Evaluation of Technical Losses in Enugu 33kV/11kV Metropolis Networks

Obinna V. Onodugo[1], Frank O. Enemuoh[2], Jude I. Aneke[3], and Sunday C. Nwokporo[4]

[1]Enugu Electricity Distribution Company, Nigeria

[2,3]Department of Electrical Engineering, Nnamdi Azikiwe University, Awka, Nigeria,

[4]Ebonyi State University, Abakaliki, Nigeria

Email: [1]onodugoobinna@gmail.com, [2]anekejude@gmail.com, and [3]sundaynwokporo@gmail.com

***Abstract*—** The inability of distribution system to return expected profit is undermining its integrity. This is highly due to power loss occurring on the distribution feeders. It was on this background, that this work presented the Simulation of Technical Losses in Enugu Metropolis Networks with a Case Study of Kingsway Line 1 33kV and Power House 11kV feeders. This research was implemented using the method of simulation and analysis with the help of Electrical Transient and Analysis Program, ETAP software. The work was carried out using practical field data and network extracted from Enugu Electricity Distribution Company, EEDC. The case study networks were characterized, modelled and simulated on ETAP environment using specific parameters. From the results of the simulation/analysis the technical loss, was calculated in the 33kV network to be at 2.28% and 3.02% for the 11kV network. In order to reduce technical loses to its barest minimum, the 11kV and 33kV distribution line cable sizes were upgraded by 50% and 20% respectively. Then a shunt capacitor was installed at two places in the 33kV network which were at Kingsway line1 feeder and Shoprite substation. At the 11kV network, the shunt capacitor was connected at the Nigerian Construction and Furniture Company, NCFC load center. This modification led to the improvement of the voltage at the injection substations in the 33kv network. The average voltage improved to 0.99PU. The 33kV distribution line loss experienced an 11% reduction from the initial loss. The technical loss in the 33kV network achieved an 8.9% reduction and technical loss dropped from 2.28% to 1.47%. The 11kV distribution line loss experienced reduction of 54% drop from the initial loss. The technical loss in the network dropped by 49% and technical loss dropped from 3.02% to 1.9%. The total technical losses for both feeders were calculated as 3.37% which was about 57% in reduction.

***Keywords* —** Distribution Line, Technical Losses, Commercial Losses, Transmission Line Losses, Shunt Capacitor.

1. INTRODUCTION

Energy is the basic necessity for national development and in this modern world, it has become part of our daily lives. Availability of sufficient amount of energy has led to shorter working days, improved agricultural output, increased industrial production, better health conditions, more nutritious diets and better transportation facilities [1]. Different forms of energy exist but electrical energy is by far the most promising form [2]. Development indicators generally correlate positively with electric power consumption. For example, research indicates that development in Nigeria goes hand-in-hand with electric power consumption when Gross Domestic Product (GDP) is used as an indicator [3]. In spite of the criticality of electric power to national development, electric power generation in Nigeria is inadequate—less than 30% of the national demand. Worse still, more than 50% of the energy generated is reported to be lost in the distribution network [4]. This calls for urgent action, almost of the same status as an emergency, backed by a robust understanding of the underlying root causes of the losses in the Nigerian power system. [5] attributes losses in the Nigerian power system predominantly to energy theft and proposed legislation against energy theft as the panacea; other causes of losses were not discussed.

Distribution systems account financially for energy generated and its consumption by various categories of consumers and also in recent years, expansion of distribution system is not unconnected to growing demand for electrical energy in newly constructed residential buildings, rural electrification project, urbanization and industrialization. These had contributed in no small measure to energy losses incurred on the distribution system as it increased the feeder route length against initial planned length, and it as well-placed unplanned pressure on distribution transformers. Electrical energy losses can be viewed as a portion of electricity supplied into the transmission and distribution grids that are not paid for by users [6]. Energy losses manifest at every stage of the power distribution process, starting with the step-up transformers that link power plants with the transmission system, and ending with the customer wiring beyond the retail meter [7]. The entire losses that occur at the distribution end have been broadly grouped into technical and non-technical losses (commercial loss) [8]. Technical losses in distribution system are inevitable regardless how carefully the system is designed, it occurs naturally in system components such as distribution lines, transformers, feeders and measurement system [9], [10]. Technical losses are relatively known and monitored, being calculated in the operation planning studies with the objective of guiding measures to be adopted aiming at their reduction. Non-technical losses on the other hand, are caused by actions external to the power system or are caused by loads and conditions that the technical losses computation failed to take into account it includes pilferage, defective meters, administrative processes, terrorism, errors in meter reading and in billing unmetered supply of energy etc. [11]. This work presents the evaluation of electric power losses on primary and secondary distribution feeder; a case study of Kingsway Distribution Line 1 and Power House, Enugu State, and the analysis was implemented in ETAP environment, and the results obtained on all the selected feeders were compared in terms of technical losses experienced. The overall losses in distribution systems, ideally, should vary between 3% and 6% in relation to the injected energy [12]. However, in developed countries, they are around 10%, while in developing countries, the same losses can reach around 20% in the average [13]. Therefore, the reduction of these percentages through the improvement of the electrical network is fundamental for electric utilities because, the smaller the losses, the greater the profit obtained in the business, also allowing the improvement of service quality provided to consumers [14],[15].

