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Operation of Circuit Breakers: Data and Analysis

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Abstract

An attempt has been made for the analysis on Circuit breakers (CBs) this paper. First, the types and arcing phenomenon of Oil and SF6 Circuit breakers were briefly discussed. However, various CBs were analyzed in terms of certain outage frequencies and reliability indices to ascertain the most reliable CB. This was possible using data collected from the 33kV Transmission Company of Nigeria (TCN) New Haven, Enugu. After the analysis, Emene Industrial CB had the highest value of availability of 0.9999 and the lowest tripping report while Ezillo had the highest failure rate of 0.1032.

Keywords: Circuit breaker; Outage; Failure rate; Availability; Reliability

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1. Introduction

Once a power system is established it is necessary to protect it from internal and external faults. So we use some protecting and sensing device like circuit breakers, Relays, Fuses etc (Saxena, Singh, Ali, Gandhi, 2012). Power circuit breaker is one of the most important protection and control apparatus in the power system (Suwanasri, Hlaing and Suwanasri, 2014).

A circuit breaker is a switching device that interrupts the abnormal or fault current. It is a mechanical device that disturbs the flow of high magnitude (fault) current and in addition, performs the function of a switch. The circuit breaker is mainly designed for closing or opening of an electrical circuit, thus protects the electrical system from damage. Circuit Breakers represent one of the most critical power apparatus in the power system. They are used to change topology of the power system to accommodate various configurations in routing the load.

CBs are also used to isolate faulted parts of the system as a part of the protective relaying operation (Kezunovic, Ren, Latisko, Sevcik, Lucey, Cook, and Koch, 2005). Circuit breaker essentially consists of fixed and moving contacts. These contacts are touching each other and carrying the current under normal conditions when the circuit is closed. When the circuit breaker is closed, the current carrying contacts, called the electrodes, engaged each other under the pressure of a spring. During the normal operating condition, the arms of the circuit breaker can be opened or closed for a switching and maintenance of the system. To open the circuit breaker, only a pressure is required to be applied to a trigger (Circuit globe, 2017).

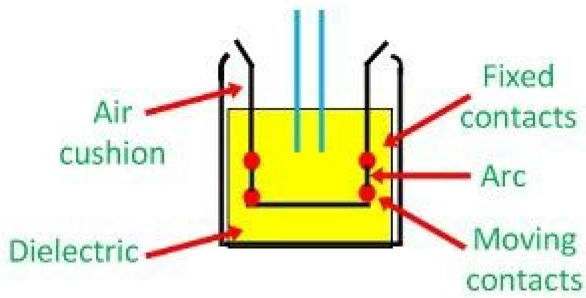


Figure 1: Diagram of an Oil Circuit Breaker (Circuit globe, 2017)

Whenever a fault occurs on any part of the system, the trip coil of the breaker gets energized and the moving contacts are getting apart from each other by some mechanism, thus opening the circuit.

According to Pinnekamp (2007), Several GVA of power can be tamed by a circuit breaker within fractions of a second. Such is the importance of this single device that tens of billions of dollars have been spent on its development over the last 100 years.

2. Types of Circuit Breaker

Circuit breakers are mainly classified on the basis of rated voltages. Circuit breakers below rated voltage of 1000V are known as the low voltage circuit breakers and above 1000V are called the high voltage circuit breakers.

The most general way of the classification of the circuit breaker is on the basis of the medium of arc extinction. Such types of circuit breakers are as follows :-

[1] Oil Circuit Breaker
 a. Bulk Oil Circuit Breaker
 b. Minimum Oil Circuit Breaker
[2] Minimum Circuit Breaker
[3] Air Blast Circuit Breaker
[4] Sulphur Hexafluoride Circuit Breaker
[5] Vacuum Circuit Breaker
[6] Air Break Circuit Breaker

All high-voltage circuit breakers may be classified under two main categories i.e oil circuit breakers and oil-less circuit breaker (Electrical concepts, Circuit breaker and Arc Phenomenon, 2017).

