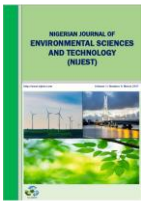
Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 5, No. 1 March 2021, pp 32 - 46



Vulnerability Assessment of Components in a Typical Rural Nigerian Power Distribution System

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https://doi.org/10.36263/nijest.2021.01.0237

ABSTRACT

The major aim of any power system is the continuous provision of safe, quality and reliable electric power to the customers. One of the greatest challenges to meeting up with this goal is the failure of components in the system. In this article, the frequency of outages caused by failure of different components in the distribution system was investigated to ascertain the ones that are more susceptible to failure by comparing their proportions in the entire failure events. The outage data obtained from Irrua Transmission Station comprising Ehor, Ubiaja and Uzebba 33kV feeders were analyzed using Microsoft Excel while the hazard rates were measured using the failure rate index. Findings revealed that 93.77% of all the forced outages in the distribution subsystem in the power sector are caused by the high exposure rate of the bare aluminum conductors used in the construction of the various overhead feeders. Subsequently, the yearly failure rates of aluminum conductors, cross arms, relay, insulators, fuses, electric poles, breakers, transformers, isolators, cables lightning surge arresters were found to be 836.0, 17.5, 17.0, 10.3, 4.3, 2.0, 1.5, 1.3, 1.0, 0.5 and 0.3 respectively in the studied network. A comparison between this study and a related work showed that the rural feeders are more prone to faults as compared to the ones in the urban areas. It was therefore recommended that regular tree trimming along the network corridor should be done. Proper conductor size should be used in every subsequent construction and every segment with undersized conductor should be replaced with the appropriate size. This study will help the power system engineers in the design, construction, maintenance and operation of the distribution power system for optimum and improved system performance.

Keywords: Vulnerability assessment, Power system components, Nigeria power sector, NEMSA, Bathtub curve, Failure rate, NERC

1.0. Introduction

Components are those hardware necessary to effect the proper functioning and operation of a process. While vulnerability in this context is a measure of weakness as a result of wear, tears, production lapses etc. of any component which can lead to its failure. A system is a common entity which comprises many components to carry out specific objective. The major objective of a power distribution system is the supply of safe and quality power to the customers (Brown, 2009). However, the level of the success of this objective is subject to the health and capacity of the installed components in the system. Hence, the arrangement and sizing of components in a power system has become a major aspect in system planning and design because the configuration, architecture and capacity can influence the component failure rate, cost and operational flexibility (Brown, 2009).

In an electrical system, all the components are connected together either in parallel, series, meshed or a combination of these. Therefore, the performance of a power system is a function of the performance state of these constituent components. According to IEEE, the definition of reliability of a system or components is simply their ability to perform the intended functions under stated conditions for a specified period of time. Hence the major point of interest in distribution system reliability assessment is the rate of component failure, repair rates and the general interruptions suffered by the customers (Akintola and Awosope, 2017). This is because the flow of power requires that all the components should be healthy and energized (except standby) before electricity can get to customers.

The adequacy of any power system is defined by the capacity of the installed component. System adequacy has become a major subject in the field of electric power system studies due to the impact on the performance of the power system (Eminoglu and Uyan, 2016). This is a situation whereby there are enough facilities to cater for the generation, transmission and distribution needs of all the served customers. This implies that the point of interest as far as system adequacy is concerned are the network structural architecture and the capacity of the installed components (Billinton and Allan, 1996; Wang, 2012).

Some of the components in the power system include conductors, electric poles, switch gears, lightning arresters, isolators, fuses, transformers and insulator (Gupta, 2005; Brown, 2009; Eke, 2003). Studies have shown that these items are susceptible to failure thereby causing interruption of power supply to the customers. Sometimes, the failure of a component can cause cascaded failure in the power system as a result of the interconnection relationship that exists between the various components.

