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Power Distribution Reliability Using Network Reinforcement Model

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ABSTRACT:*Power system reliability has been a serious challenge especially in developing world. It is obvious that every electricity user needs a reliable power supply. Based on this, the need to improve the reliability of the system is paramount. Five 33kV feeders at Port Harcourt Mains Transmission Station feeding Port Harcourt Electricity Distribution Company customers were selected for reliability assessment and enhancement. The 33kV feeders selected included Trans Amadi, Akani, Airport, Abuloma, and Uniport, because they were the only feeders reinforced at the end of the year 2021. Reliability indices were used to ascertain the performance of the feeders based on available records prior to the period of reinforcement and period after reinforcement which was the year 2022. Prior to the period of reinforcement, customer average interruption indices were: 2.74hrs on Trans Amadi 33kV feeder, 1.43hrs on Akani 33kV feeder, 2.14hrs on Airport 33kV feeder, 1.23hrs on Abuloma 33kV feeder and 1.26hrs on Uniport 33kV feeder. After the period of reinforcements, customer average interruption indices were: 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. The networks reinforcement reduced customer average interruption indices by: 0.14hrs on Trans Amadi 33kV feeder, 0.04hrs on Akani 33kV feeder, 0.14hrs on Airport 33kV feeder, 0.09hrs on Abuloma 33kV feeder and 0.22hrs on Uniport 33kV feeder. Reductions in customer average interruption indices are substantial to guarantee increased power quality and availability.*

KEY WORDS: *Power system reliability,Reliability indices, Network reinforcement, Feeder, Power outage.*

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I. INTRODUCTION

Power system reliability refers to a situation whereby the system has adequate generation, response demand and network capable of evacuating energy demanded with high degree of confidence and at the same time power quality is not compromised. Preventive maintenance in power system is very important to increase power availability and avoid compromising power quality. Energy demand is expanding all over the world without corresponding improvement in the supply-side. It will be wise to maintain all associated power facilities to keep the network ready for regular or emergency load demand [1].

There are several reliability indices to check whether a system is reliable or not. For the purpose of this, it will be imperative to highlight on reliability indices such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) and customer average interruption duration index (CAIDI). These reliability indices can provide the desired solution to the quest to provide a reliable power system. Reliability indices are essential tools to check the performance of the power system [2].

It is a known fact that Nigeria's electricity is faced with severe power generation deficit. To make the matter worst, the country's electricity supply industry has very many challenges such as overstressed transmission and distribution networks, energy theft, poor network maintenance, regular network and equipment vandalism, and absence of modern control systems 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 assessing and evaluating the reliability of the power distribution network in Port Harcourt, some feeders with obvious record of reinforcements were selected to assess and evaluate their performance before and after the reinforcement projects between 2021 and 2022. The feeders selected for the reliability assessment and evaluation are: Trans Amadi, Akani, Airport, Abuloma and Uniport 33kV feeders respectively, all radiating from Port Harcourt mains transmission station.

II. RELATED WORKS

Network or power outages can further be reduced by having quick fault detection and embarking on preventive maintenance [4]. This means that reinforcing 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[5], 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. It can be seen that maintenance plays a significant role in power system reliability as power availability will increase due to reduction in the failure of fuses and other power apparatus.

Reliability of power supply is generally the outcome of the standards and processes which drives the power system [6]. It is highly imperative to attain a high level of reliability as it determines the cost of every investment to the power network [7]. Kumar et al.[2] stated that reliability indices are useful in determining the reliability of a power system.

The ever-increasing population of humans leads to increase in energy demand and therefore, to meet this demand distributed power generation systems can be penetrated into the power system to form a new type of power system known as the micro grid. Under normal circumstances, it reduces blackouts and the adverse effects of terrorism [8]. Reliable access to power supply is a basic precondition for enhancing people's lives in rural areas, for improved standard of living, healthcare, education, and for growth within local economies [9].

III. MATERIALS AND METHOD

3.1 Power System Reliability Indices

All data required were available for the research. Durations of availability and unavailability of power, feeder names, and customer population were the basic data for this study. The reliability of five selected 33kV feeders was assessed and evaluated based on their existing status before reinforcements and after reinforcements. On each of the two scenarios, the indices were used on Trans Amadi 33kV feeder, Akani 33kV feeder, Airport 33kV feeder, Abuloma 33kV feeder and Uniport 33kV feeder accordingly.

