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

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ABSTRACT

The insulating liquids used in liquid-immersed transformers not only provide insulation, but serve to transfer heat from the windings to the surrounding. The liquid must be kept free of contaminants and moisture, just as the air insulation of dry-type transformers. This paper therefore focused on the analysis of the dielectric properties of distribution transformer oil insulation using a case study of installed distribution transformers at Jericho distribution network, Ibadan, Nigeria. Thirty samples were taken from different installed distribution transformers at Jericho distribution network. A conventional dielectric test system (Baur DTA 100 E oil tester) was used to measure the breakdown voltage of these oil samples. A transformer insulating oil passes dielectric test if the measured breakdown voltage is not less than 25kV for 11/0.415kV distribution system or 45kV for 33/0.415kV distribution system in accordance with the guideline from the American Society of testing Materials (ASTM). It was observed that fifteen test samples of transformer insulating oil passed dielectric test while with remaining fifteen samples did not meet up the required standard. This implies that those samples that failed the test would not be able to provide the insulation to the transformer winding which can lead to excessive heat, and consequently might caused explosion or fire outbreak in the transformer.

Keywords – *Distribution Transformer, Mineral oil, Breakdown Voltage, Dielectric Strength.*

1. INTRODUCTION

Electrical power transformers are used to step up or step down voltage and are an integral component of any efficient power distribution network. A typical transformer incorporates coils of conducting wire wrapped around a core and covered with a paper-based insulator (El-Sayed *et al*., 2009). Essential to the operation of these units are transformer oils that serve both functions: electrical insulation and heat dissipation.

However, 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 (Sokolov *et al*., 2010).

Power transformers are among the most valuable and important assets in electrical power systems. Insulation system ageing reduces both the mechanical and dielectrics withstand strength of the transformer (Prosr *et al*., 2010). An ageing transformer is subject to faults that result in high radial and compressive forces. In an aged transformer failure, the conductor insulation has typically deteriorated to the point where it can no longer sustain the mechanical stresses caused by a fault (Walling and Shattuck, 2007).

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Insulating oil in an electrical power transformer is commonly known as transformer oil. It is normally obtained by fractional distillation and subsequent treatment of crude petroleum. Insulating oil serves two purposes as liquid insulation and coolant for the transformer. Generally, there are two types of transformer Oil used in transformer. They are Paraffin based transformer oil and Naphtha based transformer oil. In both cases the oil quality must satisfy ASTM standard.

Oil suffers continuous deterioration and degradation due to the sustained application of the electric and cyclic thermal stresses because of loading and climatic conditions. This may be hazardous to the electric equipment and installation. Continuous monitoring of oil insulation characteristics has become an important task to avoid deterioration of oil characteristics under working conditions (Martin and Wang, 2006).

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. The dielectric breakdown is a measurement of electrical stress that an insulating oil can withstand without failure. It is measured by applying a voltage between two electrodes under prescribed conditions for the oil. Usually, the acceptability of any insulating system is based not only the dielectric breakdown voltage but also on its moisture content and power factor.

Moisture in oil is measured in parts per million (ppm) using the weight of moisture divided by the weight of oil (Spartalis *et al*., 2008). The moisture content in the oil lowers the insulating system dielectric strength and allows flashover that can damage a transformer. Moisture can also accelerate paper-insulation aging rates that will reduce the expected useful life of equipment (Andreous *et al*., 1999, 2001, 2005).

This paper therefore focused on the analysis of the dielectric status of distribution transformer oil insulation through laboratory tests using a case study of installed distribution transformer 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

Dry and clean oil exhibits an inherently high breakdown voltage. The measurement of breakdown voltage, therefore, serves primarily to indicate the presence of contaminants such as water or particles.