Power outages are unpalatable events for power users whether they were scheduled or abrupt. The unscheduled events are mainly due to failure of network components. Hence, component failure is the major technical cause of power outages (Akinloye *et al*., 2016). The effect of the outages caused by both line faults and components failures on the power system can last for long period if not quickly resolved. Some line faults could be transient and could be resolved within few seconds by operation of well-planned network switches. However, the failure of network equipment such as transformers, breakers, poles etc can take time to either replace or repair leading to long power outage duration. These system disturbances as a result of faults and failures are the major causes of outages in advanced countries like the United States and the United Kingdom where there are no issue of system inadequacy unlike in Nigeria and Ghana (Godfrey *et al*., 2006). The side effects of such outages are enormous and far worse when compared to scheduled outages because of the customers' unpreparedness for seamless transfer of their load to back-up sources to ensure continuation of operations. The scheduled events are usually as a result of the need to carry out maintenance operations on the equipment, construction and on consumer requests. Most often, customers are pre-informed of such outages in advance so they could make alternative arrangements for any critical activity that may require quality electric power.

One of the major menaces of faults on the distribution networks is the negative impact on the system reliability while also increasing the operational and maintenance costs (Gana *et al*., 2017). To this end, the utility companies have devised different means to contain the excesses of faults on the network reliability by adopting enhanced preventive maintenance policies and deployment of standard protection mechanisms in their systems.

One of the cost-effective methods to improve reliability is by attending to the identified network component that can improve power availability at minimum cost (Canazise *et al*., 2010). Hence in many reliability assessments, the focus of system level of stability are on the failure related characteristics of the components without necessarily considering the number of customers affected by the breakdown. The attention on component failure is even more crucial in series connected power system because according to Canizes *et al*. (2017), the failure of any of the major line components in such a network will result to an outage in the entire circuit due to lack of redundancy in the network. This can influence choice of equipment vendor(s)/manufacturer(s) to rely on for supply of components based on established reliability of products of different brands over time. This is sequel to the fact that the Utility Industry is expected to ensure that operation and maintenance funds are spent wisely to meet customer expectations (Layton, 2004).

The impact of the failures of these component and the consequences on the reliability of the entire power system are usually measured using their failure/hazard rates and repair times. Some of the parameters used in such assessment include permanent short circuit failure rate (λ_P), temporary short circuit failure rate (λ_T), open circuit failure rate (λ_{OC}), mean time to repair (MTTR) and probability of operational failure (POF). Others are scheduled maintenance frequency (λ_M) and mean time to maintain (MTTM) (Brown, 2009).

The study about the failure of components in the power system has become a very interesting area amongst scholars (Sambo *et al*., 2010; Brown, 2009; Xie *et al*., 2004; Min *et al*., 2009; Musa *et al*., 2015; Wang and Wu, 2011; Akintola and Awosope, 2017; Adegboyega and Dawal, 2012; Etu *et al*., 2015; Okoronkwo and Nwagu, 2006; Adoghe *et al*., 2013). This high popularity enjoyed by this field of study is not unconnected with the vital role played by these components in the distribution of electricity to customers. These studies have helped in highlighting the behavior, characteristics, importance and performance of these components in the power system. However, there is still dearth in the study of the proportion of breakdown suffered by each component in the power system. The analysis of causes of power outages presented by Brown (2009) lumped the proportion of the entire component breakdown together against other factors. The components considered by Adoghe *et al*., (2013) in their study were very few. Though, Akintola and Awosope (2017) analyzed more components and presented their proportion of failures in the studied network nevertheless, the scarcity of studies which focus on comparison of component susceptibility levels in the power system warrant more researches. Hence, in this article, the failure of components in a typical rural distribution system in Nigeria will be analyzed to ascertain the proportions of vulnerability of each component to failure. This has become very necessary in order to improve understanding on vital issue bothering on the efficient management of the power distribution industry such as 'what proportion of the forced outages is caused by the failure of a certain or any component in the system?' Hence, such knowledge will help to identify the major items responsible for forced outages thereby assisting the utility providers to plan for effective and efficient maintenance methods. Also, such information can assist in the modification of future network designs to mitigate such failures. The rest of this work will be structured as follows: The materials and method used will be presented in section 2. The finding will be discussed in section 3 while the conclusion and suggestion will be done in section 4.