Knowing that System Average Interruption Duration Index (SAIDI) is cardinal in determining the reliability of a power system, itwillbe pertinent to express that:

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

Which implies that:

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

Where N_i is number of customers per load

λ_i= Total number of customer's interruption duration

Also very imperative is System Average Interruption Frequency Index (SAIFI). This can be mathematically expressed as:

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

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

Where N_i is number of customers per load

U_i= Total number of customer's interruption

It is customary to consider Customer Average Interruption Duration Index (CAIDI) in the following way:

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

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

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

From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.2.1 System Average Interruption Duration Index (SAIDI)

Considering the equation

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

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

Data collected show that Trans Amadi 33kV line has 925 customers and 81 hours of interruption duration. Also, Rivoc, Water Works, Fimie and Nda Bros 11kV feeders, respectively have 75, 742, 300, 72 and 315 hours of interruption durations, respectively with 956, 355, 462, 1500 and 2005 customers, respectively, given a total of 6,203 customers, then:

$$\text{SAIDI} = \frac{(925 \times 81)+(956 \times 75)+(355 \times 742)+(462 \times 300)+(1500 \times 72)+(2005 \times 315)}{6203}$$

$$\text{SAIDI} = \frac{(74{,}925)+(71{,}700)+(263{,}410)+(138{,}600)+(108{,}000)+(631{,}575)}{6203}$$

$$\text{SAIDI} = \frac{1288210}{6203}$$

$$\text{SAIDI} = 207.68$$

3.2.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

Data collected show that Trans Amadi 33kV line has 56 interruptions. Also, Rivoc, Water Works, Fimie and Nda Bros 11kV feeders, respectively have 45, 562, 60, 12 and 65 interruptions, then:

$$\text{SAIFI} = \frac{(925 \times 56)+(956 \times 45)+(355 \times 562)+(462 \times 60)+(1500 \times 12)+(2005 \times 65)}{6203}$$

$$\text{SAIFI} = \frac{(51800)+(43{,}020)+(199510)+(27{,}720)+(18{,}000)+(130{,}325)}{6203}$$

$$\text{SAIFI} = \frac{470{,}375}{6203}$$

$$\text{SAIFI} = 75.83$$

3.2.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

$$\text{CAIDI} = \frac{207.68}{75.83}$$

$$\text{CAIDI} = 2.74$$

3.3 Akani (Feeder II) 33kV Feeder Reliability Indices (Before Reinforcement)

From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.3.1 System Average Interruption Duration Index (SAIDI)

From the equation

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

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

Data collected show that Rumurolu, Rumuogba, Old Aba Road, Rumuibekwe and Rumukalagbo 11kV feeders, respectively have 104, 72, 116, 110 and 79 hours of interruption durations, respectively with 985, 2700, 2036, 1319 and 2505 customers, respectively, given a total of 9,545 customers, then:

$$\text{SAIDI} = \frac{(985 \times 104) + (2700 \times 72) + (2036 \times 116) + (1319 \times 110) + (2505 \times 79)}{9545}$$

$$\text{SAIDI} = \frac{(13790) + (194400) + (236176) + (145090) + (197895)}{9545}$$

$$\text{SAIDI} = \frac{787351}{9545}$$

$$\text{SAIDI} = 82.49$$

3.3.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

Data collected show that Rumurolu, Rumuogba, Old Aba Road, Rumuibekwe and Rumukalagbo 11kV feeders, respectively have 74, 44, 81, 73 and 39 interruptions, then:

$$\text{SAIFI} = \frac{(985 \times 74) + (2700 \times 44) + (2036 \times 81) + (1319 \times 73) + (2505 \times 39)}{9545}$$

$$\text{SAIFI} = \frac{(72890) + (118800) + (164916) + (96287) + (97695)}{9545}$$

$$\text{SAIFI} = \frac{550588}{9545}$$

$$\text{SAIFI} = 57.68$$

3.3.3 Customer Average Interruption Duration Index (CAIDI)

Considering the equation

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

$$\text{CAIDI} = \frac{82.49}{57.68}$$

$$\text{CAIDI} = 1.43$$

3.4 Airport (Feeder I) 33kV Feeder Reliability Indices (Before Reinforcement)

From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.4.1 System Average Interruption Duration Index (SAIDI)

