American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-12, Issue-2, pp-108-117
www.ajer.org
Research Paper Open Access

Determination of Energy Not Supplied in Power System

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ABSTRACT: *System collapse is a serious challenge especially when interruption duration and interruption frequency are so large. Electricity users need electricity to the fullest for comfort, industrial activities, commercial activities etc. Based on this, the customer and the power provider need to adequately check the energy that the customer is denied at the time(s) of system failure. Five 33kV feeders at Port Harcourt Mains Transmission Station feeding Port Harcourt Electricity Distribution Company customers were selected for reliability evaluation. The 33kV feeders selected are Trans Amadi, Akani, Airport, Abuloma, and Uniport. Reliability indices were used to ascertain the performance of the feeders based on available records. Customer average interruption duration indices became: 2.60hrs on Trans Amadi 33kV feeder, 1.39hrs on Akani 33kV feeder, 2.0hrs on Airport 33kV feeder, 1.14hrs on Abuloma 33kV feeder, and 1.04hrs on Uniport 33kV feeder. Energy not supplied became: 277062Kwh on Trans Amadi 33kV feeder, 24112Kwh on Akani 33kV feeder, 1352Kwh on Airport 33kV feeder, 13266Kwh on Abuloma 33kV feeder, and 250777Kwh on Uniport 33kV feeder. The energy not supplied on each feeder at the time of system failure can best be realized with the use of reliability indices and energy not supplied technique.*

KEY WORDS: *System collapse,Voltage collapse***,** *Reliability indices, Voltage dip, Feeder, Power outage.*

Date of Submission: 13-02-2023 Date of acceptance: 26-02-2023

I. INTRODUCTION

System collapse refers to total blackout.A situation where there is loss of generation causing the grid to be in blackout. All customers connected to the grid will experience power outage at the time of system collapse. During the time of system collapse or system failure, the customer is denied energy. The power supplier and customers need to pay attention to the energy not supplied at the time of system failure as it is essential to understand the financial implication and discomfort this would have created. If this is understood, it will go a long way in averting preventable system failure.

It is important to attain a high level of reliability because of the cost of every investment to the power network [1]. Reliability indices are necessary to understand the reliability of the power system. Reliability indices can provide the desired solution to the quest to provide a reliable power system[2].

Nigeria's electricity supply industry has numerous challenges such as overstressed transmission and distribution networks leading to high rates of power failure [3].Frequent and prolonged power outages have been on the increase at Port Harcourt, Rivers State, Nigeria. In evaluating the reliability of the power distribution network in Port Harcourt, some feeders were selected to check energy the customer loses at the time of system failure. The feeders selected for the study are: Trans Amadi, Akani, Airport, Abuloma and Uniport 33kV feeders respectively, all radiating from Port Harcourt mains transmission station.

II. RELATED WORKS

Voltage collapse occurs when active and reactive power balance equations fail or when load dynamics cannot restore power consumption above the capability of the transmission network and the connected generation to provide the required reactive support [4].Energy demand is expanding all over the world without corresponding improvement in the supply-side. It will be more economical to maintain all associated power facilities to keep the network ready for regular or emergency load demand to prevent the system from failure [5].

The ever-increasing population of humans leads to increase in energy demand which may tend towards [6]. Reliable access to power supply is a basic precondition for improved standard of living [7].Network or power outages can be prevented with adequate preventive maintenance [8].

Effective maintenance of the network can adequately and quickly restore the power system from localized problems and not to constitute a potential system-wide imbalance. According to Achinaya[9], the distribution system reliability gives us a measure of how the system has performed and will perform if preventive and corrective maintenance are embarked upon.Energy not supplied can be used to ascertain energy lost at the time of system failure [8].

III. MATERIALS AND METHOD

3.1 Power System Reliability Indices

The reliability of five selected 33kV feeders was assessed and evaluated to ascertain energy not utilized on eache of the feeders (networks). The feeders used on the reliability study are Trans Amadi 33kV feeder, Akani 33kV feeder, Airport 33kV feeder, Abuloma 33kV feeder and Uniport 33kV feeder. Generally,System Average Interruption Duration Index (SAIDI) can beexpressed as:

$$\text{SAIDI} = \frac{Sum\ of\ all\ customer\ interruption\ durations}{Total\ number\ of\ customers\ served} \quad (3.1)$$

Which implies that:

$$\text{SAIDI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} \quad (3.2)$$

