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Reliability Assessment of Power Systems for Optimal Service Delivery

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ABSTRACT
It is very obvious that the development of every nation largely depends on availability of power supply. Users of electricity desire to have full confidence in the system for domestic and industrial activities to thrive. System Average Interruption Duration Index, System Average Interruption Frequency Index and Customer Average Interruption Duration Index were chosen to assess power system reliability in attempt to build greater customer confidence. In doing this, Greater Port Harcourt 33kV feeder at Rumuosi Transmission Station feeding Port Harcourt International Airport was considered for the reliability assessment. The results of reliability assessment on System average interruption duration index for the months of January, February and March, 2023 are 73.47hrs, 65.71hrs and 67.59hrs. Results of reliability assessment on System average interruption frequency index for the months of January, February and March, 2023 are 23.88, 21.24 and 21.94 interruptions per customer respectively while results on customer average interruption duration index for the months of January, February and March, 2023 are 3.08hrs, 3.09hrs and 3.08hrs. Each customer on the average lost power supply for about 3.08hrs in the month of January, 2023 representing 0.41% but having power supply for about 23.59hrs per day representing 99.59%. In February, customers were denied power supply for about 3.09hrs representing 0.46% but having power supply for about 23.54hrs per day representing 99.54% while for March, customers were denied power supply for about 3.08hrs representing 0.41% but having power supply for about 23.59hrs per day representing 99.59%. The values realized for the customer average interruption duration index for the various months under study point to minimal system failure, minimal fault occurrence in the different electricity distribution networks and quick response to clearing of fault(s). This indicates sufficiency in the power system with respect to demand and therefore, validates the reliability of the system because consistency test was sustained.

Keywords: *Reliability indices, feeder, power system reliability, power interruption, major demand customer*

INTRODUCTION

A system is reliable if its output is the desired following a regular order. This is achieved by not compromising the set procedure, standard and quality of the product. Every reliable power system generally should have adequate power generation, load demand response and transmission/distribution network capacity to provide customers/electricity users power based on energy demand and make the customers have very high confidence in the product arising from optimized service delivery. A power system is said to be reliable if it is sufficiently available and devoid of damage in its quality. In other words, power supply must always be a pure sinusoidal waveform (alternating current). There are several reliability indices to assess the reliability of the power system which include: System Average Interruption Duration Index, System Average Interruption Frequency Index and Customer Average Interruption Duration Index. These reliability indices have proven to be enough to assess the reliability of a power system adequately [1].

Apart from the problem of insufficiency in power generation in Nigeria, transmission and distribution systems are all stressed to their limits. One critical feeder known as Greater Port Harcourt 33kV feeder was chosen to assess the reliability of the power system. In the course of the study, data were sorted from the Port Harcourt Electricity Distribution Company. Duration of power availability, duration of unavailability of power, name of feeders, and customer population were captured for this study. A reliability assessment (involving the use of reliability indices) of the Greater Port Harcourt 33kV feeder feeding from Rumuosi transmission station was conducted successfully.

RELATED WORKS

Kumar *et al.* [1] concluded that it is possible to assess the reliability of the power system with the use of reliability indices. Power failure in Nigeria occurs intermittently coupled with the fact that both transmission and distribution networks are overstressed with load, vandals carry out dubious activities on power equipment and networks, energy theft occurs in the system regularly, maintenance of power facilities is lacking and modern protection and control equipment/systems are lacking in the power system [2].

It is not out of place to state that standards and processes which are the driver of a well-coordinated system produces the reliable power system that customers need [3]. It is a well-known fact that reliability at the highest point is considered very cardinal in all investments to the power supply network [4].

Ideally, micro grid generally contributes to reduction of outage duration and frequency. The outage or blackout situation is given birth by excessive load demand [5]. Reliable power supply provides people living in urban and rural areas with comfort. Businesses thrive in an environment that has a reliable power supply as awareness in the areas of education, business growing methods and healthcare possibilities is expressly gotten by the people [6].

MATERIALS AND METHOD

Power System Reliability Assessment

Reliability indicator data on Greater Port Harcourt 33kV feeder and Airport Complex 11kV feeder connected to it covering the month of January, February and March all in the year 2023 were collected. Greater Port Harcourt 33kV feeder radiates from the Rumuosi transmission station which feeds from Omoku generation station then linked to Port Harcourt Mains transmission station (Zone 2) for higher flexibility. The Greater Port Harcourt 33kV feeder shares T1 40MVA transformer with Rukpokwu 33kV feeder all at Rumuosi transmission station.