From the equation

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

Data collected show that Airport (Feeder I) 33kV line has 3,039 customers and 60 hours of interruption duration, then:

$$\text{SAIDI} = \frac{(3{,}039 \times 60)}{3{,}039}$$

$$\text{SAIDI} = \frac{182340}{3{,}039}$$

$$\text{SAIDI} = 60$$

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

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

Data collected show that Airport (Feeder I) 33kV line has 28 interruptions, then:

$$\text{SAIFI} = \frac{(3{,}039 \times 28)}{3{,}039}$$

$$\text{SAIFI} = \frac{85092}{3{,}039}$$

SAIFI = 28

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

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

$$\text{CAIDI} = \frac{60}{28}$$

CAIDI = 2.14

3.5 Abuloma 33kV Feeder Reliability Indices (Before Reinforcement)
From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

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

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

Data collected show that Abuloma 33kV line load has 153 customers and 15 hours of interruption duration. Also, Azuabie, Okuru and Abuloma 11kV feeders, respectively have 58, 91, and 87 hours of interruption durations, respectively with 782, 813, and 992 customers, respectively, given a total of 2,740 customers, then:

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

$$\text{SAIDI} = \frac{(153 \times 15)+(782 \times 58)+(813 \times 91)+(992 \times 87)}{2740}$$

$$\text{SAIDI} = \frac{(2295)+(45356)+(73983)+(86304)}{2740}$$

$$\text{SAIDI} = \frac{207938}{2740}$$

SAIDI = 75.89

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

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

Data collected show that Abuloma 33kV line load has 12 interruptions. Also, Azuabie, Okuru and Abuloma 11kV feeders, respectively have 52, 77, and 64 interruptions, respectively, then:

$$\text{SAIFI} = \frac{(153 \times 12)+(782 \times 52)+(813 \times 77)+(992 \times 64)}{2740}$$

$$\text{SAIFI} = \frac{(1836)+(40664)+(62601)+(63488)}{2740}$$

$$\text{SAIFI} = \frac{168589}{2740}$$

SAIFI = 61.53

3.5.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

$$\text{CAIDI} = \frac{75.89}{61.53}$$

CAIDI = 1.23

3.6 Uniport (Rumuodomaya) 33kV Feeder Reliability Indices (Before Reinforcement)

From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.6.1 System Average Interruption Duration Index (SAIDI)

From the equation

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

Data collected show that Uniport 33kV line load has 202 customers and 35 hours of interruption duration. Also, F G C, Obiwali, Eligbolo and Omachi 11kV feeders, respectively have 190, 276, 197 and 523 hours of interruption durations, respectively with 1724, 2133, 4162 and 3860 customers, respectively, given a total of 12,081 customers, then:

$$\text{SAIDI} = \frac{Sum\ of\ all\ customers\ \ inter\,ruption\ \ durations\ \ (Uniport\ \ Line\ \ Load + FGC + Obiwali + Eligbolo + Omac\,hi)}{Total\ \ number\ \ of\ customers\ \ served}$$

$$\text{SAIDI} = \frac{(202 \times 35)+(1{,}724 \times 190)+(2{,}133 \times 276)+(4{,}162 \times 197)+(3{,}860 \times 523)}{12081}$$

$$\text{SAIDI} = \frac{(7070)+(327560)+(588708)+(819914)+(2018780)}{52{,}729}$$

$$\text{SAIDI} = \frac{3762032}{12081}$$

SAIDI = 311.40

3.6.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

Data collected show that Uniport 33kV line load has 22 interruptions. Also, F G C, Obiwali, Eligbolo and Omachi 11kV feeders, respectively have 174, 226, 176 and 383 interruptions, respectively, then:

$$\text{SAIFI} = \frac{(202 \times 22)+(1{,}724 \times 174)+(2{,}133 \times 226)+(4{,}162 \times 176)+(3{,}860 \times 383)}{12081}$$

$$\text{SAIFI} = \frac{(4444)+(299976)+(482058)+(732512)+(1478380)}{12081}$$

$$\text{SAIFI} = \frac{2997370}{12081}$$

SAIFI = 248.11

3.6.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

$$\text{CAIDI} = \frac{311.40}{248.11}$$

$$\text{CAIDI} = 1.26$$

3.7 Networks Reinforcement

The networks under study were reinforced at the end of 2021. These reinforcement projects were carried out to improvethe reliability of the networksby way of attaining the desired power quality and at the same time increasing power availability. From records, the projects were carried out as follows:

3.7.1 Trans Amadi (RSPUB II) 33kV Feeder Reliability Indices (After Reinforcement)

Reinforcement projects included installation of gang isolators at T-offs after high voltage Drop-out fuses to ensure that power supply is not interrupted regularly for maintenance purposes. Also, vegetation control was embarked upon to reduce the rate of power failure due to overgrown vegetation. Sections with weak conductors were reconductored and Rivoc was partly deloaded to Nda Bros to avoid local load shedding.From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.7.1.1 System Average Interruption Duration Index (SAIDI)