3. Arc Phenomenon in Circuit Breaker

When a short-circuit occurs, a heavy current flows through the contacts of the circuit breaker before they are opened by the protective system. At the instant when the contacts begin to separate the contact area decreases rapidly and large fault current causes increased current density and hence rise in temperature.

The heat produced in the medium between contacts (usually the medium is oil or air) is sufficient to ionize the air or vaporize and ionize the oil. The ionized air or vapour, acts as conductor and an arc is struck between the contacts. The potential difference between the contacts is quite small and is just sufficient to maintain the arc. The arc provides a low resistance path and consequently the current in the circuit remains uninterrupted so long as the arc persists.

During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater arc resistance will represent to the smaller the current flow between the contacts. The arc resistance depends upon the following factors:

- ***Degree of ionization*** - the arc resistance increases with the decrease in the number of ionized particles between the contacts.
- ***Length of the arc*** - the arc resistance increases with the length of the arc i.e. separation of contacts.

- ***Cross section of arc*** - the arc resistance increase with the decrease in the area of cross section of the arc (Electrical Systems, 2017).

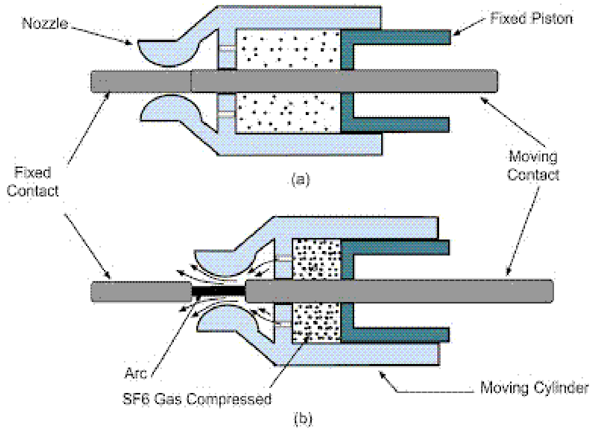


Figure 2: Diagram of the SF6 Circuit breaker (Electrical Systems, 2017)

When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc_within the shortest possible time so that heat generated by it may not reach a dangerous value (Electrical Systems, 2017).

4. Data and Analysis

The data for our analysis was collected from the 33kV Transmission Company of Nigeria (TCN) located in New Haven, Enugu (TCN, Tripping reports, 2016). It contained data of up to 59 feeders/CBs in Enugu region for the period of three (3) months (April – June 2016). The data contained the outage (tripping) report for the feeders together with the tripping time, restoration time, type of fault, time duration before restoration.

As a result of enormity of the data, we tried to group the number of outages per feeder in terms of their outage frequencies such as:

i. Most Frequent Outages: for outages greater than 100 times.
ii. Very Frequent Outages: Outages between 31-99
iii. Less frequent Outages: between 10 -30
iv. Occasional: between 3 -9
v. Rare: between 1-2

The tables and their corresponding chart representations are given to further illustrate the frequency of outages of each feeder between April and June 2016.

Table 1: Most Frequent Outages (>100)

Feeder	Outages
Ezillo	152
Yahe	140
Itigidi	133
Nnewi	131
Agulu	127
Ehamufu	116
Obosi	115
Barracks Rd.	104
North Bank	104
Umunya	102

Table 2: Very Frequent Outages (31-99)

Feeder	Outages
Achi	76
Nnpc	76
Nicuss	74
Neni	73
Neni 33	70
Atani	70
Amechi	69
Isieke	67
Ankpa	63
New Nnpc	62
Udi	62
Army Barracks	59
Oju	47
Govt House	42
Wukari	40
Katsina-Ala	39
Taraku	36
Emene Ind. Layout	33

Table 3: Less Frequent Outages (10-30)