Where N_i is number of customers per load

λ_i= Total number of customer's interruption duration

System Average Interruption Frequency Index (SAIFI) can be mathematically expressed as:

$$\text{SAIFI} = \frac{Totalnumberof\ customer\ interruption}{Totalnumber\ of\ customers\ served} \quad (3.3)$$

$$\text{SAIFI} = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \quad (3.4)$$

Where N_i is number of customers per load

U_i= Total number of customer's interruption

Customer Average Interruption Duration Index (CAIDI) can be expressed as:

$$\text{CAIDI} = \frac{Sum\ of\ all\ customer\ interruption\ durations}{Total\ number\ of\ customer\ interruptions} \quad (3.5)$$

$$\text{CAIDI} = \frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \quad (3.6)$$

Also very important is the concept of Energy Not Supplied (ENS). It can be expressed as:

$$\text{ENS} = \sum_{i=1}^{n} U_i\ \lambda_i\ \times 1000 \quad (3.7)$$

Where λ_i = Total number of customer's interruption duration

U_i = Total number of customer's interruption

3.2 Trans Amadi (RSPUB II) 33kV Feeder Reliability Indices

From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices and energy not supplied concept were to provide a far-reaching solution to the exact estimation of energy not utilized.

3.2.1 System Average Interruption Duration Index (SAIDI)

From the equation

$$\text{SAIDI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i}$$

SAIDI = $\frac{Sum\ of\ all\ customers\ \ interr\ uption\ \ durations\ \ (Trans\ Amadi\ Line\ Load+Rivoc+Water\ Works+Fimie+Nda\ Bros)}{Total\ number\ \ of\ customers\ \ served}$

Data collected show that Trans Amadi 33kV line has 925 customers and 61 hours of interruption duration. Also, Rivoc, Water Works, Fimie and Nda Bros 11kV feeders, respectively have 63, 538, 180, 57 and 267 hours of interruption durations, respectively with 956, 355, 462, 1500 and 2005 customers, respectively, given a total of 6,203 customers, then:

SAIDI = $\frac{(925\times61)+(956\times63)+(355\times538)+(462\times180)+(1500\times57)+(2005\times267)}{6203}$

SAIDI = $\frac{(56425)+(60228)+(190990)+(83160)+(85500)+(535335)}{6203}$

SAIDI = $\frac{1011638}{6203}$

SAIDI = 163.09 hours

3.2.2 System Average Interruption Frequency Index (SAIFI)

From equation 3.4,

SAIFI = $\frac{\sum_{i=1}^{n}U_iN_i}{\sum_{i=1}^{n}N_i}$

Data collected show that Trans Amadi 33kV line has 36 interruptions. Also, Rivoc, Water Works, Fimie and Nda Bros 11kV feeders, respectively have 40, 460, 49, 10 and 58 interruptions, then:

SAIFI = $\frac{(925\times36)+(956\times40)+(355\times460)+(462\times49)+(1500\times10)+(2005\times58)}{6203}$

SAIFI = $\frac{(33300)+(38240)+(163300)+(22638)+(15000)+(116290)}{6203}$

SAIFI = $\frac{388768}{6203}$

SAIFI = 62.67 Interruptions/Customer

3.2.3Customer Average Interruption Duration Index (CAIDI)
Using the equation

CAIDI = $\frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n}\lambda_iN_i}{\sum_{i=1}^{n}N_i} / \frac{\sum_{i=1}^{n}U_iN_i}{\sum_{i=1}^{n}N_i}$

CAIDI = $\frac{163.09}{62.67}$

CAIDI = 2.60hours

3.2.4 Energy Not Supplied (ENS)
Using the equation

ENS = $\sum_{i=1}^{n}U_i\ \lambda_i\ \times1000$

ENS = $[(36\times61)+(40\times63)+(460\times538)+(49\times180)+(10\times56)+(58\times267)]\times1000$

ENS = $[(2196)+(2520)+(247480)+(8820)+(560)+(15486)]\times1000$

ENS = $277{,}062\ \times1000$

ENS = 277,062 kWh

3.3 Akani (Feeder II) 33kV Feeder Reliability Indices
From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices and energy not supplied concept were to provide a far-reaching solution to the exact estimation of energy not utilized.