1.1 The power system

Typical power system consists of different components which are necessary for the generation, transmission, and distribution of electricity to the different load points as shown in Figure 1. In order to successfully achieve this, step-up transformers are used to step up the output voltage of the generators (G) for efficient transmission of the produced power. One of the advantages of transmitting electricity at high voltage is the reduction of line losses as the energy travel through long distances from point of generation to point of utilization. The high transmission line voltage requires stepping down for the purpose of distribution (Prakash *et al*., 2016). The final voltage step down is usually achieved by the distribution transformers which are fed through the primary distribution feeders. Depending on the congestion of any place and policy, the distribution conductors could be placed overhead or underground with it inherent advantages.

The efficiency and reliability of the power system largely depends on the robustness of the implemented design architecture which could be radial, ring or mesh. Mesh is the most reliable and also most complicated to operate followed by ring and then radial (Prakash *et al*., 2016). The system performance can also be affected by natural disaster, such as earthquake and cyclone. Given the fact that every power network was designed under natural disaster rated units, the damages sustained under fault conditions can affect the Mean Time To Restore/Repair (MTTR) depending on the design, control and management of that particular system (Siemens, 2008; Mariam *et al*., 2013). Though the power system comprises generation, transmission and distribution, however findings showed that 80% of all the faults in the system occur at the distribution level (Filomena *et al*., 2011).

The major role of the power distribution system is the stepping down of the transmission voltage to an appropriate level that can be safely utilized by the different customers as presented in Figure 2 (Electrical4u, 2018), and it is radial in our study such that any feeder interruption will affect the customers downstream with failure model presented in Figure 3. Thus, all the components must be in good working condition before power can be delivered to the end users due to lack of redundancy in such systems (Anthony, 2014).

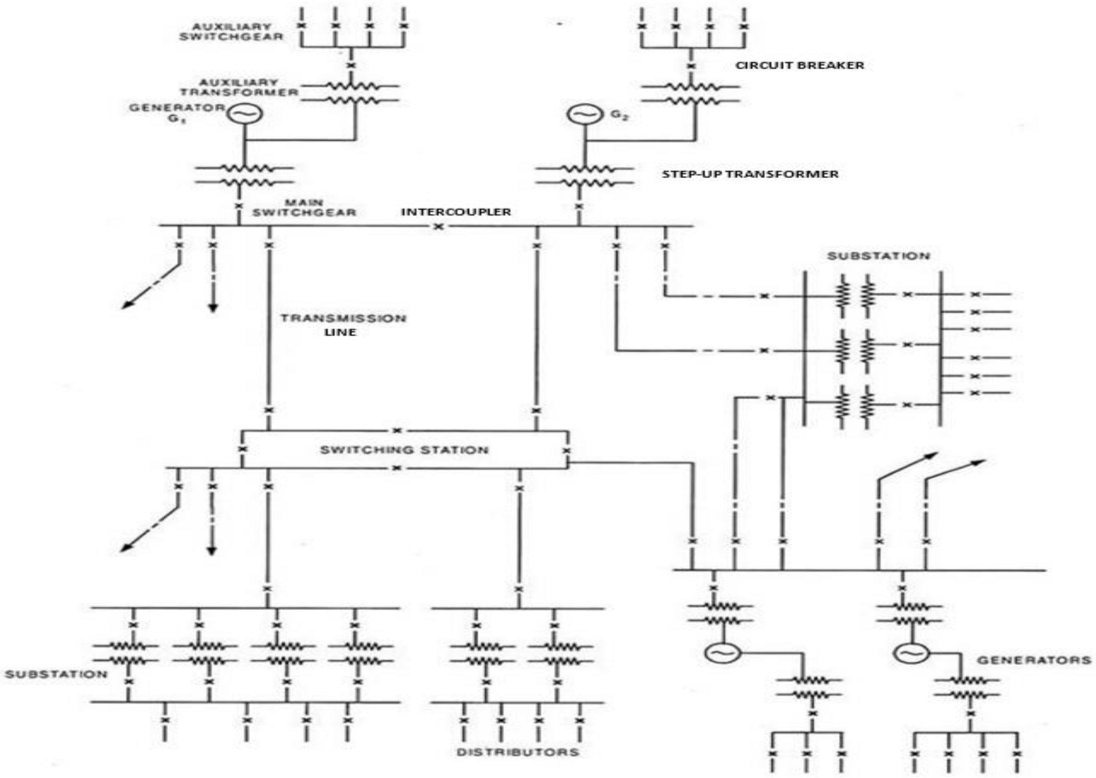


Figure 1: Simplified single line diagram of a typical power system (Anshika, 2017)

1.2. Faults in distribution systems

Faults are unhealthy system or network events. According to Meier (2006), fault is an accidental electrical connection of any live component and another conductive body at a different voltage level which results to short circuit. Research has shown that the causes of fault in the power system include vegetation and animals contact with the live lines, human errors, adverse weather conditions, damaged transformer windings, failed lightning arresters, shattered insulators etc. (Min *et al.*, 2009; Airoboman *et al.*, 2017; Hines *et al.*, 2009; Akinloye *et al.*, 2016).