Analysis of distribution transformer oil insulation was considered using a case study of installed distribution transformers at Jericho distribution network comprising of Iyaganku, Onireke, Odo-Ona, and Cocoa House Feeders (Appendix I, A-E) in Ibadan, South West Nigeria. To achieve this, dielectric test was carried out. The motor driven insulating oil tester (Baur DTA 100E) was used for the dielectric test on samples of the transformer insulating oil (Adejumobi and Oyagbirin, 2007).

Prior to 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.

In all, thirty samples were taken from different installed distribution transformers all from the Jericho distribution network. The test validity is dependent upon the validity of the sample. It was ensured that clean, dry, glass containers with non rubber wax sealed stoppers were used to prevent leakage. Oil samples were taken when the oil is at least as warm as or warmer than the surrounding air and always on a clear windless day when the relative humidity does not exceed 70%. The samples were placed in a refrigerator's freezing compartment overnight. A cloudy sample indicates free water and another sample was taken to determine whether the water was in the sample container or in the oil.

A conventional dielectric test system was used to measure the breakdown voltage of the 30 different samples of selected transformer oil (five oil samples each from six distribution transformers (DT1, DT2, DT3, DT4, DT5 and DT6). The Baur DTA 100 E oil tester is fully automated and it is very convenient for long test series. It detects breakdown within a short period of time. The Oil tester is also characterized with low energy in the test cell, which prevents carbonation of the oil test sample. The oil tester, typically presented in Fig. 1 has a glass cylinder, where oil specimens were poured. The tests were carried out according to ASTM D1816, using spherical electrodes with 25 mm radius, separated by dielectric thickness of 2.0 mm.

The dielectric test for each sample was carried out four times and the average dielectric voltage recorded. To obtain the dielectric strength, the equation developed by Herald and Wilism as reported by Adejumobi and Oyagbirin, (2007) was used:

$$D_s = \frac{V_{bk}}{d} \quad (1)$$

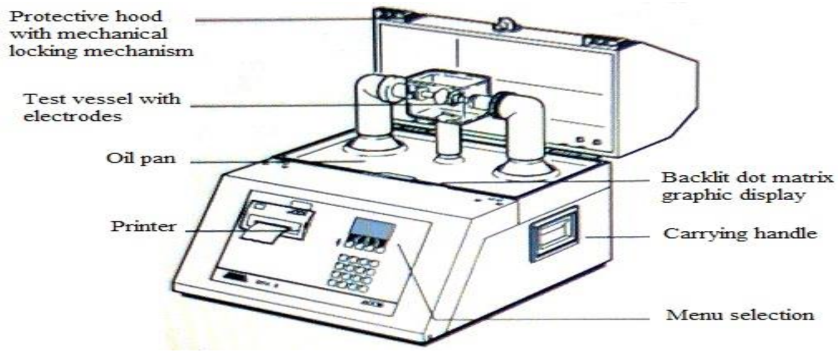

Figure 1: Baur DTA 100 E Automatic Insulating Liquid Tester (Source: www.baur.at)

Where D_s = Dielectric strength

v_{bk} = Breakdown voltage of insulator

d = dielectric thickness (mm)

Standard Values for AC Breakdown Voltage for Different Transformer Ratings

The recommended ratings in respect of breakdown voltage as reported by Adejumobi and Oyagbirin (2007) are as follows: the minimum breakdown voltage of 11/0.415 kV transformer insulating oil should not be less than 25 kV while for 33/0.415 kV transformer, the minimum breakdown voltage of the insulating oil should not be less than 45 kV.

3. RESULTS AND DISCUSSION

Using a conventional dielectric test system described in section 2 above, the breakdown voltage of the 30 different samples of transformer oil taken from distribution transformers at Jericho distribution network, Ibadan as detailed out in the appendix I (A-E) attached was measured. The dielectric test for each sample was carried out four times and the average dielectric voltage recorded. Dielectric strength was thereafter determined using equation (1). The results obtained are presented in Tables 1 to 6.