3.3.1 System Average Interruption Duration Index (SAIDI)
From the equation

$$SAIDI = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i}$$

$$SAIDI = \frac{Sum\ of\ all\ customers\ interruption\ durations\ (Rumurolu\ + Rumuogba\ + Old\ Aba\ Road + Rumuibekwe\ + Rumukalagbo\ )}{Total\ number\ of\ customers\ served}$$

Data collected show that Rumurolu, Rumuogba, Old Aba Road, Rumuibekwe and Rumukalagbo 11kV feeders, respectively have 83, 61, 101, 92 and 54 hours of interruption durations, respectively with 985, 2700, 2036, 1319 and 2505 customers, respectively, given a total of 9,545 customers, then:

$$SAIDI = \frac{(985 \times 83) + (2700 \times 61) + (2036 \times 101) + (1319 \times 92) + (2505 \times 54)}{9545}$$

$$SAIDI = \frac{(81755) + (164700) + (205636) + (121348) + (135270)}{9545}$$

$$SAIDI = \frac{708709}{9545}$$

SAIDI = 74.25 hours

3.3.2 System Average Interruption Frequency Index (SAIFI)
From the equation

$$SAIFI = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$$

Data collected show that Rumurolu, Rumuogba, Old Aba Road, Rumuibekwe and Rumukalagbo 11kV feeders, respectively have 71, 39, 78, 66 and 35 interruptions, then:

$$SAIFI = \frac{(985 \times 71) + (2700 \times 39) + (2036 \times 78) + (1319 \times 66) + (2505 \times 35)}{9545}$$

$$SAIFI = \frac{(69935) + (105300) + (158808) + (87054) + (87675)}{9545}$$

$$SAIFI = \frac{508772}{9545}$$

SAIFI = 53.30 Interruptions/Customer

3.3.3Customer Average Interruption Duration Index (CAIDI
Using the equation

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$$

$$CAIDI = \frac{74.25}{53.30}$$

CAIDI = 1.39hours

3.3.4 Energy Not Supplied (ENS)
Using the equation

ENS = $\sum_{i=1}^{n} U_i \ \lambda_i \ \times 1000$

ENS = $[(71 \times 83) + (39 \times 61) + (78 \times 101) + (66 \times 92) + (35 \times 54)] \times 1000$

ENS = $[(5893) + (2379) + (7878) + (6072) + (1890)] \times 1000$

ENS = $24{,}112 \times 1000$

ENS = 24,112 kWh

3.4 Airport (Feeder I) 33kV Feeder Reliability Indices
From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices and energy not supplied concept were to provide a far-reaching solution to the exact estimation of energy not utilized.

3.4.1 System Average Interruption Duration Index (SAIDI)
From the equation

SAIDI = $\frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Airport (Feeder I) 33kV line has 3,039 customers and 52 hours of interruption duration, then:

SAIDI = $\frac{(3{,}039 \times 52)}{3{,}039}$

SAIDI = $\frac{158028}{3{,}039}$

SAIDI = 52 hours

3.4.2 System Average Interruption Frequency Index (SAIFI)
Considering the equation

SAIFI = $\frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Airport (Feeder I) 33kV line has 26 interruptions, then:

SAIFI = $\frac{(3{,}039 \times 26)}{3{,}039}$

SAIFI = $\frac{79014}{3{,}039}$

SAIFI = 26 Interruptions/Customer

3.4.3 Customer Average Interruption Duration Index (CAIDI)
Using the equation

CAIDI = $\frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

CAIDI = $\frac{52}{26}$

CAIDI = 2.0hours

3.4.4 Energy Not Supplied (ENS)
Using the equation

ENS = $\sum_{i=1}^{n} U_i \ \lambda_i \ \times 1000$

ENS = $[(26 \times \ 52)] \ \times 1000$

ENS = $1{,}352 \times 1000$

ENS = 1,352 kWh

3.5Abuloma 33kV Feeder Reliability Indices
From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices and energy not supplied concept were to provide a far-reaching solution to the exact estimation of energy not utilized.