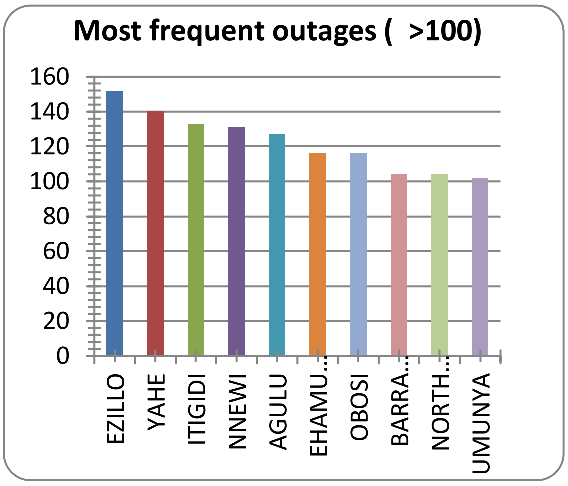
Feeder	Outages
Enugu-Ukwu	27
Ind.Layout	26
Ituku/Ozalla	25
Yandev	22
Kingsway Line2/9th Mile	20
Asaba	18
Awada Ii	18
Emene	17
Feeder 1	17
Makurdi	16
Water Works	16
Feeder 2	13
Feeder 4	12
Mobtr	10

Table 4: Occasional Outages (3-9)

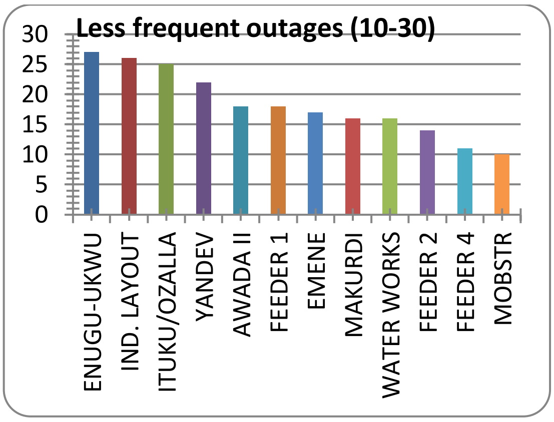
Feeder	Outages
Afikpo	9
Golden Oil	9
Thinkers Corner	8
Aguleri	7
Unn	7
Feeder 3	6
Kingsway Line 1	5
Ibagwa	4
Nsukka	3

Table 5: Rare Outages (1-2)

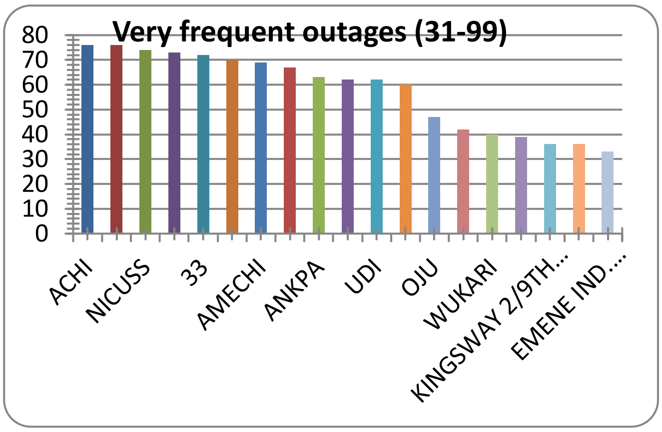
Feeder	Outages
Feeder 5	2
Mobtr 2	2
Mob 45	2
Oji	2
Agbor	1
Bcc 1&Ii	1
Emene Industrial	1
Oji Local	1


Most frequent outages (>100)
160
140
120
100
80
60
40
20
0
EZILLO
YAHE
ITIGIDI
NNEWI
AGULU
EHAMU...
OBOSI
BARRA...
NORTH...
UMUNYA