The pattern of events and the phases in the life-time of components with respect to failure rates is defined by a bathtub shape to includes early infant mortality failure resulting from factory errors, wrong handling and poor workmanship, constant/random failures dependent on component functions and exposure rate to hazardous environment, and wear-out failures that are age dependent (Zhang, 2007; Neubeck, 2004; Lienig and Bruemmer, 2017; Dhillon, 2002; Brown, 2009; Xie *et al.*, 2004; Akintola, 2017). Every fault results to power failure or outage in the power system. Hence there is no hardline drawn between the usage of these terms (i.e. faults and failures) in this study. For the purpose of operation, faults are broadly categorized to either line or equipment faults.

Power distribution lines are susceptible to faults of varying types and magnitudes, classified as either single phase to ground, double phase to ground, phase to phase, three phases to ground or three-phase faults (Ewesor, 2003). In analyzing these faults, we have balanced (symmetrical) three-phase faults (i.e. short circuit/shunt fault), unbalanced (unsymmetrical) faults, one line/series faults and simultaneous faults. The associated fault level can be classified as low impedance and high impedance faults, distinguished by the fault current values which resulted from the arching between the phase to the surface of contact. Unlike low impedance, high impedance faults are difficult to be detected (Wester, 1998). It requires customized approaches that can extract information of these high impedance faults from the available data occurrence (Gana *et al.*, 2017). The shunt faults have been researched to be more severe than the series faults.