- The Case Study Networks

1.1. The 33kV Kingsway Line 1 Network

This the 33kV primary distribution network that supplies power to 33/11kV Kingsway Injection Substation from New Haven 132/33kV transmission company substation. It is about 8.82km long with 94 High-Tension electric poles. The network is feeding six (6) 33/11kV distribution substations (DSS) which include Enugu State Secretariat Substation, Shoprite Substation, Golden Royale Substation, Coal City Garden Substation, Ebeano Tunnel Injection Substation and finally, Kingsway Injection Substation. The network is extracted from EEDC Enugu metropolis distribution map while its ETAP model is shown in Figure 1.

1.2. The 11kV Power House Network

This is a radial distribution network that receives supply from the Kingsway 11kV Injection Substation and supplies/feeds fifty-four (54) 11/0.415kV distribution substations (DSS). The DSS include Government Printing Press, Court Avenue, Police Command State Headquarters, State CID Enugu, Housing Development Authority, Constitution, Coal City Garden 1, Coal City Garden 2, Coal City Garden 3, Coal City Garden 4, Coal City Garden 5, Collery Ave. Ridgeway DSS and many others. It is about 8.354km long with 303 High-Tension electric poles. The network is extracted from EEDC Enugu metropolis distribution map while the ETAB model of the network is shown in Figure 2.

2. MODELLING OF ENUGU 33KV/11KV METROPOLIS NETWORKS

The Network, consist of a 33kV Kingsway line 1 distribution line and 11kV Power House distribution line. The existing load in the system is specified. The parameters of the existing distribution line in the system are also provided. The power source of the 33kV distribution network is imported from New Heaven transmission sub-station and the power sources for the 11kV distribution line is gotten from Kingsway injection substation. Figure 1 shows the ETAP model of Kingsway 33kV line1. It is a primary distribution network that supplies power to 33/11kV Kingsway Injection Substation from New Haven 132/33kV transmission company substation.

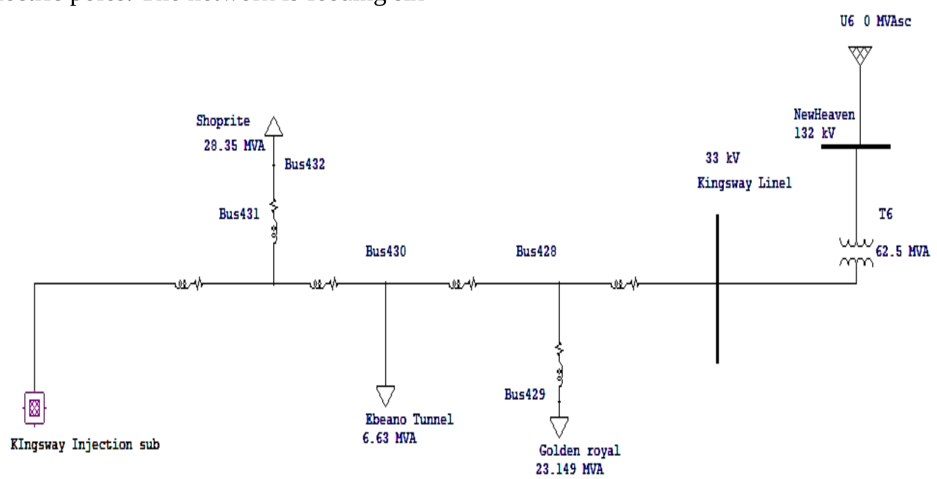

Figure 1: ETAP model of Kingsway 33kV line1

Figure 2 shows the ETAP model of the 11kV power house distribution feeders. It is a radial distribution network that receives supply from the Kingsway 11kV Injection Substation and supplies fifty-four (54) 11/0.415kV distribution substations (DSS).