Table 1: Dielectric Test on Distribution Transformer (DT1) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kV)	Dielectric Strength (kV/mm)
TOS 01	DT1	33/0.415	250	47.90	23.95
TOS 02	DT1	33/0.415	250	47.70	23.85
TOS 03	DT1	33/0.415	250	48.00	24.00
TOS 04	DT1	33/0.415	250	47.80	23.90
TOS 05	DT1	33/0.415	250	48.00	24.00

Table 2: Dielectric Test on Distribution Transformer (DT2) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power(kVA)	Breakdown Voltage(kVA)	Dielectric Strength (kV/mm)
TOS 06	DT2	33/0.415	300	43.20	21.60
TOS 07	DT2	33/0.415	300	41.40	20.70
TOS 08	DT2	33/0.415	300	40.90	20.45
TOS 09	DT2	33/0.415	300	39.90	19.95
TOS 10	DT2	33/0.415	300	41.20	20.60

Table 3: Dielectric Test on Distribution Transformer (DT3) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kVA)	Dielectric Strength (kV/mm)
TOS 11	DT3	33/0.415	500	13.50	6.75
TOS 12	DT3	33/0.415	500	12.00	6.00
TOS 13	DT3	33/0.415	500	14.10	7.05
TOS 14	DT3	33/0.415	500	12.80	6.40
TOS 15	DT3	33/0.415	500	13.00	6.50

Table 4: Dielectric Test on Distribution Transformer (DT4) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kV)	Dielectric Strength (kV/mm)
TOS 16	DT4	11/0.415	300	28.10	14.05
TOS 17	DT4	11/0.415	300	27.60	13.80
TOS 18	DT4	11/0.415	300	28.00	14.00
TOS 19	DT4	11/0.415	300	28.50	14.25
TOS 20	DT4	11/0.415	300	26.90	13.45

Table 5: Dielectric Test on Distribution Transformer (DT5) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kV)	Dielectric Strength (kV/mm)
TOS 21	DT5	11/0.415	200	30.10	15.05
TOS 22	DT5	11/0.415	200	29.90	14.95
TOS 23	DT5	11/0.415	200	30.40	15.20
TOS 24	DT5	11/0.415	200	30.20	15.10
TOS 25	DT5	11/0.415	200	30.60	15.30
TOS 26	DT6	11/0.415	500	11.20	5.60

Table 6: Dielectric Test on Distribution Transformer (DT6) Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kV)	Dielectric Strength (kV/mm)
TOS 26	DT6	11/0.415	500	11.20	5.60
TOS 27	DT6	11/0.415	500	10.60	5.30
TOS 28	DT6	11/0.415	500	10.50	5.25
TOS 29	DT6	11/0.415	500	11.00	5.50
TOS 30	DT6	11/0.415	500	10.80	5.40

Average values of results for dielectric test on 30 transformer oil specimen on 6 kinds of distribution transformers are presented in Table 7.

Table 7: Dielectric Test on 30 Transformer Oil Specimen on 6 kinds of Distribution Transformers

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Transformer Rated Power (kVA)	Breakdown Voltage(kV)	Dielectric Strength (kV/mm)
TOS 1-5	DT1	33/0.415	250	47.88	23.94
TOS 6-10	DT2	33/0.415	300	41.32	20.66
TOS 11-15	DT3	33/0.415	500	13.08	6.54
TOS16-20	DT4	11/0.415	300	27.82	13.91
TOS 21-25	DT5	11/0.415	200	30.24	15.12
TOS 26-30	DT6	11/0.415	500	10.82	5.41

For mineral oil, a generally accepted minimum dielectric breakdown voltage is 45 kV for transformers with a high-voltage rating of 33 kV and above and 25 kV for transformers with a voltage rating of 11 kV. New oil should have a minimum dielectric strength of 35 kV by ASTM D1816 method of testing.

From Table 1, it was observed that all the five transformer oil samples (TOS 01 – TOS 05) from distribution transformers (DT1; 33/0.415kv type) passed breakdown voltage test since all the samples had breakdown voltage greater than 45 kV.