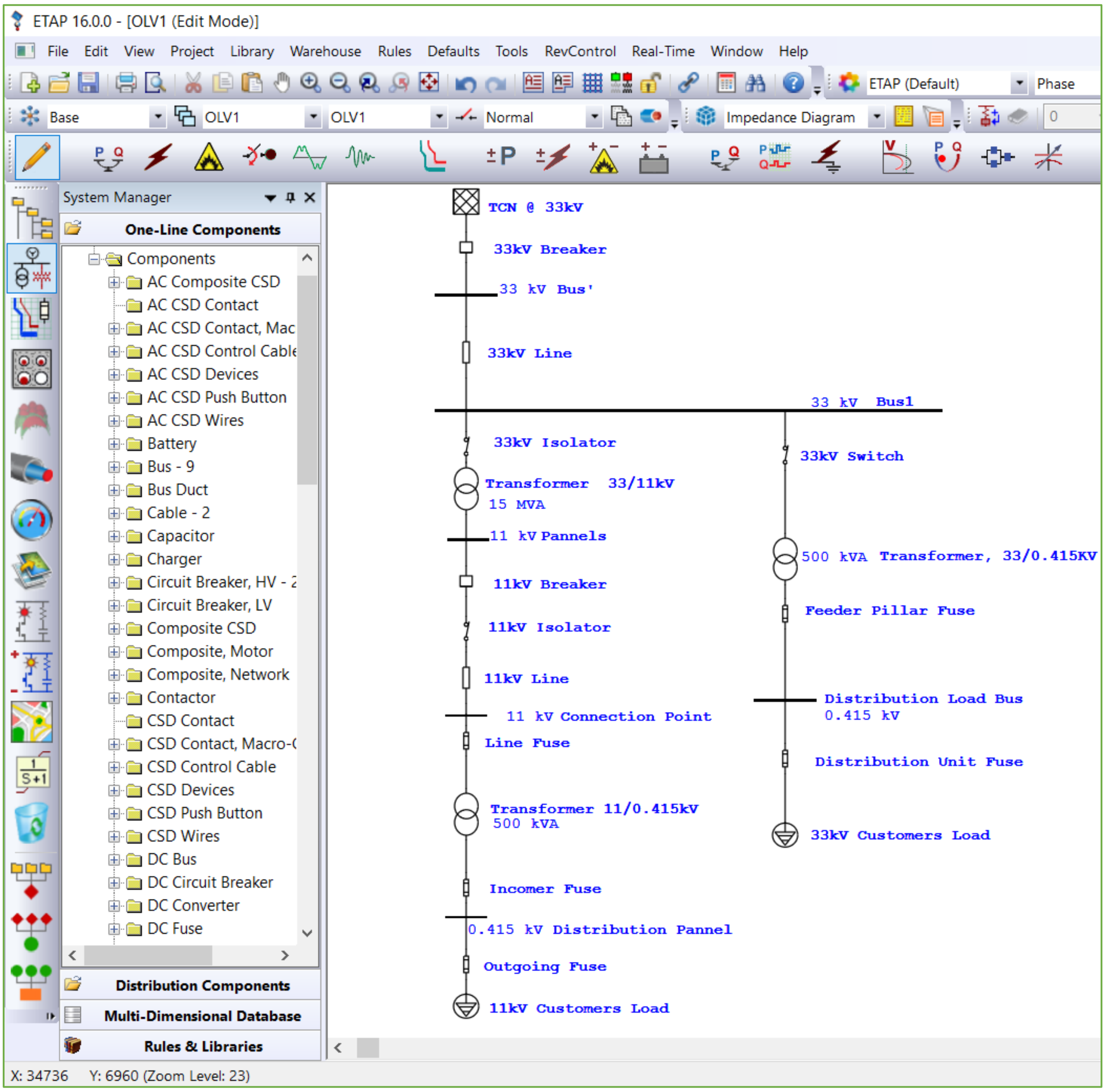


Figure 2: An ETAP software presentation of a typical Single-End Radial Network Configuration

Figure 3: Series network structure (Dorji, 2009).

Where λ_P, = Failure rate
r = Component repair time

Apart from line faults presented, there are also instances of fault conditions on the power system because of breakdown of equipment and these affect the system reliability. Some of the equipment that are susceptible to breakdown include transformers arising from insulation failure of windings, shattered bushings and oil leakage. These can result to rise in winding and oil temperature, oil shortage, fire outbreak and total failure of the transformer (Gupta, 2005; Dhakal, 2000). Another component that can break down are breakers, which have to do with their arc quenching medium and operations mechanism failures (Gupta, 2005). Other vulnerable components include line isolators, electric poles, lightning arresters and insulators (Anshika, 2017).

The findings from the study carried out in the US as presented in Figure 4 showed that the outages in the power system were as a result of trees, lightning, animals, overload, traffic accidents and dig ins (excavation activities), and the highest cause of outages are equipment failures (Brown, 2009). Figure 5 is a graphical representation of the failure rates of the different components in the distribution substation. The chart shows that fuses, line conductors and switchgear are the susceptible components in a power system with very high failure rates. However, it should be noted that faults such as failed joints/terminations are not specific to a particular equipment due to the fact that there are vibration in some equipment as current flows through them and lead to increase in resistance at such points, which can lead to high wastage of energy and fire outbreak if not properly maintained (Gupta, 2005).