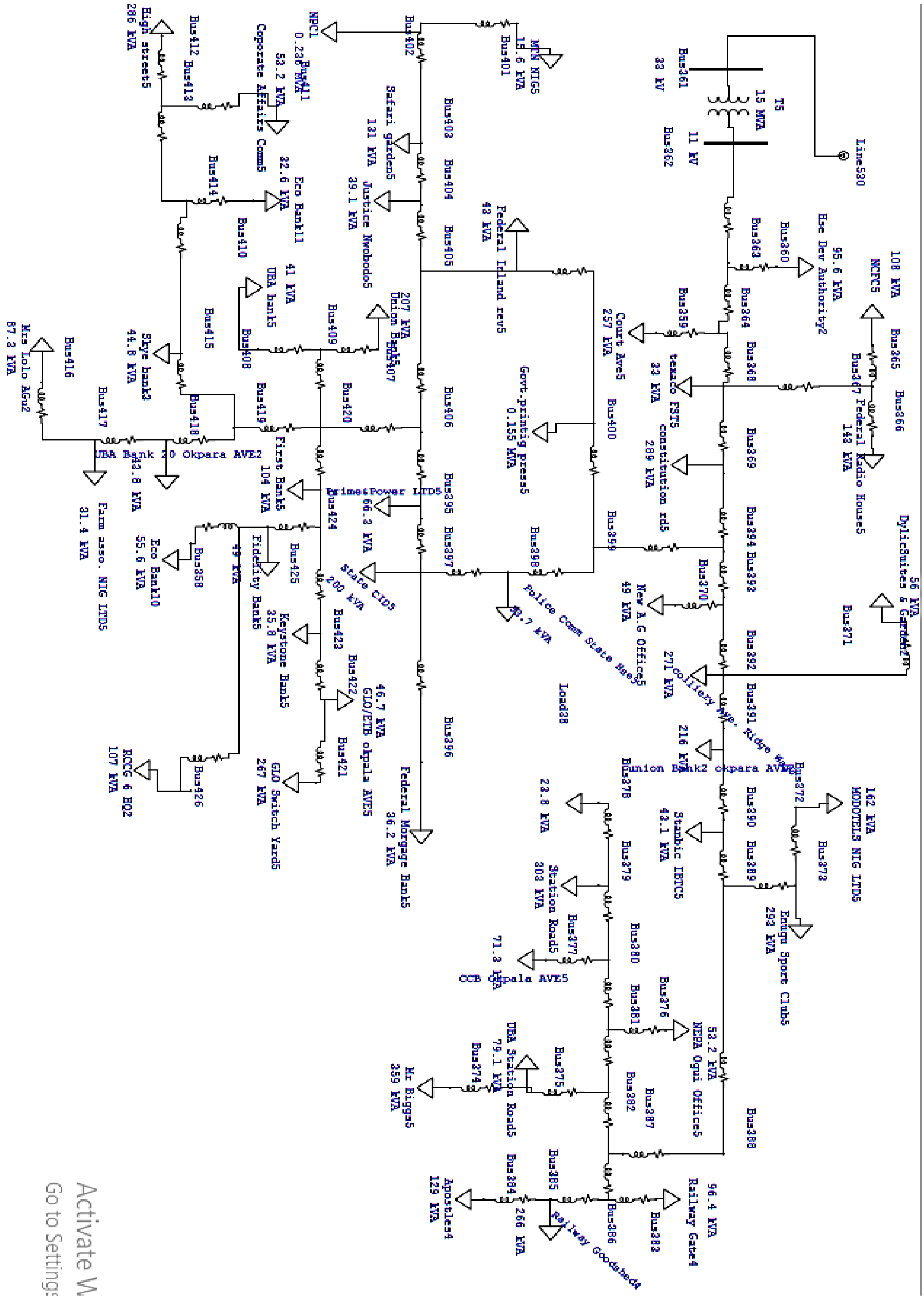

Figure 2: ETAP model of 11kV power house distribution network

3. REDUCTION OF TECHNICAL LOSSES ON THE DISTRIBUTION NETWORKS

In order to reduce and improve voltages at the load center and reduce technical losses at the distribution lines, shunt capacitor was installed at some load centers as shown in Table 1 and the diameter of the distribution line was increased from 250mm^2 to 300mm^2 for 33kV distribution line and from 120mm^2 to 150mm^2 for 11kV distribution line.

Table 1: Capacitor specification for each load center

Connected Load	Rated Voltage	Micro-Farad	Xc	Kvar Rating
Shoprite	33	77.95	34.03	16000
Kingsway line 1 feeder	33	39.87	68.06	32000
NCFC	11	5.481	484	250

4. POWER FLOW SOLUTION FOR THE 33kV AND 11kV NETWORK

Load flow solution is a solution of the network under steady state condition subjected to certain inequality constraints under which the system operates Invalid source specified**.**

These constraints can be in the form of load magnitude, bus voltages, reactive power generation of the generators, etc.

The load flow solution gives the bus voltages and phase angles, hence the power injection at all the buses and power flow through interconnecting distribution lines can be easily calculated.

These analyses require number of load flow solutions under both normal and abnormal (outage of distribution line or outage of some generators) operating conditions.

5. RESULT FOR THE SIMULATION OF 33kV DISTRIBUTION LINE

Figure 2 shows the voltage profile of the 33kV network. The standard operating range of voltages is between 0.95PU – 1.05PU (31.35kV – 34.65kV).

If the bus value falls below 0.95PU, it is known as under-voltage while the bus that has a value higher than 1.05PU is known as over-voltage.

The load buses in Figure 2 were seen to fall below or above the standard operating range of voltages at an average voltage of 0.89PU.

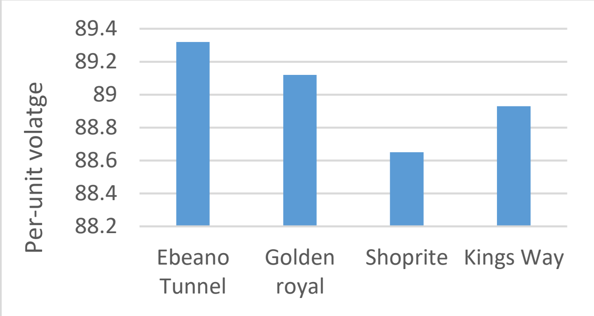

Figure 3: Load buses on 33kV distribution system.