However, the oil samples (TOS 06 – TOS 10) from distribution transformers (DT2; 33/0.415kV type) failed breakdown voltage test due to the fact that all the samples had breakdown voltage less than 45 kV. This is evident from Table 2. Similarly, oil samples (TOS 11 – TOS 15) from distribution transformers (DT3; 33/0.415 kV type) failed breakdown voltage test due to the fact that all the samples had breakdown voltage less than 45 kV. This is evident from Table 3.

From Table 4, it was observed that all the five transformer oil samples (TOS 16 – TOS 20) from distribution transformers (DT4; 11/0.415 kV type) passed breakdown voltage test since all the samples had breakdown voltage greater than 25 kV. Similarly, all the five transformer oil samples (TOS 21 – TOS 25) from distribution transformers (DT5; 11/0.415 kV type) passed breakdown voltage test since all the samples had breakdown voltage greater than 25 kV.

All the five transformer oil samples (TOS 26 – TOS 30) from distribution transformers (DT6; 11/0.415 kV type) however failed breakdown voltage test because all the samples had breakdown voltage less than 25kV.

These results are interpreted in Table 8. The dielectric test measures the ability of the oil to withstand electric stress without failure. The higher the value of dielectric strength, the lower the presence of contaminants such as water, dirt, or other conductive particles. The dielectric strength of insulating oil is a measure of the oil's ability to withstand electrical stress without failure (Koch *et al*., 2007). Contaminants such as water, sediment and conducting particles reduce the dielectric strength of insulating oil. Combination of these tends to reduce the dielectric strength to a greater degree. Clean dry oil has an inherently high dielectric strength but this does not necessarily indicate the absence of all contaminates, it may merely indicate that the amount of contaminants present between the electrodes is not large enough to affect the average breakdown voltage of the liquid.

4. CONCLUSION

From the tests results, it can be seen that fifteen test samples of transformer insulating oil passed dielectric test. These oil test samples are TOS 01 – TOS 05, TOS 16 – TOS 25. This indicates that the transformer insulating oil from distribution transformers DT1, DT4 and DT5 are in good condition, which implies that insulation deterioration 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 fifteen oil test samples (TOS 06 – TOS 15 and TOS 26 – TOS 30) indicate that the transformer insulating oil from distribution transformers DT2, DT3 and DT6 were not in good condition. Fifteen out of thirty samples did not pass the dielectric test. This indicates the excess use of the oil or the presence of the contaminants in the oil from these transformers. The failure of transformer oil insulation to meet up with the required standard 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. A failure of transformer oil insulation occurs when the oil is overused or normal routine checks are not duly observed.

Table 8: Interpretation of Results for Dielectric Conducted on the 30 Samples of Distribution Transformer Oil

Transformer Oil Specimen	Distribution Transformer	Transformer Type	Breakdown Voltage(kV)	Remarks
TOS 01	DT1	33/0.415	47.90	Passed
TOS 02	DT1	33/0.415	47.70	Passed
TOS 03	DT1	33/0.415	48.00	Passed
TOS 04	DT1	33/0.415	47.80	Passed
TOS 05	DT1	33/0.415	48.00	Passed
TOS 06	DT2	33/0.415	43.20	Failed
TOS 07	DT2	33/0.415	41.40	Failed
TOS 08	DT2	33/0.415	40.90	Failed
TOS 09	DT2	33/0.415	39.90	Failed
TOS 10	DT2	33/0.415	41.20	Failed
TOS 11	DT3	33/0.415	13.50	Failed
TOS 12	DT3	33/0.415	12.00	Failed
TOS 13	DT3	33/0.415	14.10	Failed
TOS 14	DT3	33/0.415	12.80	Failed
TOS 15	DT3	33/0.415	13.00	Failed
TOS 16	DT4	11/0.415	28.10	Passed
TOS 17	DT4	11/0.415	27.60	Passed
TOS 18	DT4	11/0.415	28.00	Passed
TOS 19	DT4	11/0.415	28.50	Passed
TOS 20	DT4	11/0.415	26.90	Passed
TOS 21	DT5	11/0.415	30.10	Passed
TOS 22	DT5	11/0.415	29.90	Passed
TOS 23	DT5	11/0.415	30.40	Passed
TOS 24	DT5	11/0.415	30.20	Passed
TOS 25	DT5	11/0.415	30.60	Passed
TOS 26	DT6	11/0.415	11.20	Failed
TOS 27	DT6	11/0.415	10.60	Failed
TOS 28	DT6	11/0.415	10.50	Failed
TOS 29	DT6	11/0.415	11.00	Failed
TOS 30	DT6	11/0.415	10.80	Failed