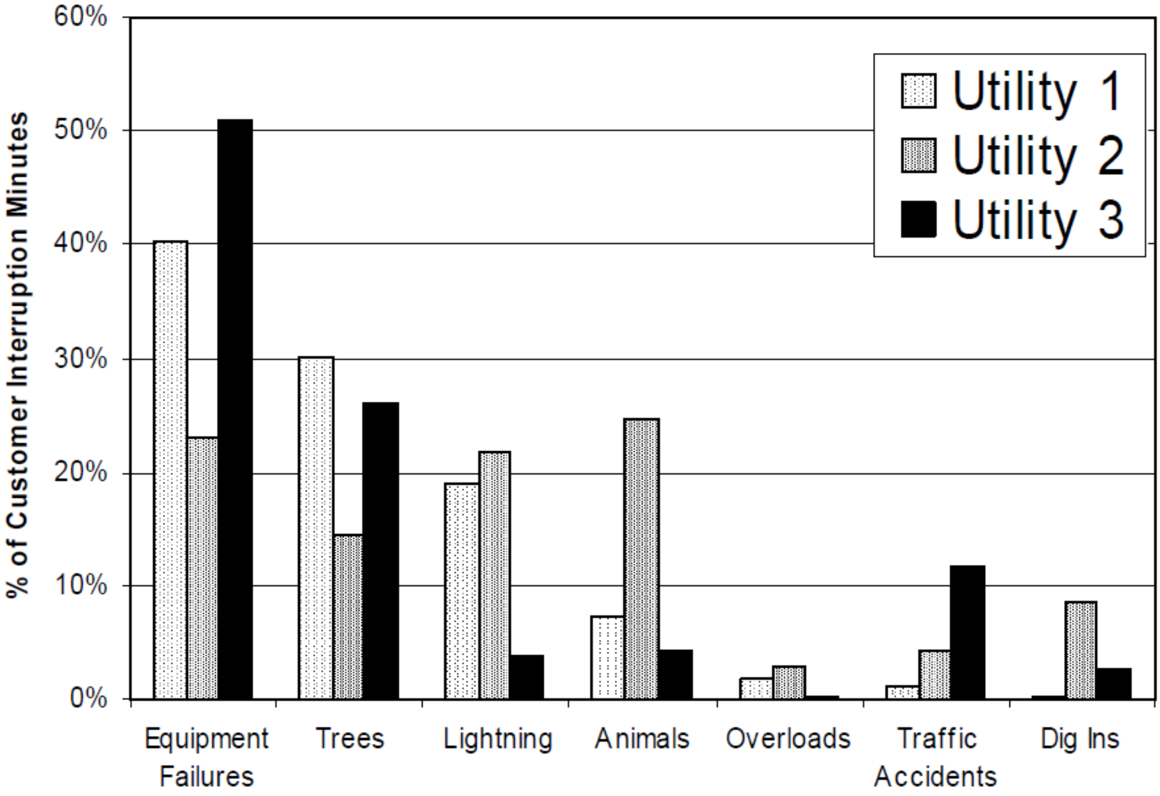


Figure 4: Major causes of power outages for three US utilities (Brown, 2009)