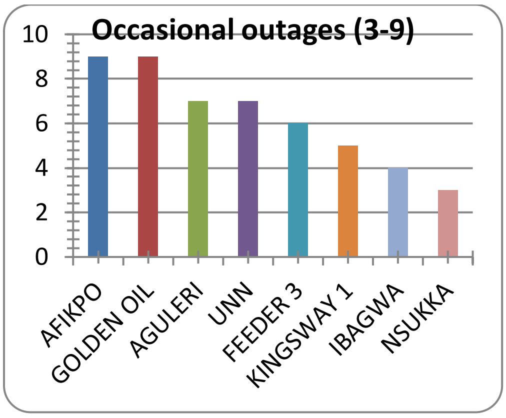
(a)


Less frequent outages (10-30)
30
25
20
15
10
5
0
ENUGU-UKWU
IND. LAYOUT
ITUKU/OZALLA
YANDEV
AWADA II
FEEDER 1
EMENE
MAKURDI
WATER WORKS
FEEDER 2
FEEDER 4
MOBSTR

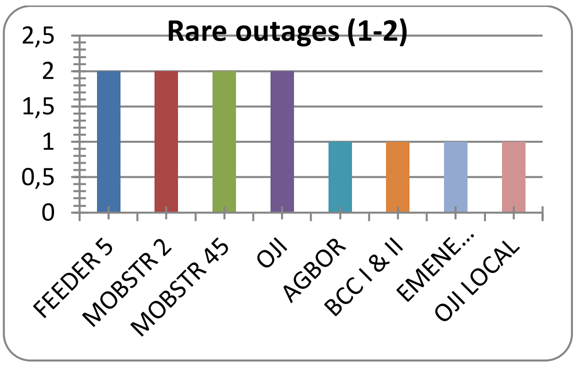
(c)


Very frequent outages (31-99)
80
70
60
50
40
30
20
10
0
ACHI
NICUSS
33
AMECHI
ANKPA
UDI
OJU
WUKARI
KINGSWAY 2/9TH...
EMENE IND....

(b)


Occasional outages (3-9)
10
8
6
4
2
0
AFIKPO
GOLDEN OIL
AGULERI
UNN
FEEDER 3
KINGSWAY 1
IBAGWA
NSUKKA

(d)


Rare outages (1-2)
2,5
2
1,5
1
0,5
0
FEEDER 5
MOBSTR 2
MOBSTR 45
OJI
AGBOR
BCC I & II
EMENE...
OJI LOCAL

(e)

Figure 3: Charts showing the various frequency of outage of the CBs (a) most frequent outages (b) very frequent outages (c) less frequent outages (d) occasional outages (e) rare outages

5. Reliability Analysis

According to Anyaka B.O. (2012), Some reliability indices were calculated from the data obtained such as:

- **Mean Time to Repair (MTTR)**

$$MTTR = \frac{Total\ Outage\ Duration}{Total\ Outages} \quad (1)$$

- **Mean Time between Failures (MTBF)**

$$MTBF = \frac{Total\ Period - Total\ Outage\ Duration}{Total\ Outages} = \frac{Total\ Operating\ Time}{Total\ Outages} \quad (2)$$

- **Failure Rate, λ**

$$\lambda = \frac{1}{MTBF} \quad (3)$$

- **Availability, A**

$$A = \frac{MTBF}{MTBF+MTTR} \quad (4)$$

It should be noted that the total period stands for the total time in consideration (i.e. 3 months = 2184 hours). After calculations, the results are shown in Tables and graphs. Table 6 and Figure 4 shows Most Frequent Outages Reliability results.