Considering the equation

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

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

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:

$$\text{SAIDI} = \frac{(925 \times 61) + (956 \times 63) + (355 \times 538) + (462 \times 180) + (1500 \times 57) + (2005 \times 267)}{6203}$$

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

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

$$\text{SAIDI} = 163.09$$

3.7.1.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

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:

$$\text{SAIFI} = \frac{(925 \times 36) + (956 \times 40) + (355 \times 460) + (462 \times 49) + (1500 \times 10) + (2005 \times 58)}{6203}$$

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

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

SAIFI = 62.67

3.7.1.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

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

CAIDI = 2.60

3.7.2 Akani (Feeder II) 33kV Feeder Reliability Indices (After Reinforcement)

Underground cables to the Injection substation were replaced because they were weak. The overhead line from the transmission station to the Injection substation was also replaced. From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.7.2.1 System Average Interruption Duration Index (SAIDI)

From the equation

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

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

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:

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

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

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

SAIDI = 74.25

3.7.2.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

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

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

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

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

SAIFI = 53.30

3.7.2.3 Customer Average Interruption Duration Index (CAIDI
Considering the equation

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

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

CAIDI = 1.39

3.7.3 Airport (Feeder I) 33kV Feeder Reliability Indices (After Reinforcement)
Auto-recloser was installed on the main line at Rukpokwu to avoid frequent power interruption due to network maintenance. Gang isolator was installed at every distribution substation connected to the feeder to reduce the frequency of interruption as it is not connected to any injection substation. Vegetation was also cleared.From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

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

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

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

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

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

SAIDI = 52

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

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

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

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

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

SAIFI = 26

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

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

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

CAIDI = 2.0

3.7.4 Abuloma 33kV Feeder Reliability Indices (After Reinforcement)

Reinforcement projects included installation of gang isolators at T-offs after high voltage Drop-out fuses to ensure that power supply is not interrupted frequently for maintenance purposes. Also, overgrown vegetation was cleared to reduce the rate of power failure. Sections with weak conductors were reconductored. From among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.7.4.1 System Average Interruption Duration Index (SAIDI)

From the equation

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

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:

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

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

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

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

$$\text{SAIDI} = 66.77$$

3.7.4.2 System Average Interruption Frequency Index (SAIFI)

Considering the equation

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

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:

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

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

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

$$\text{SAIFI} = 58.58$$

3.7.4.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

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

$$\text{CAIDI} = 1.14$$

3.7.5 Uniport (Rumuodomaya) 33kV Feeder Reliability Indices (After Reinforcement)

Auto-recloser was installed on the main line at Rumuokoro after Rumuodomaya Injection substation to avoid frequent power interruption due to network maintenance. Gang isolator was installed at every distribution substation connected to the feeder to reduce the frequency of interruption. Vegetation was also cleared.From

among the several indices, preferred are SAIDI, SAIFI and CAIDI. The reliability indices selected were to provide a far-reaching solution to poor power system reliability.

3.7.5.1 System Average Interruption Duration Index (SAIDI)

Considering the equation

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

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:

$$\text{SAIDI} = \frac{Sum\ of\ all\ customers\ \ interruption\ \ durations\ \ (Uniport\ \ Line\ \ Load + FGC + Obiwal\ i + Eligbolo + Omac\ hi)}{Total\ number\ \ of\ customers\ \ served}$$

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

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

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

$$\text{SAIDI} = 246.19$$

3.7.5.2 System Average Interruption Frequency Index (SAIFI)

From the equation

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

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:

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

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

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

$$\text{SAIFI} = 236.67$$

3.7.5.3 Customer Average Interruption Duration Index (CAIDI)

Using the equation

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

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

$$\text{CAIDI} = 1.04$$

IV. RESULTS AND DISCUSSION

4.1 System Average Interruption Duration Index Result Summary (Before and After Reinforcements)

The results are displayed in this segment. The results obtained from the system average interruption duration index (SAIDI) before and after reinforcements on the five selected feeders at Port Harcourt mains transmission station are shown in Table 4.1 and Figure 4.1 respectively.