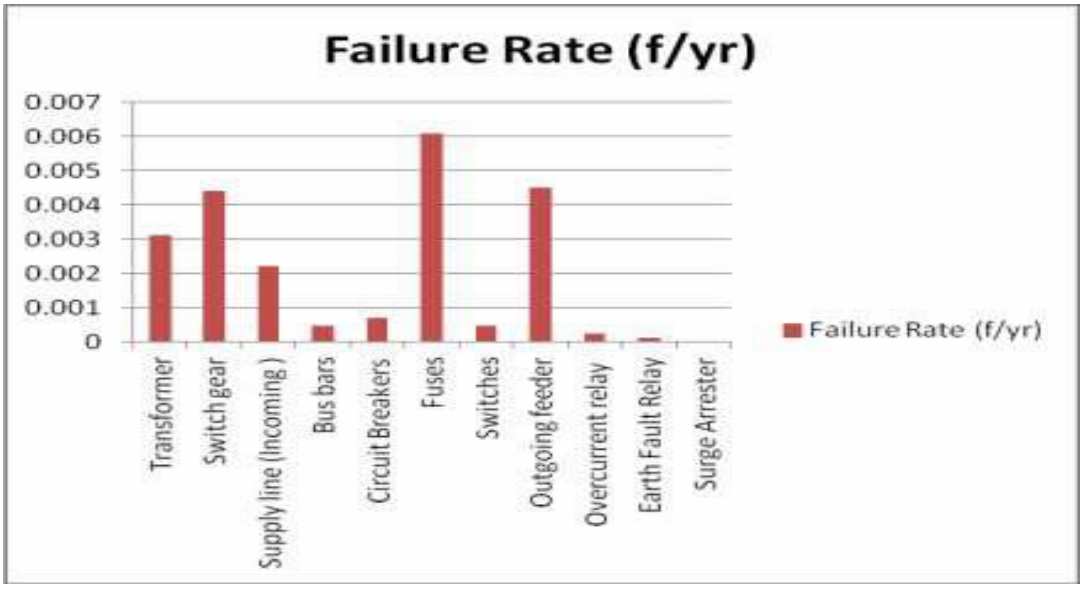


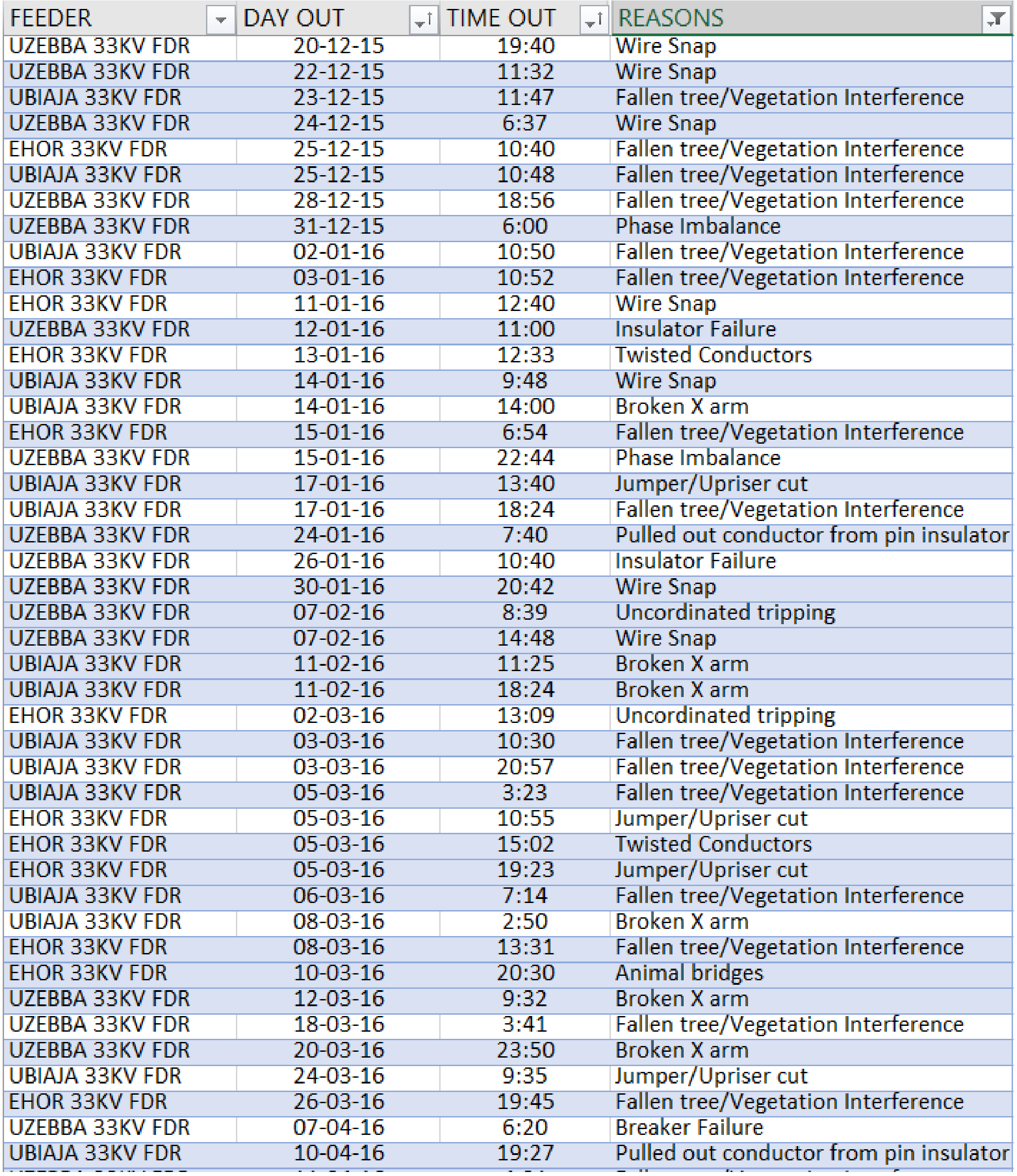
Figure 5: Bar chart showing the failure rate of each component (Akintola and Awosope, 2017)

2.0. Materials and Method

The data for this study were obtained from the outage records of some 33kV feeders in Irrua Transmission Station, Transmission Company of Nigeria (TCN). This comprises Ehor, Ubiaja and Uzebba feeders and the event duration was from 2015 to 2018. Special focus was placed on those forced outages which are caused by component failures hence outages caused by load management and maintenance purposes where not considered The components investigated includes Aluminum conductors, cross arms, relays, insulators, fuses, poles, breakers, transformers, isolators, cables and lightning arresters.