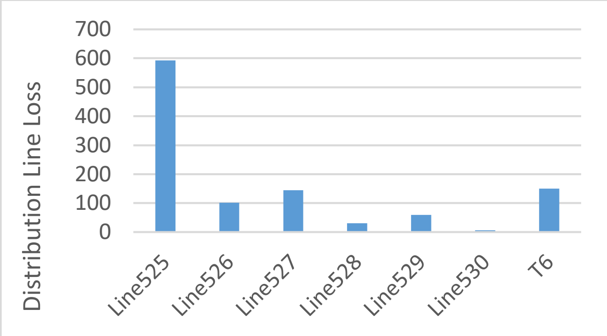

Figure 4: 33kV distribution line loss

Figure 3 shows the distribution line loss for the 33kV connected system. It is observed that line 525 have the highest loss of about 593kw. The symbol T6 represent the power transformer feeding power to the 33kV Kingsway line1 distribution network from the 132kV New Haven transmission substation. The transformer loss was at 150kwh and the transformer loading was at ninety-one percent (91%).

5.1 Calculated Technical Losses for 33kV Distribution Loss

The technical loss is calculated as the total distribution loss + the transformer loss.

Therefore, **the Technical Loss = 934 + 150 = 1084kwh**

The aggregate technical and commercial loss is calculated as [16].

$$\frac{(\text{Energy Input} - \text{Energy Realised}) * 100}{Energy\ input}$$

Now, Energy input from New-Haven substation = **47474kwh**

Energy realized is total energy consumed by each injection substation at 33kV distribution network which is equal to **41367.03kwh**