Table 4.1: System Average Interruption Duration Index (SAIDI)

Feeder	SAIDI (HRS) -Before Reinforcements	SAIDI (HRS)-After Reinforcements
Trans Amadi	207.68	163.09
Akani	82.49	74.25
Airport	60	52
Abuloma	75.89	66.77
Uniport	311.4	246.19

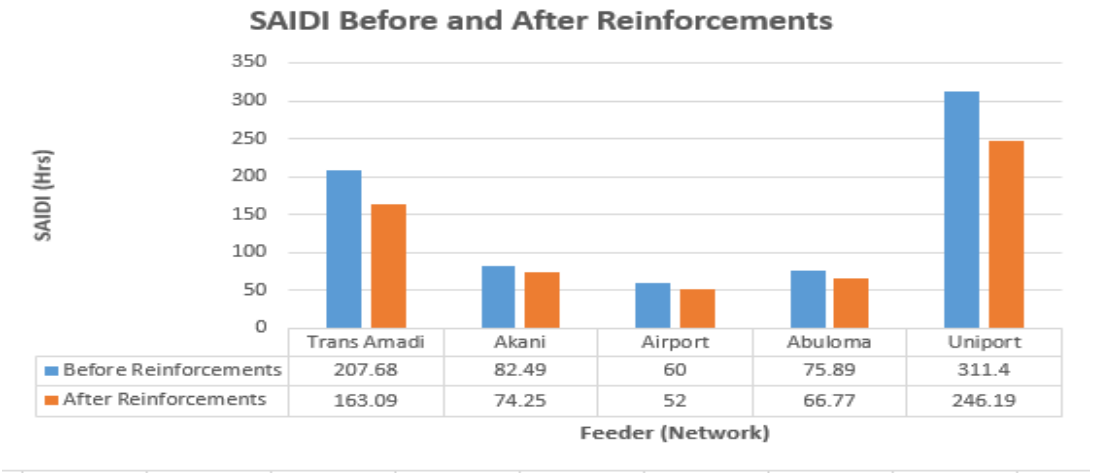

Figure 4.1: Chart of SAIDI Before and After Reinforcements

4.2 System Average Interruption Frequency Index Result Summary (Before and After Reinforcements)

The results are displayed in this segment for clarity. The results obtained from the system average interruption frequency index (SAIFI) before and after reinforcements on the five selected feeders at Port Harcourt mains transmission station are shown in Table 4.2 and Figure4.2 respectively.

Table 4.2: System Average Interruption Frequency Index (SAIFI)

Feeder	SAIFI (Interruptions/Customer) -Before Reinforcements	SAIFI (Interruptions/Customer)-After Reinforcements
Trans Amadi	75.83	62.67
Akani	57.68	53.3
Airport	28	26
Abuloma	61.53	58.58
Uniport	248.11	236.67

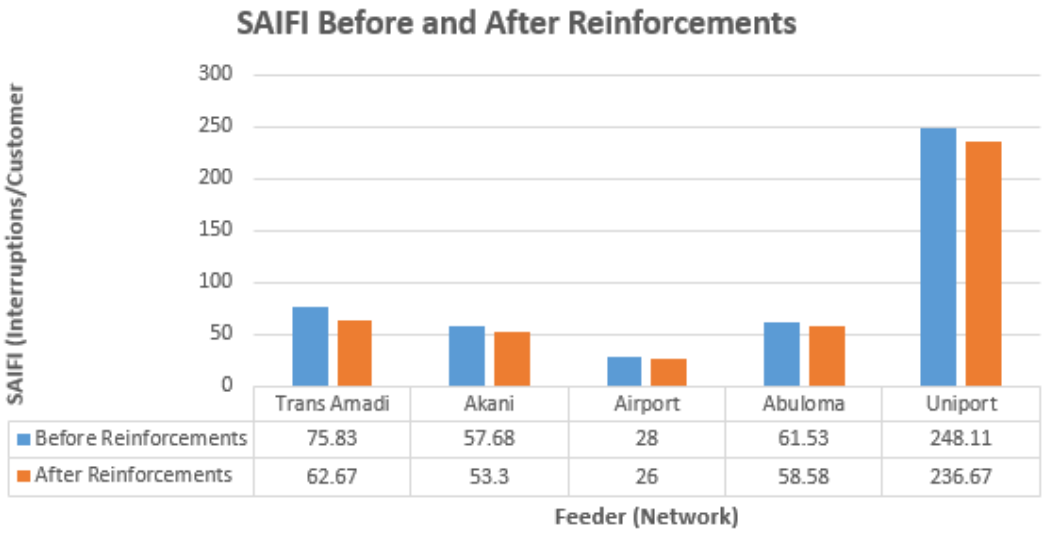

Figure 4.2: Chart of SAIFI Before and After Reinforcements

4.3Customer Average Interruption Duration Index Result Summary (Before and After Reinforcements)

The results are displayed for clarity. The results obtained from the customer average interruption duration index (CAIDI) before and after reinforcements on the five selected feeders at Port Harcourt mains transmission station are shown in Table 4.3 and Figure4.3 respectively.