Therefore, there is a need for reconditioning of the transformer oil in the fifteen transformers (DT2, DT3 and DT6 type) from where the fifteen oil samples were taken.

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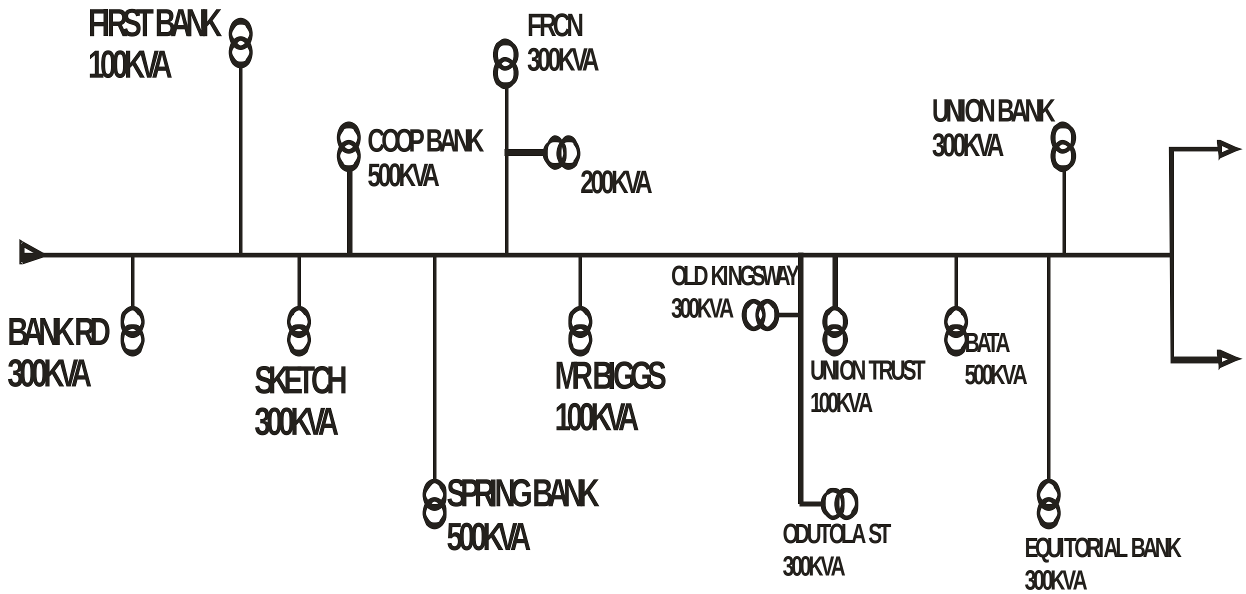
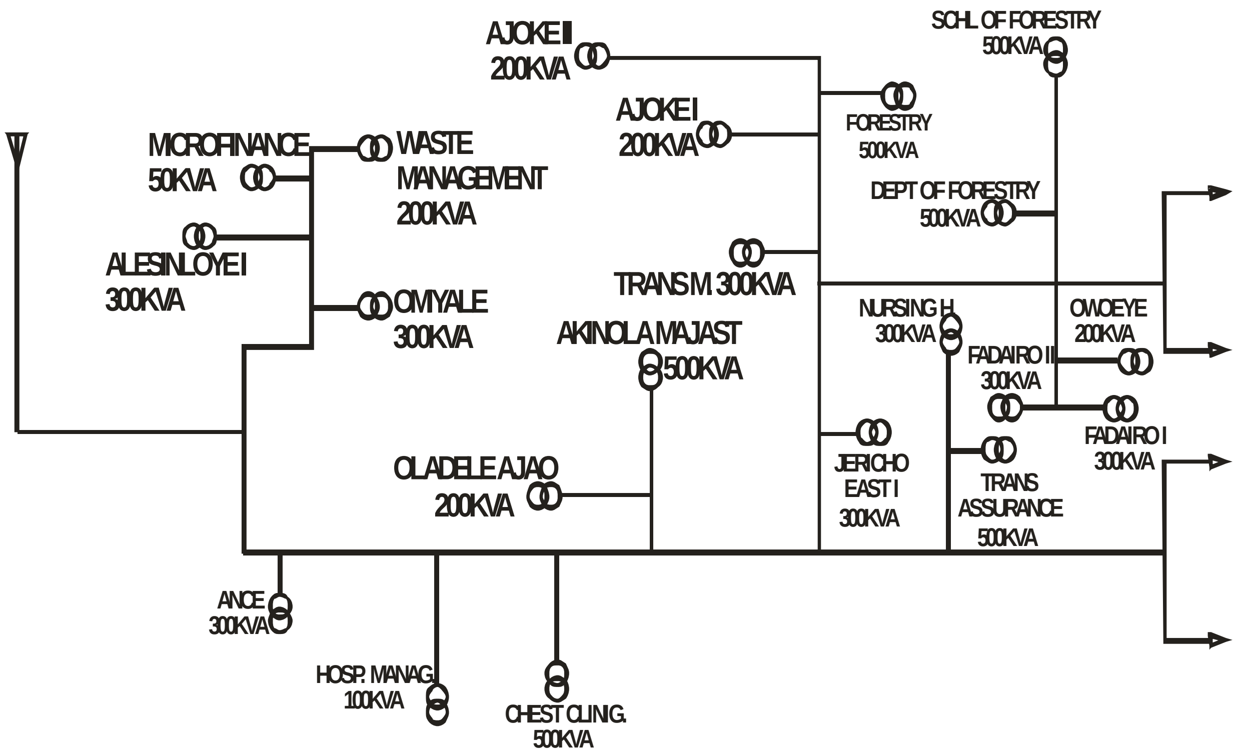
APPENDIX I (A-E)