Therefore, the aggregate technical and commercial loss

$$\frac{(47474 - 46390) * 100}{47474} = \mathbf{2.28\%}$$

6. RESULT OF THE SIMULATION OF THE 11KV DISTRIBUTION LINE

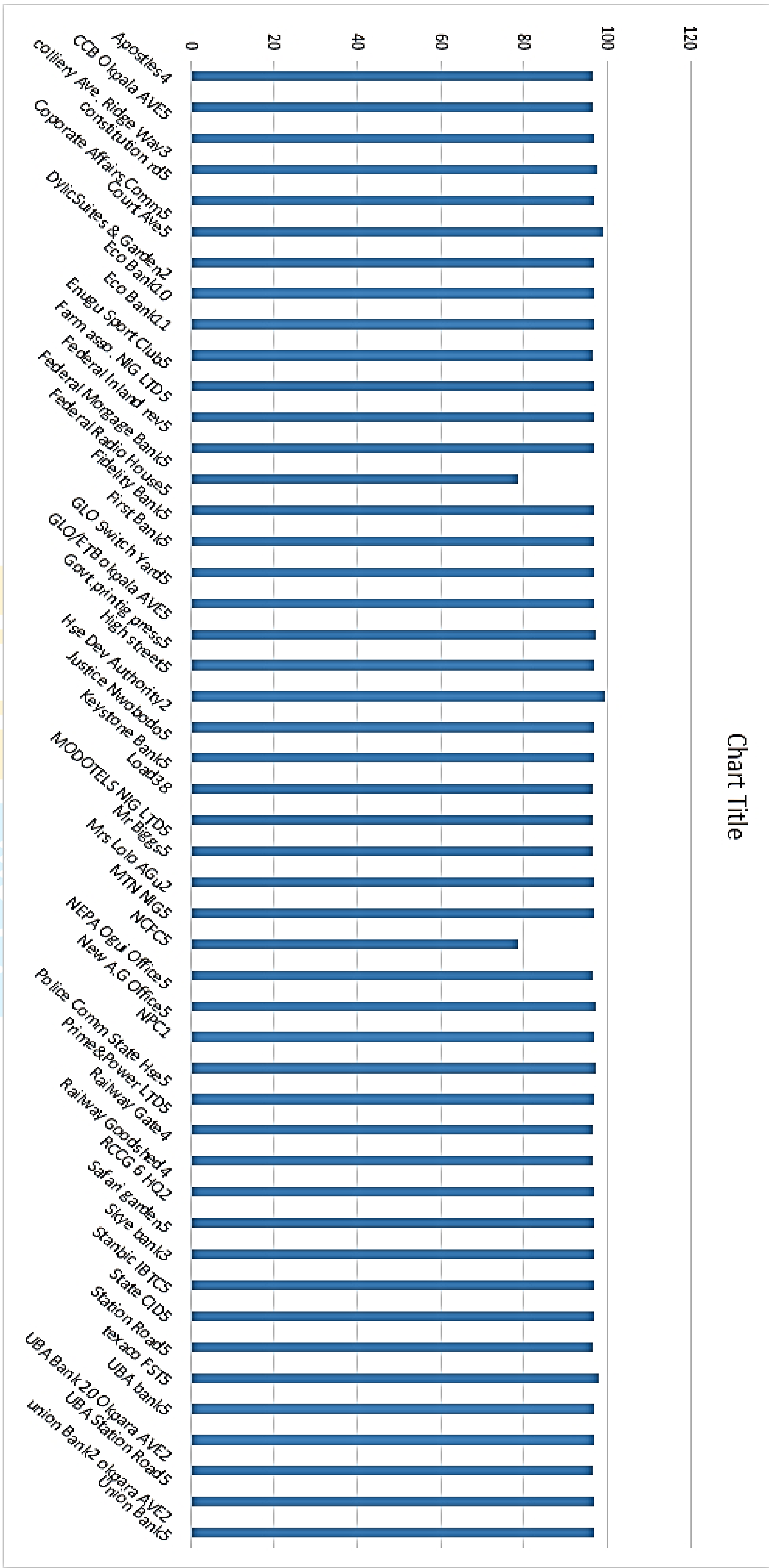

Figure 5: Load buses on 11kV distribution system

Figure 4 shows the voltage profile of the network. The standard operating range of voltages is between 0.95PU – 1.05PU (10.45kV – 11.55kV). If the bus value falls below 0.95PU, it is known as under-voltage while the bus that has a value higher than 1.05PU is known as over-voltage. The load buses in Figure 4 were seen to fall below or above the standard operating range of voltages are Federal radio house and NCFC which both have a per-unit voltage of about 0.79PU the average at the 11kV network was 0.96PU. Figure 5 shows the distribution line loss for the 11kV connected system. The distribution lines with noticeable loses are line462, line465, line460 with their values at 52.445kwh, 25.85kwh, 18.25kwh respectively. High concentration of losses on one part of the distribution network led to the drop in voltage at NCFC and Federal Radio House. The symbol T6 represent the power transformer feeding power to the 11kV distribution network from the 33kV Kings Way line1 Distribution network. The transformer loss was at 10.42kw and the transformer loading was at about 38%.

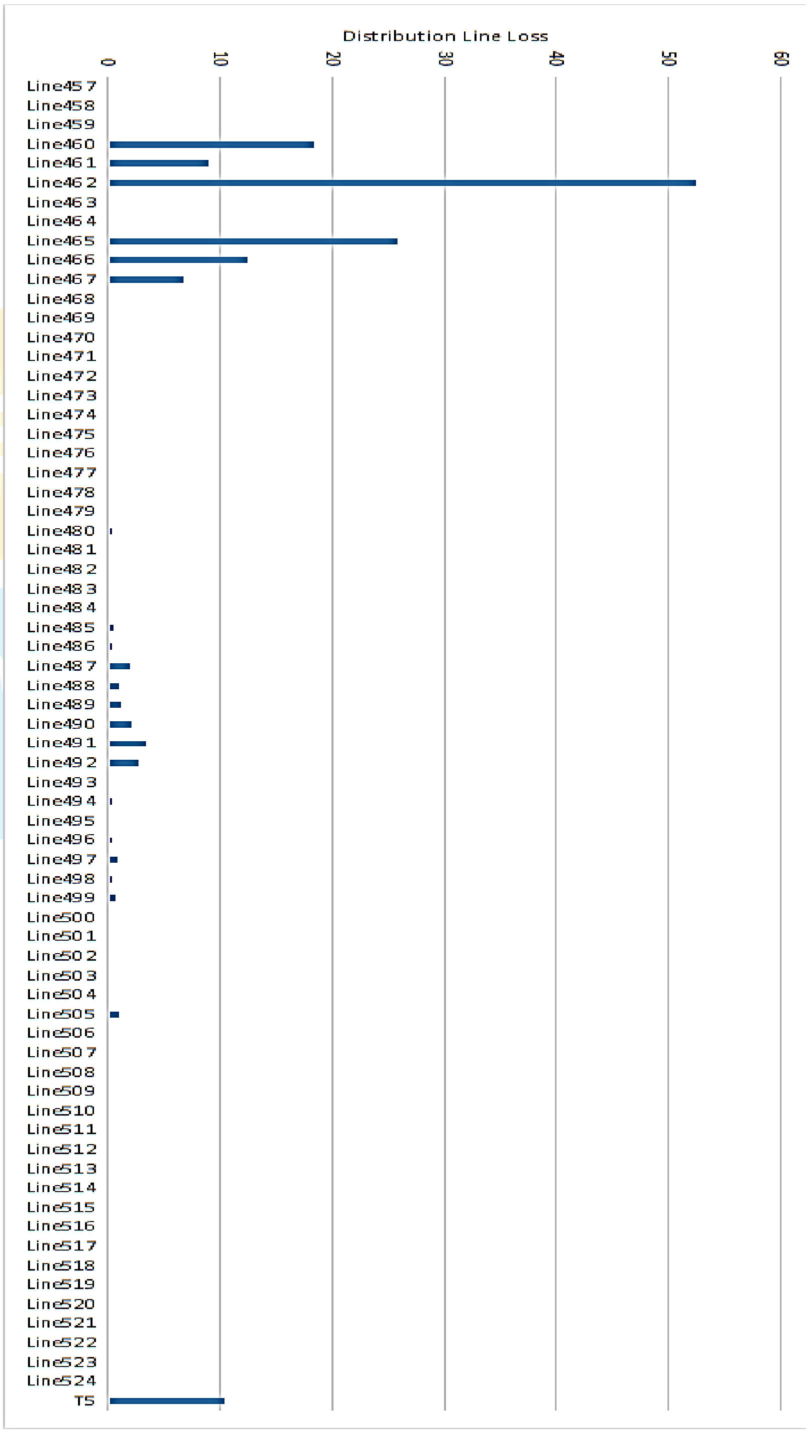

Figure 6: 11kV distribution Line Loss

6.1. Calculated Technical Losses for 11kV Distribution Line

The technical loss is calculated as the total distribution loss + the transformer loss.