Table 4.3: Customer Average Interruption Duration Index (CAIDI)

Feeder	CAIDI (HRS) -Before Reinforcements	CAIDI (HRS)-After Reinforcements
Trans Amadi	2.74	2.6
Akani	1.43	1.39
Airport	2.14	2
Abuloma	1.23	1.14
Uniport	1.26	1.04

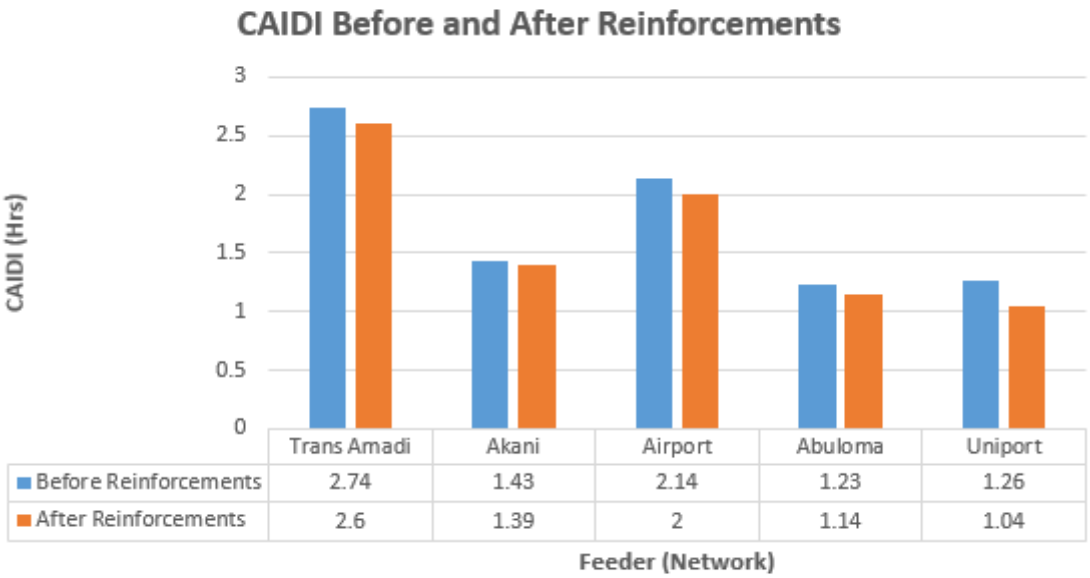

Figure 4.3: Chart of CAIDI Before and After Reinforcements

V. CONCLUSION

5.1 Conclusion

Five 33kV feeders were used to ascertain the improvement of power system reliability by comparing the networks performance before and after reinforcements. System average interruption duration indices reduced from: 207.68hrs to 163.09hrs on Trans Amadi 33kV feeder, 82.49hrs to 74.25hrs on Akani 33kV feeder, 60hrs to 52hrs on Airport 33kV feeder, 75.89hrs to 66.77hrs on Abuloma 33kV feeder and 311.40hrs to 246.19hrs on Uniport 33kV feeder.

System average interruption frequency indices reduced from: 75.83 to 62.67(interruptions per customer) on Trans Amadi 33kV feeder, 57.68 to 53.30 (interruptions per customer) on Akani 33kV feeder, 28 to 26 (interruptions per customer) on Airport 33kV feeder, 61.53 to 58.58 (interruptions per customer) on Abuloma 33kV feeder and 248.11 to 236.67 (interruptions per customer) on Uniport 33kV feeder. Also, customer average interruption duration indices reduced from: 2.74hrs to 2.60hrs on Trans Amadi 33kV feeder, 1.43hrs to 1.39hrs on Akani 33kV feeder, 2.14hrs to 2.0hrs on Airport 33kV feeder, 1.23hrs to 1.14hrs on Abuloma 33kV feeder and 1.26hrs to 1.04hrs on Uniport 33kV feeder

Comparatively, the SAIDI, SAIFI and CAIDI of the networks were reduced substantially after the reinforcements. This provided improved reliability of the five selected feeders or networks.

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