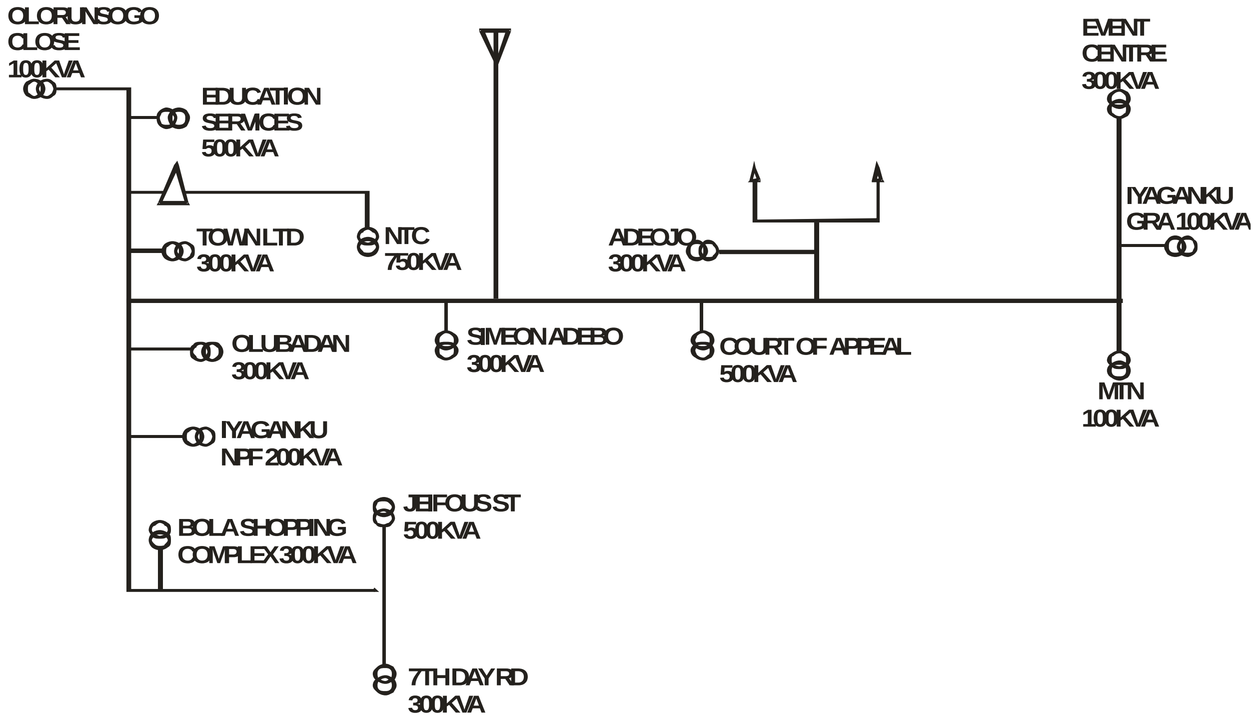
COCOA HOUSE FEEDER (A)