If SAIDI is System Average Interruption Duration Index then, it can be stated that:

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

Which implies that:

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 for a given load

λ_i = Total number of interruption duration of a customer

Also, if SAIFI is System Average Interruption Frequency Index then, it becomes mathematically possible to express that:

SAIFI = $\frac{Total\ number\ of\ customer\ interruption}{Total\ number\ of\ customers\ served}$ (3.3)

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 for a given load

U_i = Total number of interruptions for a customer
If CAIDI is Customer Average Interruption Duration Index then, we can state that:

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

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)

Greater Port Harcourt 33kV Feeder Reliability Indices (January, 2023)
Reliability indices chosen were to provide adequate information for customers to understand the state of the power system especially customers tagged as Greater Port Harcourt line loads and those on Airport Complex 11kV feeder since Igwuruta 11kV feeder is yet to be commissioned at Airport 33/11kV injection substation.

System average interruption duration index (SAIDI)
We can state that

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

SAIDI = $\frac{Sum\ of\ all\ customers\ interruption\ durations\ (School\ of\ Nursing + Abacha\ Road)}{Total\ number\ of\ customers\ served}$

Data collected show that Greater Port Harcourt 33kV feeder has as line loads: OPM, Mgbodo, Omoda, Aluu, Salvation Ministries, Jesut College, C 4 Eye, 3 filling stations, 2 hotels,

Today FM, UPTH and Uniport which amount to 15 major demand (MD) customers with 73 hours of interruption durations while Airport Complex 11kV feeder feeding from Greater Port Harcourt 33/11kV injection substation situated at the Port Harcourt International Airport, Umuagwa, Port Harcourt is considered to have 2 major demand (MD) customers namely: Airport complex and Nigerian Civil Aviation Authority with 77 hours of interruption durations, then:

SAIDI = $\frac{(15 \times 73)+(2 \times 77)}{17}$

SAIDI = $\frac{(1095)+(154)}{17}$

SAIDI = $\frac{1249}{17}$

SAIDI = 73.47hrs

System average interruption frequency index (SAIFI)
We can say that

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

It has proven that Greater Port Harcourt 33kV line load has 24 interruptions. Also, Airport Complex 11kV feeder has 23 interruptions, then:

SAIFI = $\frac{(15 \times 24)+(2 \times 23)}{17}$

SAIFI = $\frac{(360)+(46)}{17}$

SAIFI = $\frac{406}{17}$

SAIFI = 23.88 Interruptions/Customer

Customer average interruption duration index (CAIDI)
We can say that

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 = $\frac{73.47}{23.88}$

CAIDI = 3.08hrs

Greater Port Harcourt 33kV Feeder Reliability Indices (February, 2023)
Reliability indices chosen were to provide adequate information for customers to understand the state of the power system especially customers tagged as Greater Port Harcourt line loads and those on Airport Complex 11kV feeder since Igwuruta 11kV feeder is yet to be commissioned at Airport 33/11kV injection substation.

System average interruption duration index (SAIDI)
We can state that

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

SAIDI = $\frac{Sum\ of\ all\ customers\ interruption\ durations\ (School\ of\ Nursing + Abacha\ Road)}{Total\ number\ of\ customers\ served}$

Data collected show that Greater Port Harcourt 33kV feeder has as line loads: OPM, Mgbodo, Omoda, Aluu, Salvation Ministries, Jesut College, C 4 Eye, 3 filling stations, 2 hotels, Today FM, UPTH and Uniport which amount to 15 major demand (MD) customers with 65 hours of interruption durations while Airport Complex 11kV feeder tied to Greater Port Harcourt 33/11kV injection substation situated at the Port Harcourt International Airport, Umuagwa, Port Harcourt is considered to have 2 major demand (MD) customers namely: Airport complex and Nigerian Civil Aviation Authority with 71 hours of interruption durations, then :

SAIDI = $\frac{(15 \times 65) + (2 \times 71)}{17}$

SAIDI = $\frac{(975) + (142)}{17}$

SAIDI = $\frac{1117}{17}$

SAIDI = 65.71hrs

System average interruption frequency index (SAIFI)
We can state that

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

It has proven that Greater Port Harcourt 33kV line load has 21 interruptions. Again, Airport Complex 11kV feeder has 23 interruptions, then:

SAIFI = $\frac{(15 \times 21) + (2 \times 23)}{17}$
SAIFI = $\frac{(315) + (46)}{17}$

SAIFI = $\frac{361}{17}$

SAIFI = 21.24 Interruptions per Customer

Customer average interruption duration index (CAIDI)
We can say that
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 = $\frac{65.71}{21.24}$
CAIDI = 3.09hrs

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Greater Port Harcourt 33kV Feeder Reliability Indices (March, 2023)

Reliability indices chosen were to provide adequate information for customers to understand the state of the power system especially customers tagged as Greater Port Harcourt line loads and those on Airport Complex 11kV feeder since Igwuruta 11kV feeder is yet to be commissioned at Airport 33/11kV injection substation.