3.5.1 System Average Interruption Duration Index (SAIDI)
Considering the equation

SAIDI = $\frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Abuloma 33kV line load has 153 customers and 12 hours of interruption duration. Also, Azuabie, Okuru and Abuloma 11kV feeders, respectively have 51, 81, and 76 hours of interruption durations, respectively with 782, 813, and 992 customers, respectively, given a total of 2,740 customers, then:

SAIDI = $\frac{Sum\ of\ all\ customers\ \ interruption\ \ \ durations\ \ (Abuloma\ \ Line\ Load + Azuabie\ \ + Okuru + Abuloma\ )}{Total\ number\ \ of\ customers\ \ served}$

SAIDI = $\frac{(153 \times \ 12)+(782 \times \ 51)+(813 \times 81)+(992 \times 76)}{2740}$

SAIDI = $\frac{(1836)+(39882)+(65853)+(75392)}{2740}$

SAIDI = $\frac{182963}{2740}$

SAIDI = 66.77 hours

3.5.2 System Average Interruption Frequency Index (SAIFI)
From the equation

SAIFI = $\frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Abuloma 33kV line load has 11 interruptions. Also, Azuabie, Okuru and Abuloma 11kV feeders, respectively have 49, 75, and 60 interruptions, respectively, then:

SAIFI = $\frac{(153 \times \ 11)+(782 \times 49)+(813 \times 75)+(992 \times 60)}{2740}$

SAIFI = $\frac{(1683)+(38318)+(60975)+(59520)}{2740}$

SAIFI = $\frac{160496}{2740}$

SAIFI = 58.58 Interruptions/Customer

3.5.3Customer Average Interruption Duration Index (CAIDI)
Considering the equation

CAIDI = $\frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

CAIDI = $\frac{66.77}{58.58}$

CAIDI = 1.14hours

3.5.4 Energy Not Supplied (ENS)
Using the equation

ENS = $\sum_{i=1}^{n} U_i \;\; \lambda_i \;\; \times 1000$

ENS = $[(11 \times 12) + (49 \times 51) + (75 \times 81) + (60 \times 76)] \times 1000$

ENS = $[(132) + (2499) + (6075) + (4560)] \times 1000$

ENS = $13{,}266 \times 1000$

ENS = 13,266 kWh

3.6 Uniport (Rumuodomaya) 33kV Feeder Reliability Indices
From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices and energy not supplied concept were to provide a far-reaching solution to the exact estimation of energy not utilized.

3.6.1 System Average Interruption Duration Index (SAIDI)
From the equation

SAIDI = $\frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Uniport 33kV line load has 202 customers and 31 hours of interruption duration. Also, F G C, Obiwali, Eligbolo and Omachi 11kV feeders, respectively have 173, 204, 152 and 415 hours of interruption durations, respectively with 1724, 2133, 4162 and 3860 customers, respectively, given a total of 12,081 customers, then:

SAIDI = $\frac{Sum\ of\ all\ customers\ \ interruption\ \ durations\ \ (Uniport\ \ Line\ Load + FGC + Obiwali + Eligbolo + Omachi)}{Total\ number\ \ of\ customers\ \ served}$

SAIDI = $\frac{(202 \times 31) + (1{,}724 \times 173) + (2{,}133 \times 204) + (4{,}162 \times 152) + (3{,}860 \times 415)}{12081}$

SAIDI = $\frac{(6262) + (298252) + (435132) + (632624) + (1601900)}{52{,}729}$

SAIDI = $\frac{2974170}{12081}$

SAIDI = 246.19 hours

3.6.2 System Average Interruption Frequency Index (SAIFI)
Considering the equation
SAIFI = $\frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

Data collected show that Uniport 33kV line load has 20 interruptions. Also, F G C, Obiwali, Eligbolo and Omachi 11kV feeders, respectively have 169, 201, 168 and 372 interruptions, respectively, then:

SAIFI = $\frac{(202 \times 20)+ (1,724 \times 169)+ (2,133 \times 201) + (4,162 \times 168)+ (3,860 \times 372)}{12081}$

SAIFI = $\frac{(4040)+ (291356)+ (428733) + (699216)+ (1435920)}{12081}$

SAIFI = $\frac{2859265}{12081}$

SAIFI = 236.67 Interruptions/Customer

3.6.3Customer Average Interruption Duration Index (CAIDI)
Using the equation

CAIDI = $\frac{SAIDI}{SAIFI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i}$

CAIDI = $\frac{246.19}{236.67}$

CAIDI = 1.04hours

3.6.4 Energy Not Supplied (ENS)
Using the equation

ENS = $\sum_{i=1}^{n} U_i \ \lambda_i \ \times 1000$

ENS=$[(20 \times 31) + (169 \times 173) + (201 \times 204) + (168 \times 152) + (372 \times 415)] \times 1000$

ENS = $[(620) + (29237) + (41004) + (25536) + (154380)] \times 1000$

ENS = $250,777 \times 1000$

ENS = 250,777 kWh

IV. RESULTS AND DISCUSSION

4.1 Reliability Assessment Result Summary

The results obtained from the reliability assessment of the selected 33kV feeders at Port Harcourt mains transmission station are shown in Table 4.1. For purpose of clarity system average interruption duration index on the 33kV feeders, system average interruption frequency index on the 33kV feeders, customer average interruption duration index on the 33kV feeders, and energy not supplied on the 33kV feeders are shown in Figures 4.1- 4.4 respectively.