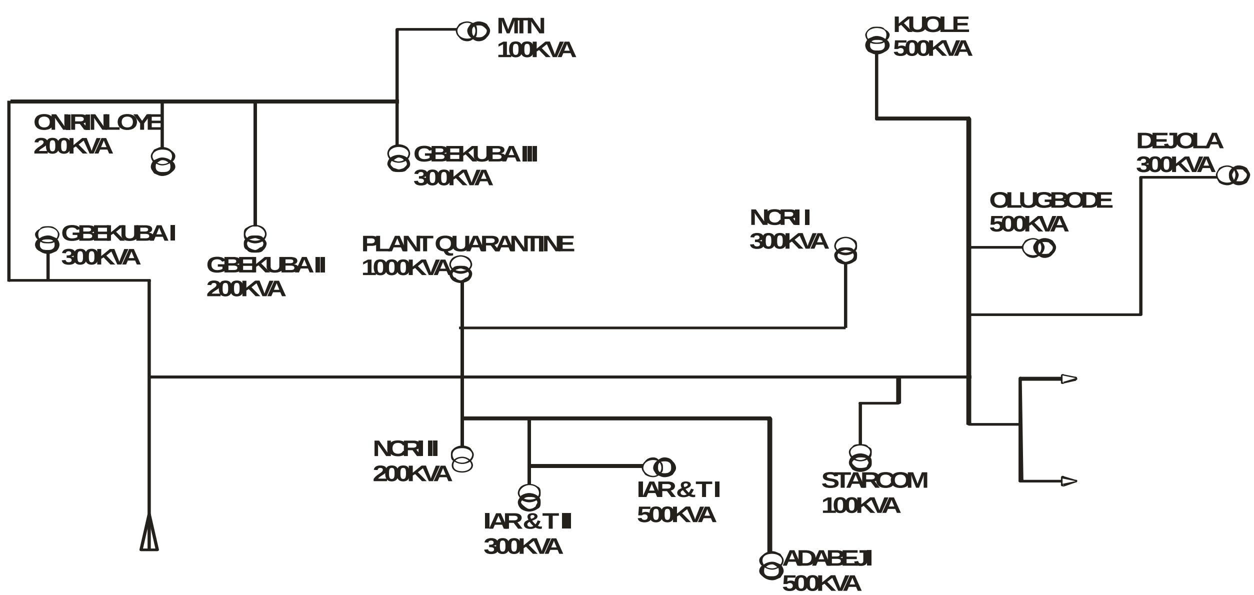
ONIREKE FEEDER (B)