System average interruption duration index (SAIDI)

We can state that

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

SAIDI = $\frac{Sum\ of\ all\ customers\ interruption\ durations\ (School\ of\ Nursing + Abacha\ Road)}{Total\ number\ of\ customers\ served}$

Data collected show that Greater Port Harcourt 33kV feeder has as line loads: OPM, Mgbodo, Omoda, Aluu, Salvation Ministries, Jesut College, C 4 Eye, 3 filling stations, 2 hotels, Today FM, UPTH and Uniport which amount to 15 major demand (MD) customers with 67 hours of interruption durations while Airport Complex 11kV feeder feeding from Greater Port Harcourt 33/11kV injection substation situated at the Port Harcourt International Airport, Umuagwa, Port Harcourt is considered to have 2 major demand (MD) customers namely: Airport complex and Nigerian Civil Aviation Authority with 72 hours of interruption durations, then:

SAIDI = $\frac{(15 \times 67) + (2 \times 72)}{17}$

SAIDI = $\frac{(1005) + (144)}{17}$

SAIDI = $\frac{1149}{17}$

SAIDI = 67.59hrs

System average interruption frequency index (SAIFI)

We may write that

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

It has proven that Greater Port Harcourt 33kV line load has 21 interruptions. Again, Airport Complex 11kV feeder has 29 interruptions, then:

SAIFI = $\frac{(15 \times 21) + (2 \times 29)}{17}$

SAIFI = $\frac{(315) + (58)}{17}$

SAIFI = $\frac{373}{17}$

SAIFI = 21.94 Interruptions per Customer

Customer average interruption duration index (CAIDI)
We may write that

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

$$CAIDI = \frac{67.59}{21.94}$$

CAIDI = 3.08hrs

RESULTS AND DISCUSSION

Reliability Evaluation Result Summary

The results so far realized in the course of carrying out the reliability assessment of Greater Port Harcourt 33kV feeder at Rumuosi transmission station are indicated in Tables 1. For reason of quick understanding, system average interruption duration index, system average interruption frequency index and customer average interruption duration index on the 33kV feeder are indicated in Figures 1, 2 & 3 while Figure 4 shows customer average interruption duration index under consistency test.

Table 1: *Calculated Reliability Indices of Greater Port Harcourt 33kV Feeder.*

Period	SAIDI (Hrs)	SAIFI (Interruptions/Customer)	CAIDI (Hrs)
January, 2023	73.47	23.88	3.08
February, 2023	65.71	21.24	3.09
March, 2023	67.59	21.94	3.08

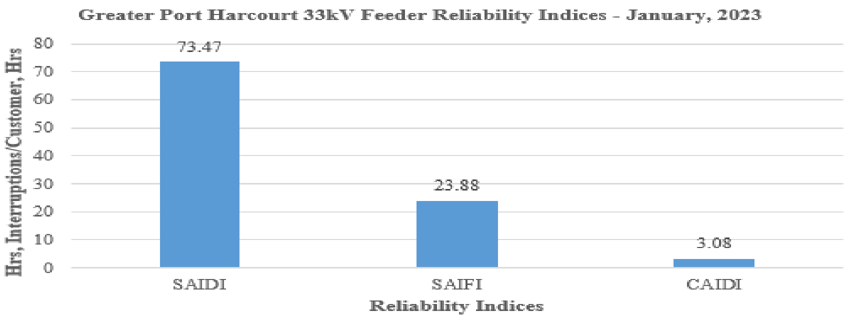

Fig. 1: *Chart of SAIDI, SAIFI and CAIDI on Greater Port Harcourt 33kV Feeder – January, 2023.*

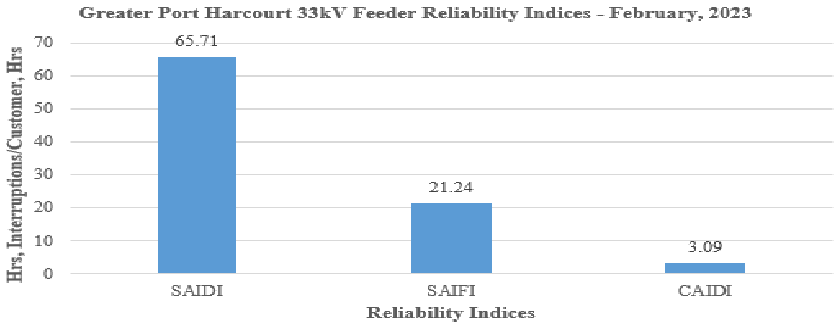

Fig. 2: *Chart of SAIDI, SAIFI and CAIDI on Greater Port Harcourt 33kV Feeder – February, 2023*