Table 6. Most Frequent Outage Reliability results

FEEDER	Outages	Duration	MTTR	MTBF	Failure rate	Availability
EZILLO	152	711	4.68	9.69	0.1032	0.6743
YAHE	140	544.43	3.89	11.71	0.0854	0.7506
ITIGIDI	133	863.12	6.49	9.93	0.101	0.6048
NNEWI	131	672.55	5.13	11.88	0.0842	0.6984
AGULU	127	487.97	3.84	13.35	0.075	0.7766
EHAMUFU	116	357.3	3.08	15.75	0.0635	0.8364
OBOSI	115	621.29	5.4	13.59	0.0736	0.7156
BARRACKS RD.	104	314.48	3.02	17.98	0.0556	0.8562
NORTH BANK	104	374.64	3.6	17.4	0.0575	0.8286
UMUNYA	102	564.83	5.54	15.87	0.063	0.7412

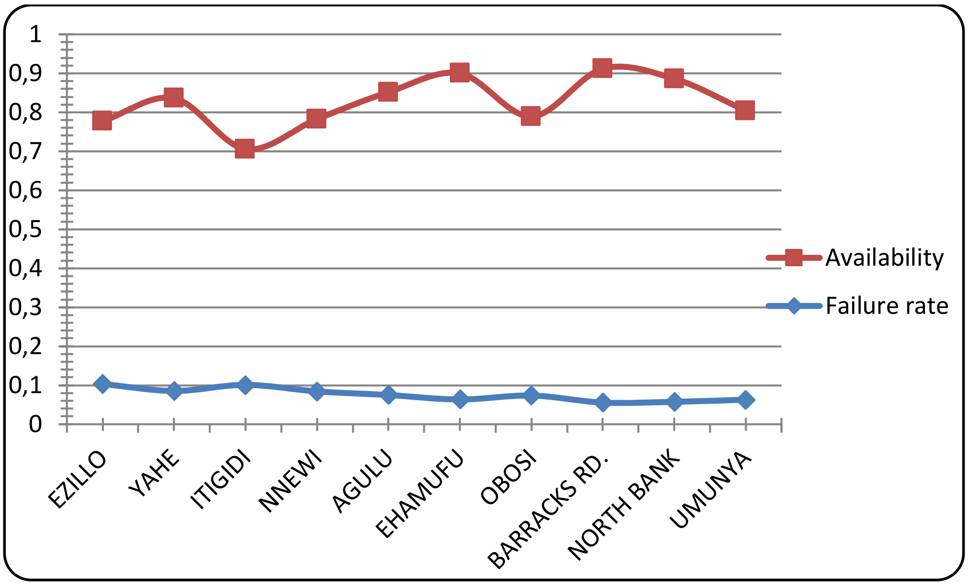


Figure 4: Availability and failure rate characteristic for most frequent outages.

Table 7 and Figure 5 show very Frequent Outage Reliability results.

Table 7: Very frequent Outage reliability results

FEEDER	Outages	Duration	MTTR	MTBF	Failure rate	Availability
ACHI	76	534.68	7.04	21.7	0.0461	0.755
NNPC	76	170.85	2.25	26.49	0.0378	0.9217
NICUSS	74	328.73	4.44	25.07	0.0399	0.8495
NENI	73	408.04	5.59	24.33	0.0411	0.8132
33	70	571.7	8.17	23.03	0.0434	0.7381
ATANI	70	207.03	2.96	28.24	0.0354	0.9051
AMECHI	69	435.48	6.31	25.34	0.0395	0.8006
ISIEKE	67	475.55	7.1	25.5	0.0392	0.7822
ANKPA	63	175.12	2.78	31.89	0.0314	0.9198
NEW NNPC	62	89.29	1.44	33.79	0.0296	0.9591
UDI	62	677.78	10.93	24.29	0.0412	0.6897
ARMY BARRACKS	59	194.7	3.3	33.72	0.0297	0.9109
OJU	47	247.58	5.27	41.2	0.0243	0.8866
GOVT HOUSE	42	61.33	1.46	50.54	0.0198	0.9719
WUKARI	40	232.01	5.8	48.8	0.0205	0.8938
KATSINA-ALA	39	399.93	10.25	45.75	0.0219	0.817
TARAKU	36	254.88	7.08	53.59	0.0187	0.8833
EMENE IND. LAY.	33	77.9	2.36	63.82	0.0157	0.9604

