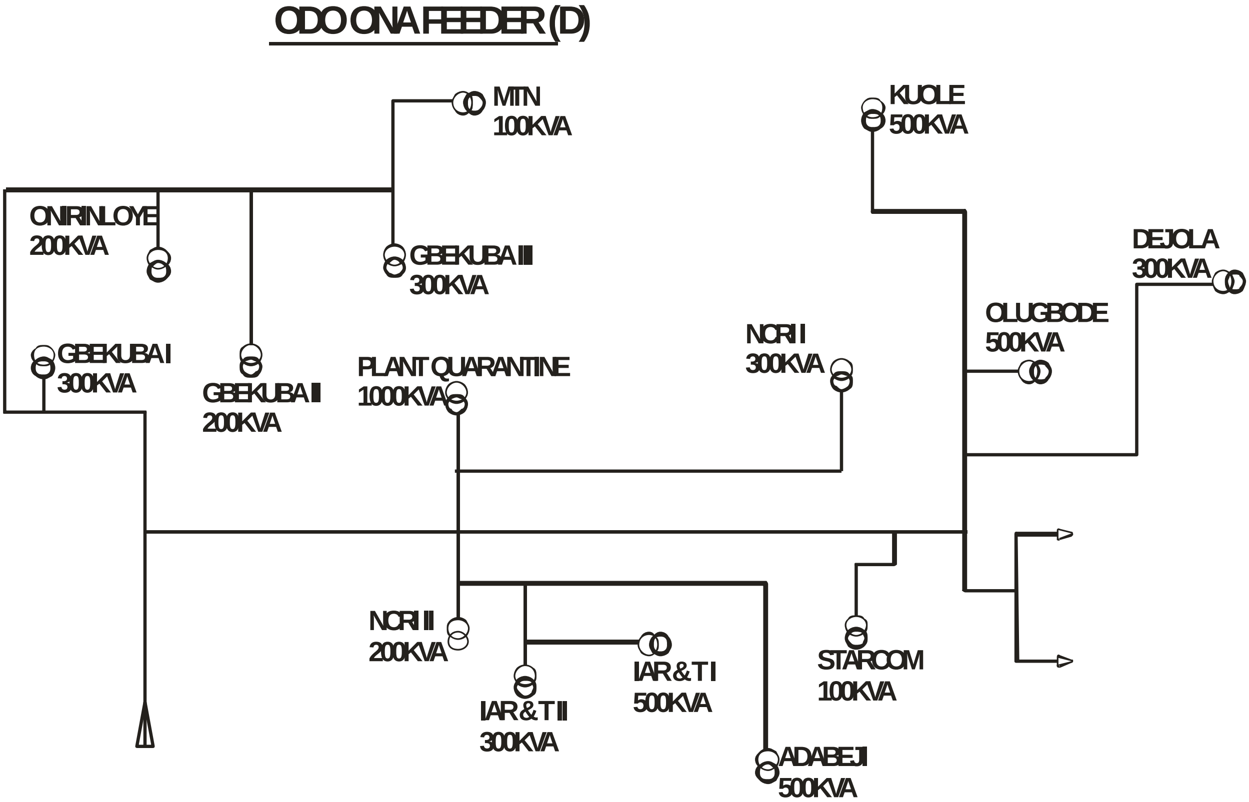
6. APPENDIX I (A-E)