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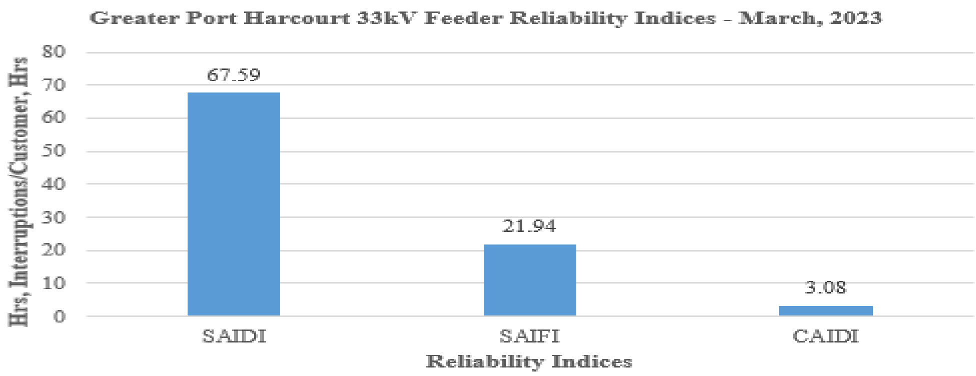

Fig. 3: *Chart of SAIDI, SAIFI and CAIDI on Greater Port Harcourt 33kV Feeder – March, 2023*

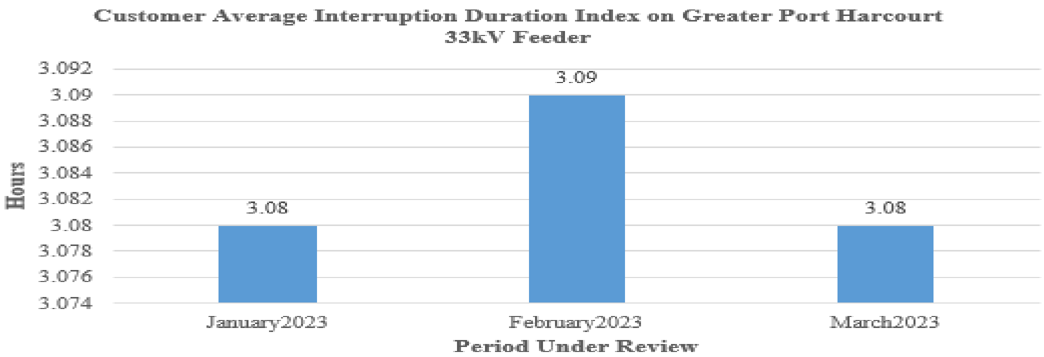

Fig. 4: *Chart of CAIDI on Greater Port Harcourt 33kV Feeder (January - March, 2023)*

CONCLUSION

The results of reliability assessment on System average interruption duration index for the months of January, February and March, 2023 are 73.47hrs, 65.71hrs and 67.59hrs. Results of reliability assessment on System average interruption frequency index for the months of January, February and March, 2023 are 23.88, 21.24 and 21.94 interruptions per customer respectively while results on customer average interruption duration index for the months of January, February and March, 2023 are 3.08hrs, 3.09hrs and 3.08hrs. On the average, each customer was denied power supply for about 3.08hrs in the month of January, 2023 representing 0.41% but having power supply for about 23.59hrs per day representing 99.59%. Customers were denied power supply for about 3.09hrs is representing 0.46% but having power supply for about 23.54hrs

per day representing 99.54% in February while for March, customers were denied power supply for about 3.08hrs representing 0.41% but having power supply for about 23.59hrs per day representing 99.59%. There is considerably very insignificant system failure, less faults occurrence in the system and prompt response to faults for quick elimination.

RECOMMENDATIONS

Based on the findings, it is pertinent to apply some of the strategic recommendations on the test case as well as other power supply networks that have power supply inadequacy to establish investors' confidence.

- To further develop wellbeing, power quality, and dependability, normal pre-unsettling influence strategies incorporate assurance enhancements, voltage and VAR control through power factor revision and voltage improvement, and framework investigation and support. Post-aggravation activities incorporate issue area strategies and occasion investigation.
- Some factors affecting system reliability may not be connected to machine only but factors related to human behaviour which is essentially: understanding of the job, ability to collaborate with other staff and level of motivation of staff.
- Different types of power-conditioning equipment help in improving the power quality supplied to the final loads. Some of them are noise filters, isolation transformers, voltage regulators, and UPS. In order to remove unwanted frequency signals and associated problems, noise filters have to be used.
- The system, operators and all concerned should always encourage reinforcement projects that will enhance power supply quality and availability. Reinforcement projects such as installation of line isolators at T-offs, vegetation control, replacement of weak conductors and appropriate maintenance strategy should be adopted as required.
- Fault locating devices for quicker response to fault conditions that will increase and maintain feeder service reliability as well as engendering the needed power supply efficiency must be in place.

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