Therefore, the **Technical Loss = 142.61 + 10.34 = 152.95kwh**

The aggregate technical and commercial loss is calculated as

$$\frac{(\text{Energy Input} - \text{Energy Realised})}{\textit{Energy input}} * 100$$

But, Energy input = 5028kwh

Energy realized is the total energy consumed by each customer at 11kV distribution line which is equal to 4876.42kwh

Therefore, the aggregate technical and commercial loss

$$\frac{(5028 - 4876.42)*100}{47474} = 3.02\%$$

7. LOAD FLOW RESULTS OF THE REDUCTION OF TECHNICAL LOSSES ON THE DISTRIBUTION NETWORKS

Figure 6 shows the voltage result for the 33kV connected system before compensation and after compensation. The blue bar chart represents the load flow simulation of the 33kV distribution network before modification while the brown chart represents the load flow simulation of the 33kV distribution network after modification. It is observed that there was improvement in voltages. By comparing the voltage before and after modification in terms of their average voltage is observed that the average voltage increased from 0.89PU to about 0.99PU which 11.24% improvement and the voltages have fallen within the operating voltage.

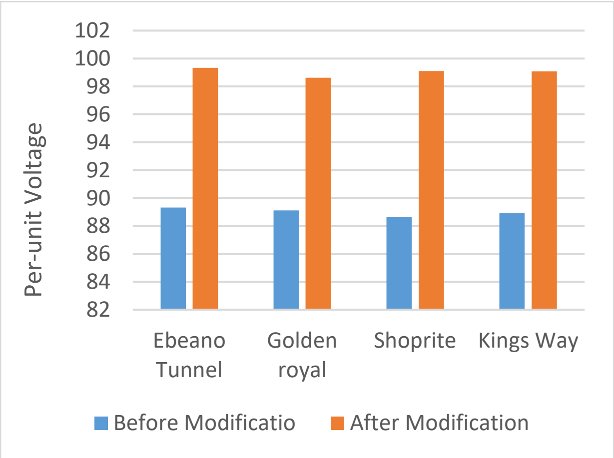

Figure 7: load buses on 33kV distribution system

Figure 7 shows the distribution lines loss for the 33kV connected system before compensation and after compensation. The blue bar chart represents the load flow simulation of the 33kV distribution network before modification while the brown chart represents the load flow simulation of the 33kV distribution network after modification. The total power loss in the network was 845kwh which is about 11% drop. There was also a slight increase in the transformer loss.

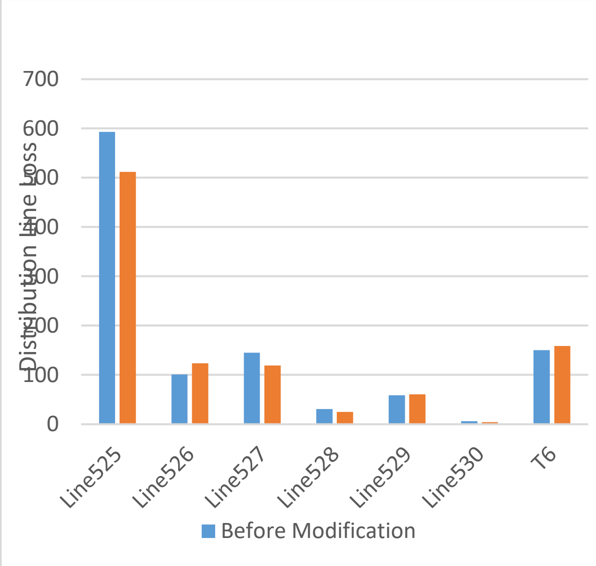

Figure 8: Distribution line loss

7.1. Calculated Technical Losses for 33kV Distribution Line after Shunt Capacitor Connection

The technical loss is calculated as the total distribution loss + the transformer loss

Therefore, the **Technical Loss = 845.317 + 159 = 1004.317kwh**

Again, the aggregate technical and commercial loss is calculated as

$$\frac{(\text{Energy Input} - \text{Energy Realised})}{\textit{Energy input}} * 100$$

Energy input = 57464kwh

Now, Energy realized is the total energy consumed by each customer at 33kv distribution line which about 56618kwh.

Therefore, the aggregate technical and commercial loss

$$\frac{(57464 - 56618)*100}{57464} = 1.47\%$$

8. LOAD FLOW RESULT OF 11KV DISTRIBUTION NETWORK AFTER NETWORK IMPROVEMENT

Figure 8 shows the voltage result for the 11kV connected system before compensation and after compensation. The blue bar chart represents the load flow simulation of the 11kV distribution network before modification while the brown chart represents the load flow simulation of the 11kV distribution network after modification. It is observed that there was improvement in voltage. By comparing the voltage before and after modification in terms of their average voltage is observed that the average voltage increased from 0.96PU to about 0.99PU which is 3.13% improvement and the voltages have fallen within the operating voltage.