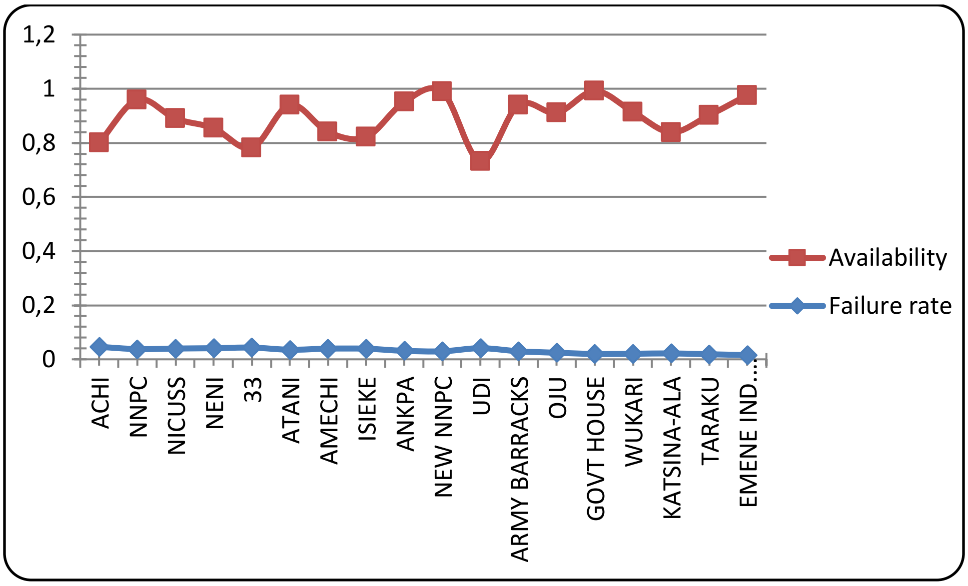


Figure 5: Availability and failure rate characteristic for very frequent outages

Table 8 and Figure 6 show the most Frequent Outages Reliability results.

Table 8: Less frequent outage reliability results

FEEDER	Outages	Duration	MTTR	MTBF	Failure rate	Availability
ENUGU-UKWU	27	425.42	15.76	65.13	0.0154	0.8052
IND.LAYOUT	26	44.85	1.73	82.28	0.0122	0.9794
ITUKU/OZALLA	25	106.53	4.26	83.1	0.012	0.9512
YANDEV	22	151.62	6.89	92.38	0.0108	0.9306
KINGSWAY LINE2/9TH MILE	20	38.3	1.92	107.29	0.00932	0.9824
ASABA	18	133.1	7.39	113.94	0.00878	0.9391
AWADA II	18	21.17	1.18	120.16	0.00832	0.9903
EMENE	17	67.85	3.99	124.48	0.00803	0.9689
FEEDER 1	17	57.1	3.36	125.11	0.00799	0.9738
MAKURDI	16	44.8	2.8	133.7	0.00748	0.9795
WATER WORKS	16	187.33	11.71	124.79	0.00801	0.9142
FEEDER 2	13	50.9	3.92	164.08	0.00609	0.9767
FEEDER 4	12	45.3	3.78	178.23	0.00561	0.9792
MOBTR	10	6.63	0.66	217.74	0.00459	0.997