Table 4.1: Calculated Reliability Indices of the Selected 33kV Feeders

Feeder	SAIDI (Hrs)	SAIFI (Interruptions/Customer)	CAIDI (Hrs)	ENS (Kwh)
Trans Amadi	163.09	62.67	2.6	277062
Akani	74.25	53.3	1.39	24112
Airport	52	26	2	1352
Abuloma	66.77	58.58	1.14	13266
Uniport	246.19	236.67	1.04	250777

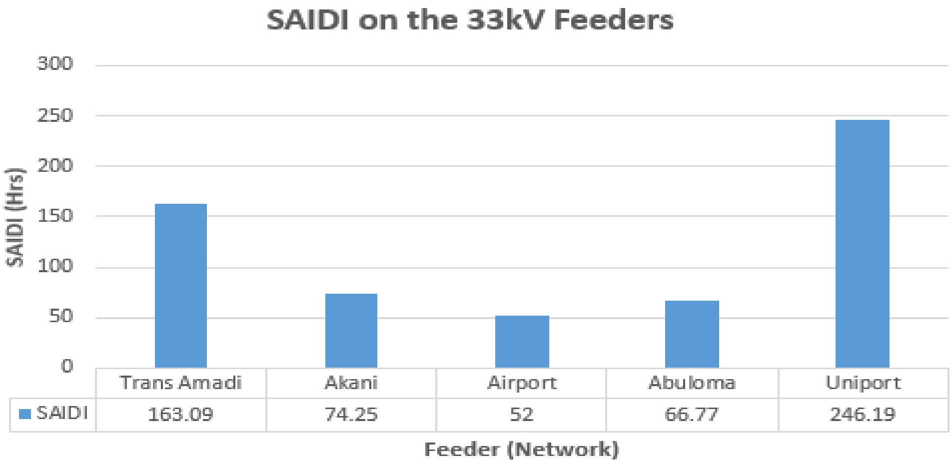

Figure 4.1: Chart of SAIDI on the 33kV Feeders

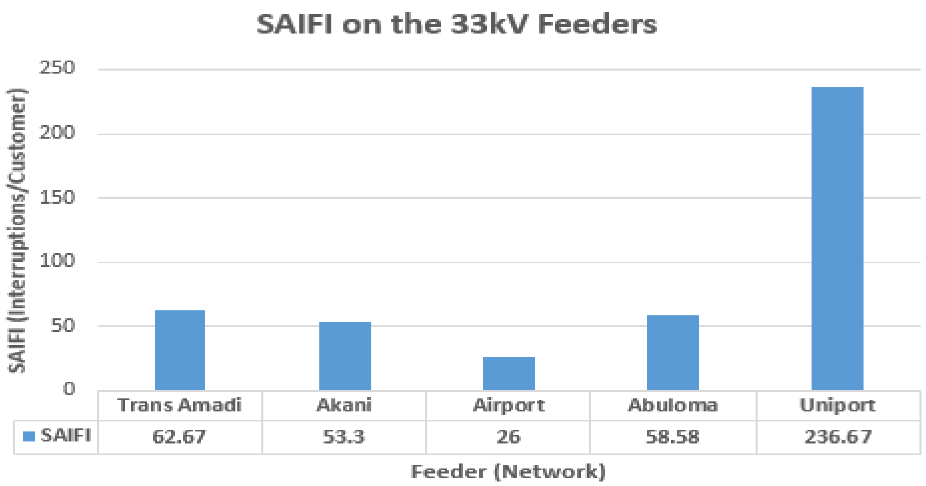

Figure 4.2: Chart of SAIFI on the 33kV Feeders

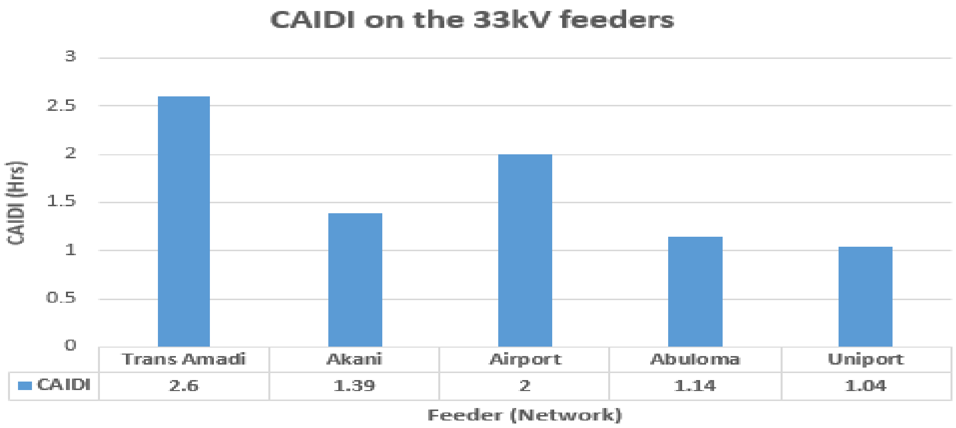

Figure 4.3: Chart of CAIDI on the 33kV Feeders

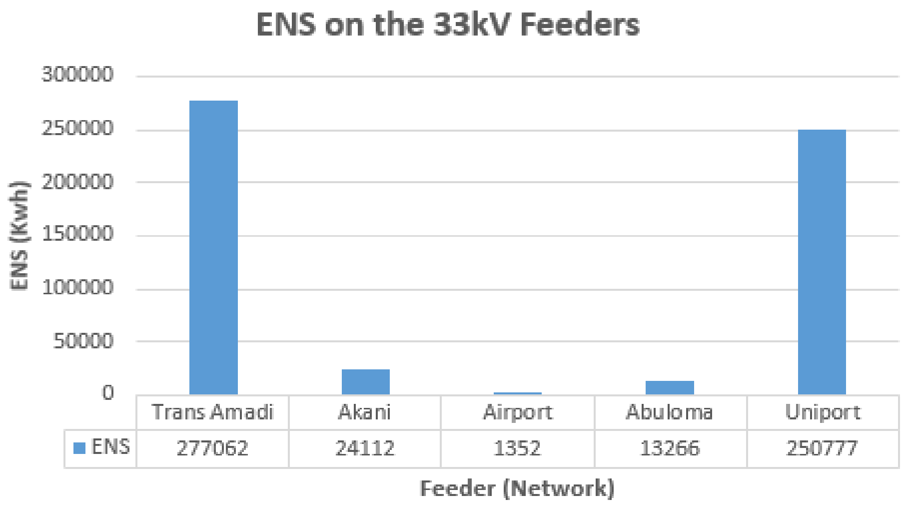

Figure 4.4: Chart of ENS on the 33kV Feeders

V. CONCLUSION

5.1 Conclusion

Five 33kV feeders were used to evaluate the reliability of power system and consequently ascertain the energy denied the customers due to system failure. In the course of evaluation, System average interruption duration indices became: 163.09hrs on Trans Amadi 33kV feeder, 74.25hrs on Akani 33kV feeder, 52hrs on Airport 33kV feeder, 66.77hrs on Abuloma 33kV feeder, and 246.19hrs on Uniport 33kV feeder.

System average interruption frequency indices became: 62.67interruptions per customer on Trans Amadi 33kV feeder, 53.30 interruptions per customer on Akani 33kV feeder, 26 interruptions per customer on Airport 33kV feeder, 58.58interruptions per customer on Abuloma 33kV feeder, and 236.67 interruptions per customer on Uniport 33kV feeder. Also, customer average interruption duration indices became: 2.60hrs on Trans Amadi 33kV feeder, 1.39hrs on Akani 33kV feeder, 2.0hrs on Airport 33kV feeder, 1.14hrs on Abuloma 33kV feeder, and 1.04hrs on Uniport 33kV feeder.

Finally, energy not suppliedbecame: 277062Kwh on Trans Amadi 33kV feeder, 24112Kwh on Akani 33kV feeder, 1352Kwh on Airport 33kV feeder, 13266Kwh on Abuloma 33kV feeder, and 250777Kwh on Uniport 33kV feeder. The above values representing energy not supplied are valid and particularly in place when the power system is not reliable.

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