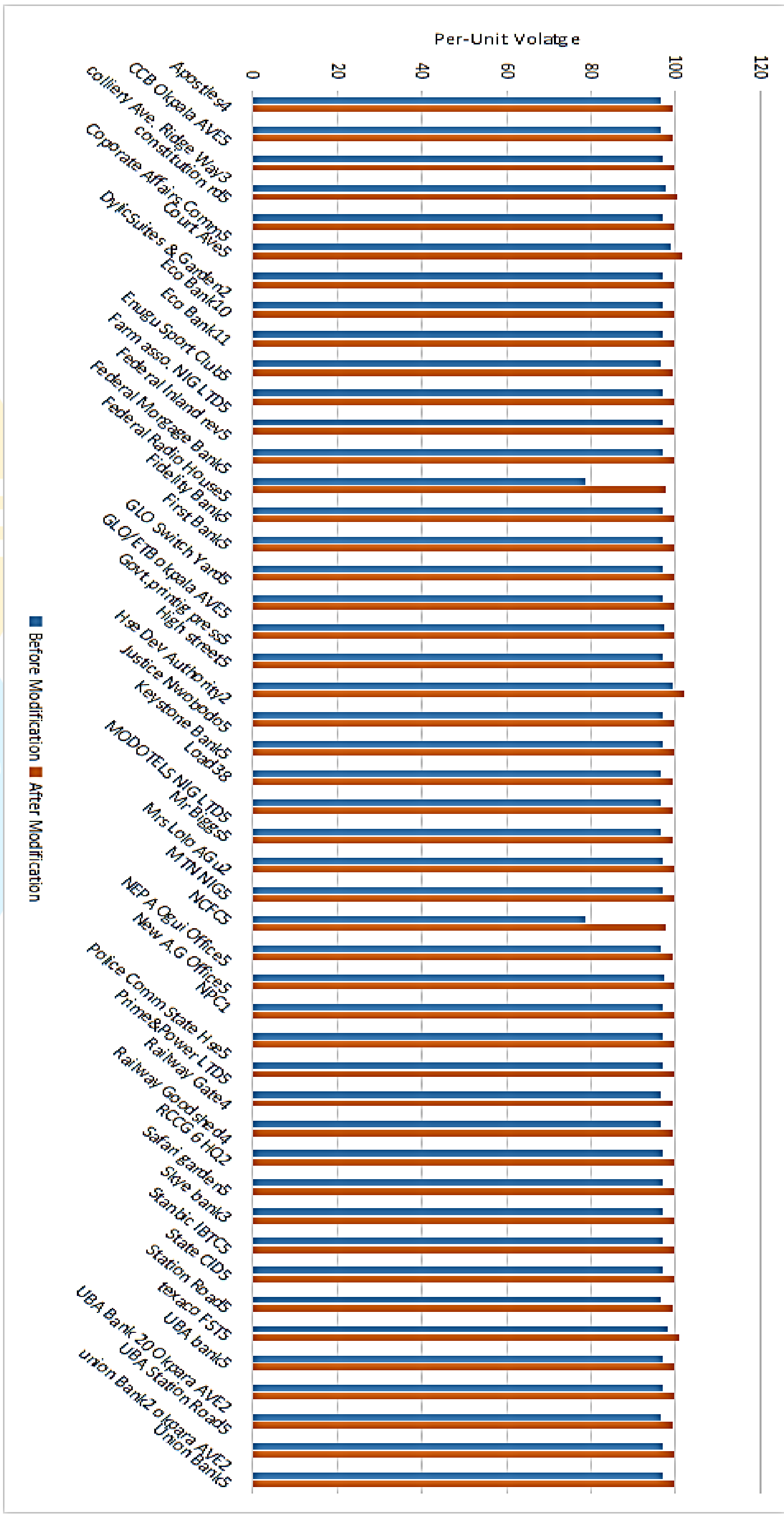

Figure 9: Voltage profile of 11kV Distribution Network after network improvement

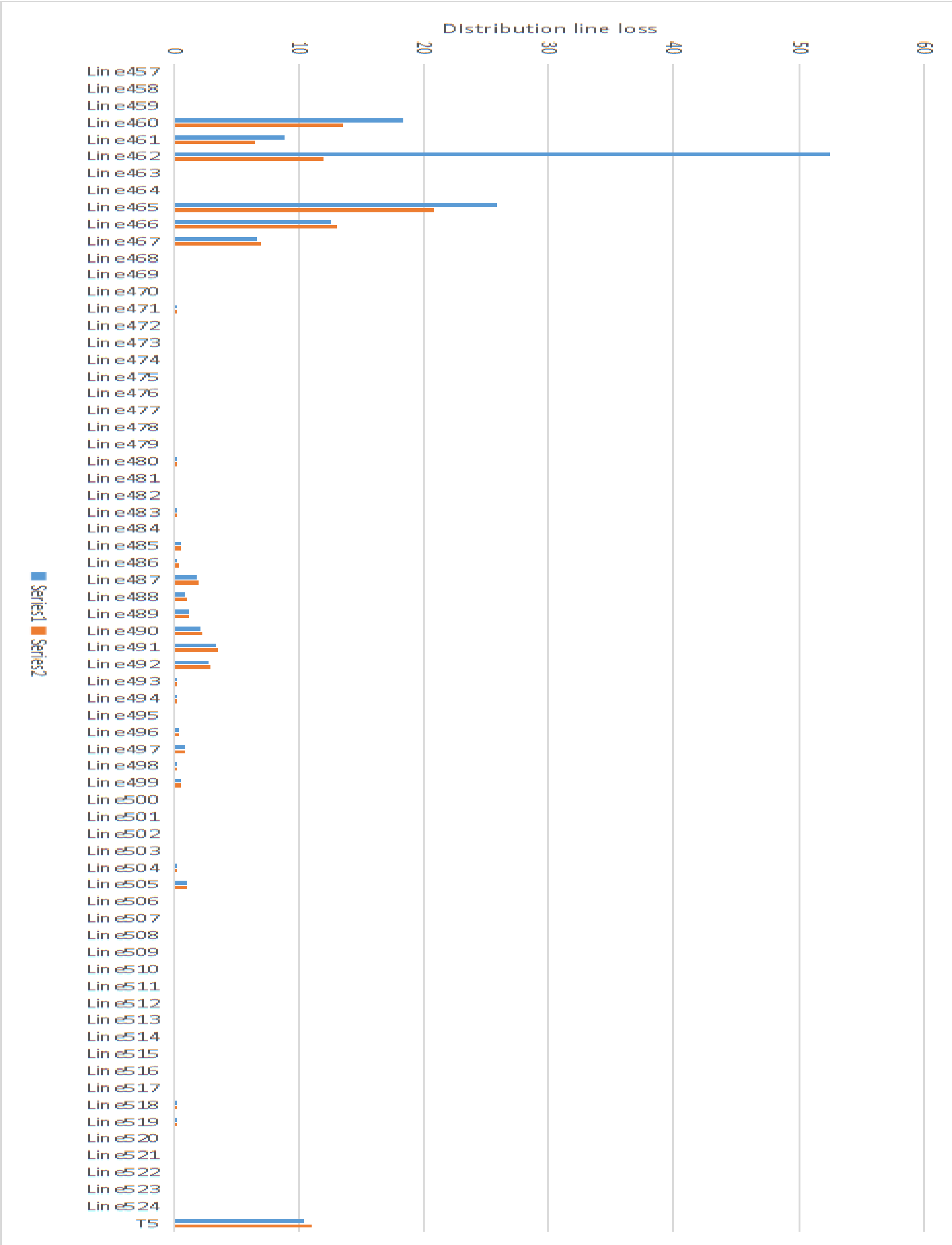

Figure 10: 11kV distribution Line Loss

Figure 9 shows the distribution lines loss for the 11kV connected system before compensation and after compensation. The blue bar chart represents the load flow simulation of the 11kV distribution network before modification while the brown chart represents the load flow simulation of the 11kV distribution network after modification. The total power loss in the network dropped from 141kwh to about 91kwh which is about 54% drop. There was also a slight increase in the transformer loss.

8.1. Calculated Technical Losses for 11kV Distribution Line

The technical loss is calculated as the total distribution loss + the transformer loss [16].

Therefore, the **Technical Loss** = 91.41 + 11.04 = 102.45**kwh**

The aggregate technical and commercial loss is calculated as

$$\frac{(\text{Energy Input} - \text{Energy Realised})}{Energy\ input} * 100$$

Energy input = 5418kwh

Energy realized is the total energy consumed by each customer at 33kV distribution line which about 5315kwh

Therefore, the aggregate technical and commercial loss

$$\frac{(5418 - 5314)*100}{5418} = 1.9\%$$

9. CONCLUSION

This work tried to estimate the technical losses along the Kingsway line 1 33kV distribution network and the power house 11kV distribution network. Load flow simulation was performed to estimate our unknown parameters such as our line loss, node voltages power flow into the load centers. From the result of the simulation, we can observe that at the 33kV distribution line, the average voltage of the network was at 0.89PU it was also observed that the whole load centers were operating below the operating range of voltages (0.95PU-1.05PU) and the total loss in the network was at 1089kwh. For the 11kV network, it is observed that the average voltage was at 0.96PU and it was also observed that the load center at NCFC and Radio House were operating below the operating voltages and the total loss of the network was at 