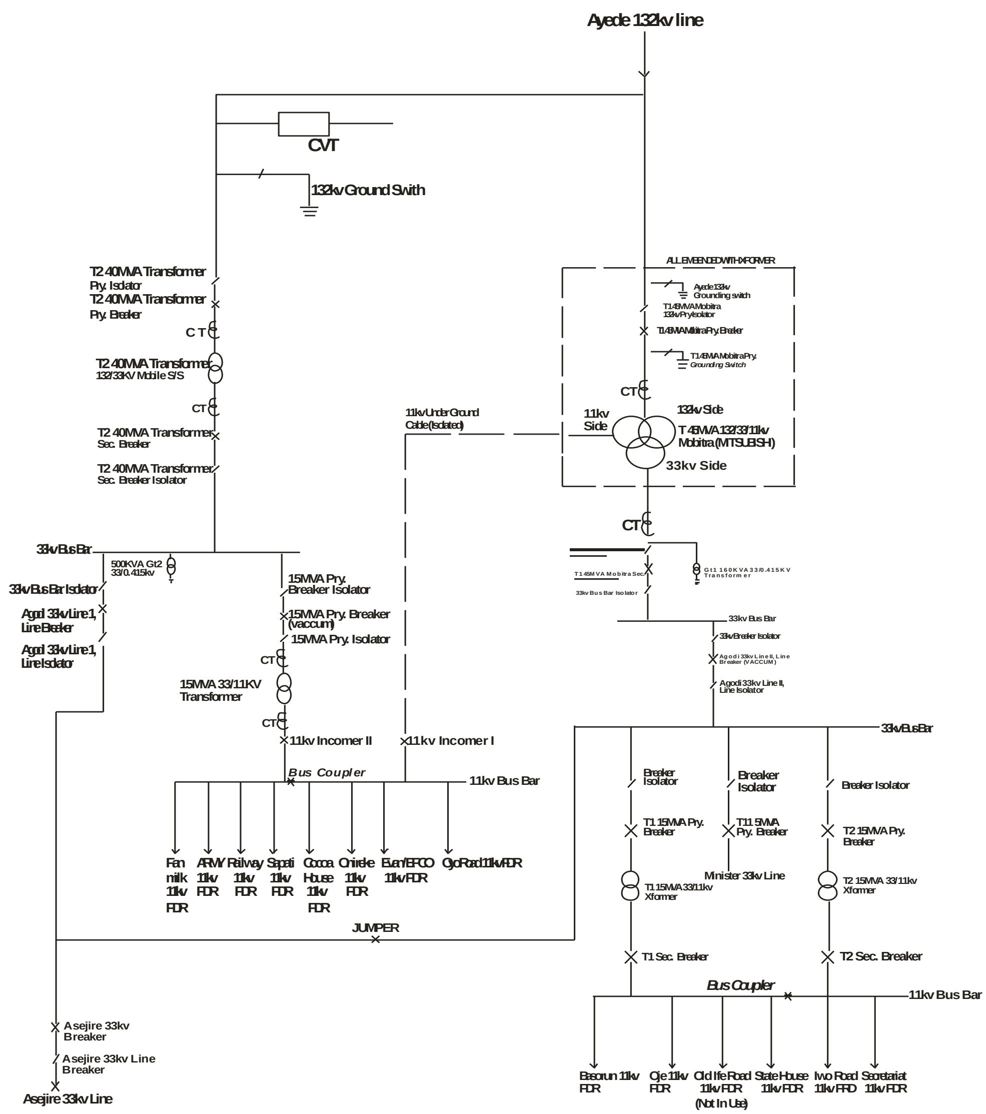
IYAGANKU FEEDER (C)



ODO ONA FEEDER (D)



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	