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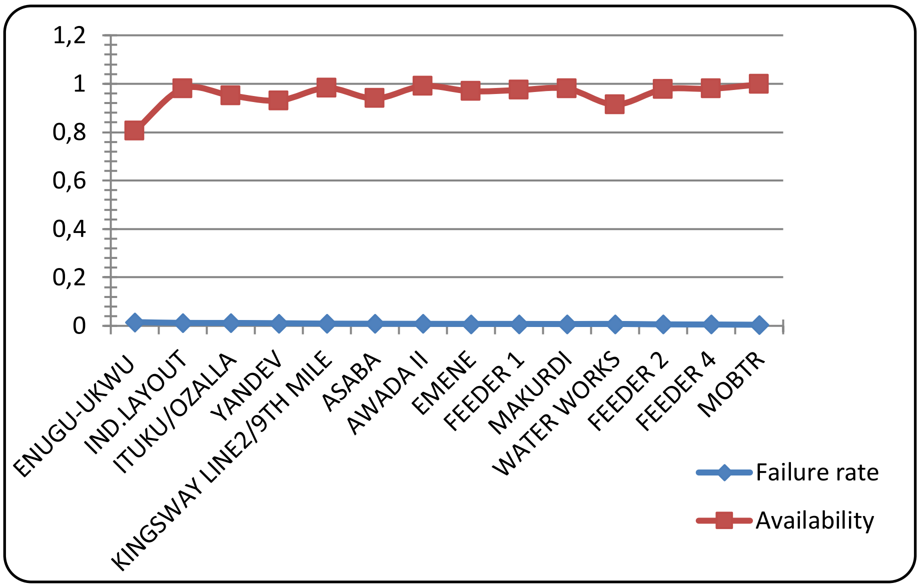

Figure 6: Availability and failure rate characteristic for less frequent outages

Table 9 and Figure 7 show the most Frequent Outages Reliability results.

Table 9: Occasional outage reliability results

FEEDER	Outages	Duration	MTTR	MTBF	Failure rate	Availability
AFIKPO	9	193.2	21.47	221.2	0.00452	0.9115
GOLDEN OIL	9	45.75	5.08	237.58	0.00421	0.9791
THINKERS CORNER	8	18.15	2.27	270.73	0.00369	0.9917
AGULERI	7	357.95	51.13	260.86	0.0038	0.8361
UNN	7	56.95	8.14	303.86	0.00329	0.9739
FEEDER 3	6	16.68	2.78	361.22	0.00277	0.9924
KINGSWAY LINE 1	5	3.83	0.766	436.03	0.00229	0.9982
IBAGWA	4	26.2	6.55	539.45	0.00185	0.988
NSUKKA	3	91.72	30.57	697.43	0.00143	0.958

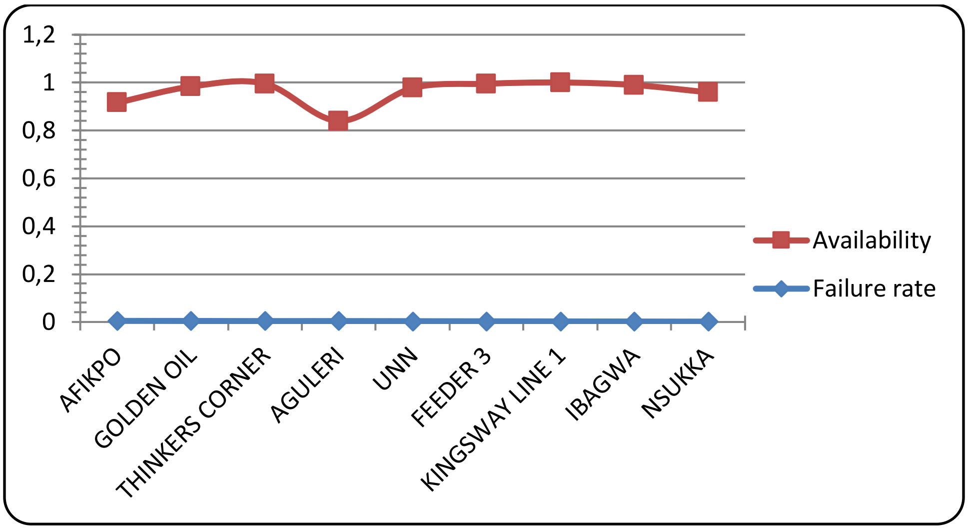

Figure 7: Availability and failure rate characteristic for Occasional outages

Table 10 and Figure 8 show the most Frequent Outages Reliability results.