152kwh. So, the total loss in the entire network for both 33kV and 11kV network was calculated as 1241kwh. The technical loss was calculated in the 33kV network to be at 2.28% and for the 11kv network, the technical loss was calculated to be at 3.02%. The 11kV distribution network experienced a higher technical loss than the 33kV network. The total technical losses for both feeders were at 5.31%.

In order to reduce the technical loses to its barest minimum, the sizes of conductors of the distribution lines in the 11kV and 33kV distribution line were upgraded by 50% and 20% respectively. Then a shunt capacitor was installed at two places in the 33kV network which were at Kings Way line1 feeder and Shoprite injection substation. At the 11kV network, the shunt capacitor was connected at the NCFC load centre. This modification led to the improvement of the voltage at the injection substations in the 33kV network. The average voltage improved to about 0.99PU.

The 33kV distribution line loss experience reduction to about 845kwh which is about 11% from the initial loss. The technical loss in the 33Kv network reduced from 1089kwh to about 1004kwh which is about 8.9% drop. The technical loss dropped to about 1.47%.

The 11kV distribution line loss experience reduction to about 91kwh which is about 54% drop from the initial loss. The technical loss in the network reduced from 153kwh to about 103kwh which is about 49% drop. The technical loss dropped to about 1.9%. The total technical losses were calculated as 3.37% which was about 57% in reduction

As a way of filling the knowledge gap identified, this research work has been able to examine and simulate the technical losses on 33kV Kingsway distribution line 1 and 11kV Power House feeders in Enugu metropolis distribution network map of EEDC with its associated parameters. This thereby provides relevant information on losses on these case networks which will help EEDC in network planning and increase revenue generation when implemented the installation of shunt capacitor at the recommended load centers.

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