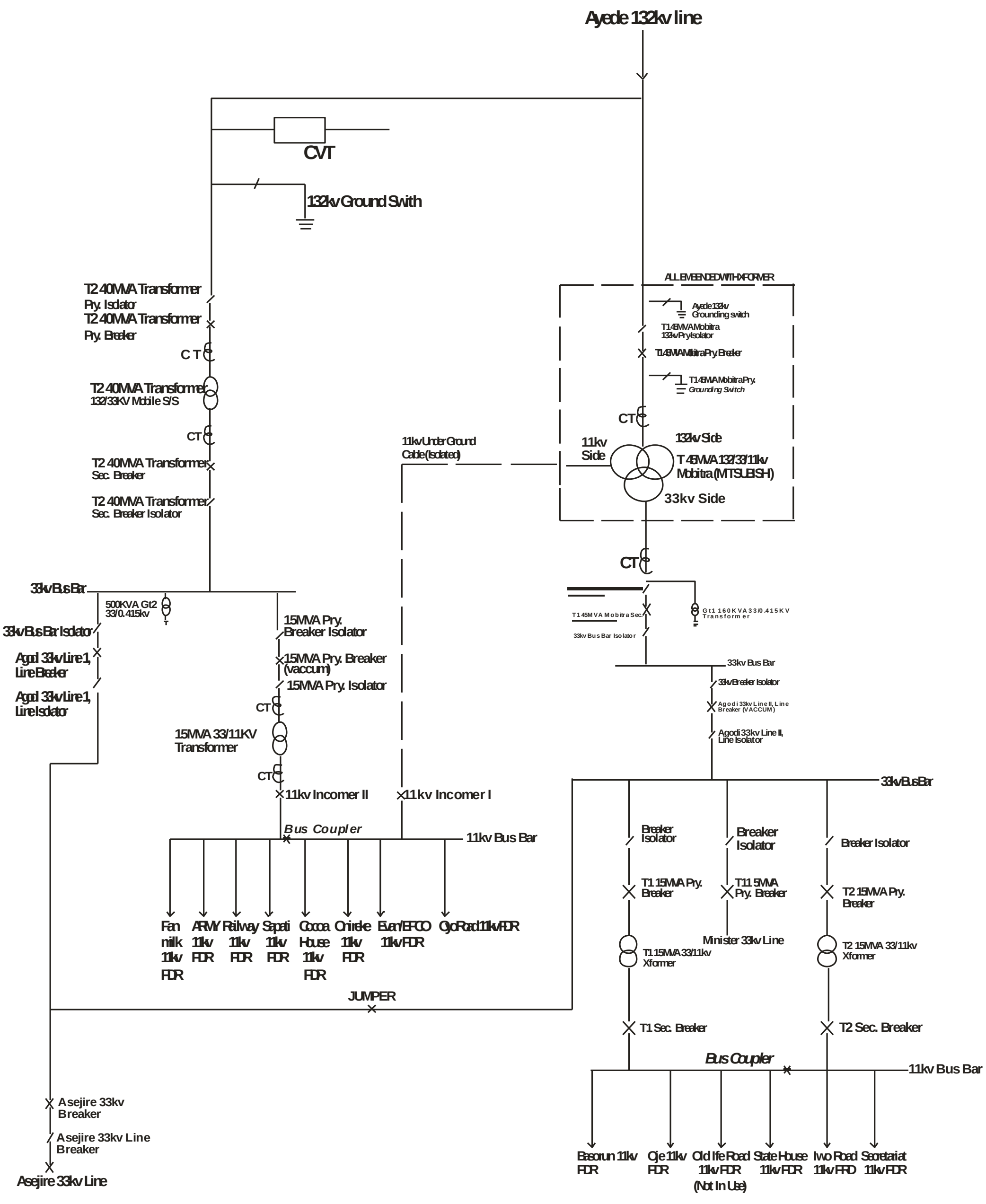





IYAGANKU FEEDER (C)
OLORUNSOGO CLOSE 100KVA
EDUCATION SERVICES 500KVA
TOWN LTD 300KVA
NTC 750KVA
ADEOJO 300KVA
EVENT CENTRE 300KVA
IYAGANKU GRA 100KVA
OLUBADAN 300KVA
SIMEON ADEBO 300KVA
COURT OF APPEAL 500KVA
MTN 100KVA
IYAGANKU NPF 200KVA
JEIFOUS ST 500KVA
BOLA SHOPPING COMPLEX 300KVA
7TH DAY RD 300KVA


ODO ONA FEEDER (D)
MTN 100KVA
KUOLE 500KVA
ONIRINLOYE 200KVA
GBEKUBA III 300KVA
DEJOLA 300KVA
OLUGBODE 500KVA
NCRI I 300KVA
GBEKUBA I 300KVA
GBEKUBA II 200KVA
PLANT QUARANTINE 1000KVA
NCRI II 200KVA
IAR & T I 500KVA
STARCOM 100KVA
IAR & T II 300KVA
ADABEJI 500KVA

STATION DIAGRAM OF JERICHO DISTRIBUTION NETWORKOF PHCN IBADAN(E)



LEGEND		STATION DIAGRAM OF JERICHO DISTRIBUTION NETWORK OF PHCN IBADAN.
CT	Current Transformer	
CVT	Capacitor Voltage Transformer	
GT	Grounding Transformer	
FDR	Feeder	SCALE 1:200