Table 10: Rare outage reliability results

FEEDER	Outages	Duration	MTTR	MTBF	Failure rate	Availability
FEEDER 5	2	100.11	50.06	1041.95	0.00096	0.9542
MOBTR 2	2	1.07	0.54	1091.47	0.000916	0.9995
MOB 45	2	1.67	0.84	1091.17	0.000916	0.9992
OJI	2	3.35	1.68	1090.33	0.000917	0.9985
AGBOR	1	4.75	4.75	2179.25	0.00046	0.9978
BCC 1&II	1	37.73	37.73	2146.27	0.00047	0.9827
EMENE INDUSTRIAL	1	0.12	0.12	2183.88	0.000458	0.9999
OJI LOCAL	1	1.93	1.93	2182.07	0.000458	0.9991

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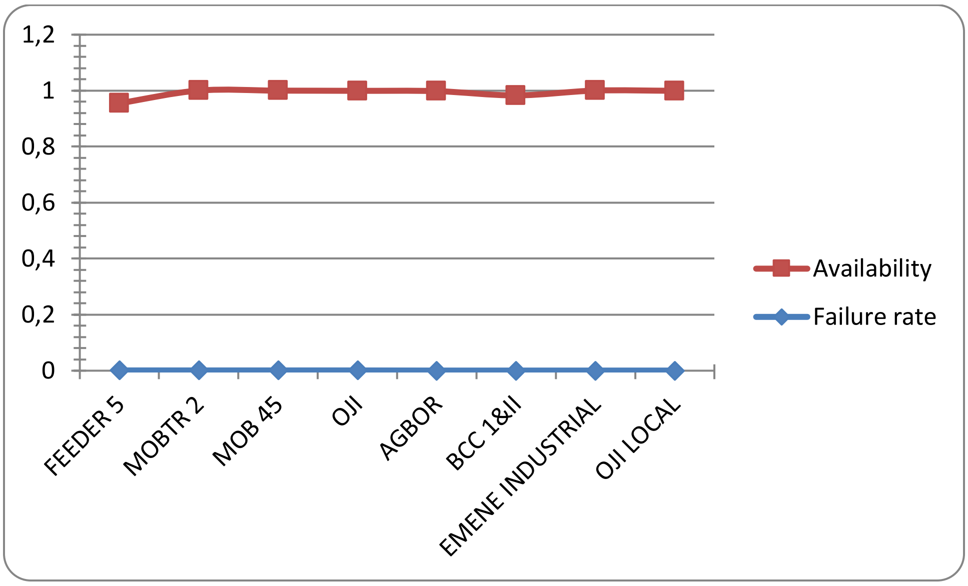

Figure 8: Availability and failure rate characteristic for rare outages.

6. Observations and Conclusion

From the reliability analysis carried out, the following observations are made:

- In the most frequent outage result, we can observe low availabilities at Itigidi and Obosi Feeders with corresponding high failure rates.
- The very frequent outage result showed low availability values and high failure rates at Achi, 33kV Onitsha and Udi feeders.
- The Feeder at Enugu-Ukwu has the lowest availability in the less frequent outage results.
- Aguleri CB has the highest failure rate in the occasional outage results
- Feeder 5 in Asaba station has the lowest availability in the rare outage results.

The availability of a system shows how reliable the system is. From our analysis, the high outages as a result of over-current and earth faults imply that the particular feeder is less reliable. By calculation, Ezillo CB has the lowest availability value (0.6743) and Emene Industrial CB has the highest availability value (0.9999). Hence, Emene Industrial CB has the highest reliability.

However, this does not necessary mean that this feeder is the most reliable one because any CB can fail at any time due to some factors such as overloading, malfunction, weather conditions, human errors and so on. The earth-fault and over-current directional and inverse time relays should be employed in the power system to reduce the high outages due to faults on the system.

Compensation should also be done on areas with high loading to improve voltage profile and reactive power and hence increase transmission line load ability.

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Conflicts of Interest: The authors declare no conflict of interest.

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