The raw data as presented in Table 1 was processed using Microsoft Excel application to obtain and present the counts of events in tabular form. Summarized annual outage events as a result of failure of components in the network are presented in Table 2.

Table 1: Sample of the interruption data of Ehor, Ubiaja and Uzebba 33kV Feeders.



FEEDER	DAY OUT	TIME OUT	REASONS
UZEBBA 33KV FDR	20-12-15	19:40	Wire Snap
UZEBBA 33KV FDR	22-12-15	11:32	Wire Snap
UBIAJA 33KV FDR	23-12-15	11:47	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	24-12-15	6:37	Wire Snap
EHOR 33KV FDR	25-12-15	10:40	Fallen tree/Vegetation Interference
UBIAJA 33KV FDR	25-12-15	10:48	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	28-12-15	18:56	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	31-12-15	6:00	Phase Imbalance
UBIAJA 33KV FDR	02-01-16	10:50	Fallen tree/Vegetation Interference
EHOR 33KV FDR	03-01-16	10:52	Fallen tree/Vegetation Interference
EHOR 33KV FDR	11-01-16	12:40	Wire Snap
UZEBBA 33KV FDR	12-01-16	11:00	Insulator Failure
EHOR 33KV FDR	13-01-16	12:33	Twisted Conductors
UBIAJA 33KV FDR	14-01-16	9:48	Wire Snap
UBIAJA 33KV FDR	14-01-16	14:00	Broken X arm
EHOR 33KV FDR	15-01-16	6:54	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	15-01-16	22:44	Phase Imbalance
UBIAJA 33KV FDR	17-01-16	13:40	Jumper/Upriser cut
UBIAJA 33KV FDR	17-01-16	18:24	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	24-01-16	7:40	Pulled out conductor from pin insulator
UZEBBA 33KV FDR	26-01-16	10:40	Insulator Failure
UZEBBA 33KV FDR	30-01-16	20:42	Wire Snap
UZEBBA 33KV FDR	07-02-16	8:39	Uncordinated tripping
UZEBBA 33KV FDR	07-02-16	14:48	Wire Snap
UBIAJA 33KV FDR	11-02-16	11:25	Broken X arm
UBIAJA 33KV FDR	11-02-16	18:24	Broken X arm
EHOR 33KV FDR	02-03-16	13:09	Uncordinated tripping
UBIAJA 33KV FDR	03-03-16	10:30	Fallen tree/Vegetation Interference
UBIAJA 33KV FDR	03-03-16	20:57	Fallen tree/Vegetation Interference
UBIAJA 33KV FDR	05-03-16	3:23	Fallen tree/Vegetation Interference
EHOR 33KV FDR	05-03-16	10:55	Jumper/Upriser cut
EHOR 33KV FDR	05-03-16	15:02	Twisted Conductors
EHOR 33KV FDR	05-03-16	19:23	Jumper/Upriser cut
UBIAJA 33KV FDR	06-03-16	7:14	Fallen tree/Vegetation Interference
UBIAJA 33KV FDR	08-03-16	2:50	Broken X arm
EHOR 33KV FDR	08-03-16	13:31	Fallen tree/Vegetation Interference
EHOR 33KV FDR	10-03-16	20:30	Animal bridges
UZEBBA 33KV FDR	12-03-16	9:32	Broken X arm
UZEBBA 33KV FDR	18-03-16	3:41	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	20-03-16	23:50	Broken X arm
UBIAJA 33KV FDR	24-03-16	9:35	Jumper/Upriser cut
EHOR 33KV FDR	26-03-16	19:45	Fallen tree/Vegetation Interference
UZEBBA 33KV FDR	07-04-16	6:20	Breaker Failure
UBIAJA 33KV FDR	10-04-16	19:27	Pulled out conductor from pin insulator

Table 2: Summary of component failure incidences

Feeders	2015	2016	2017	2018
Ehor	289	348	361	482
Ubiaja	259	307	293	336
Uzebba	131	250	242	268

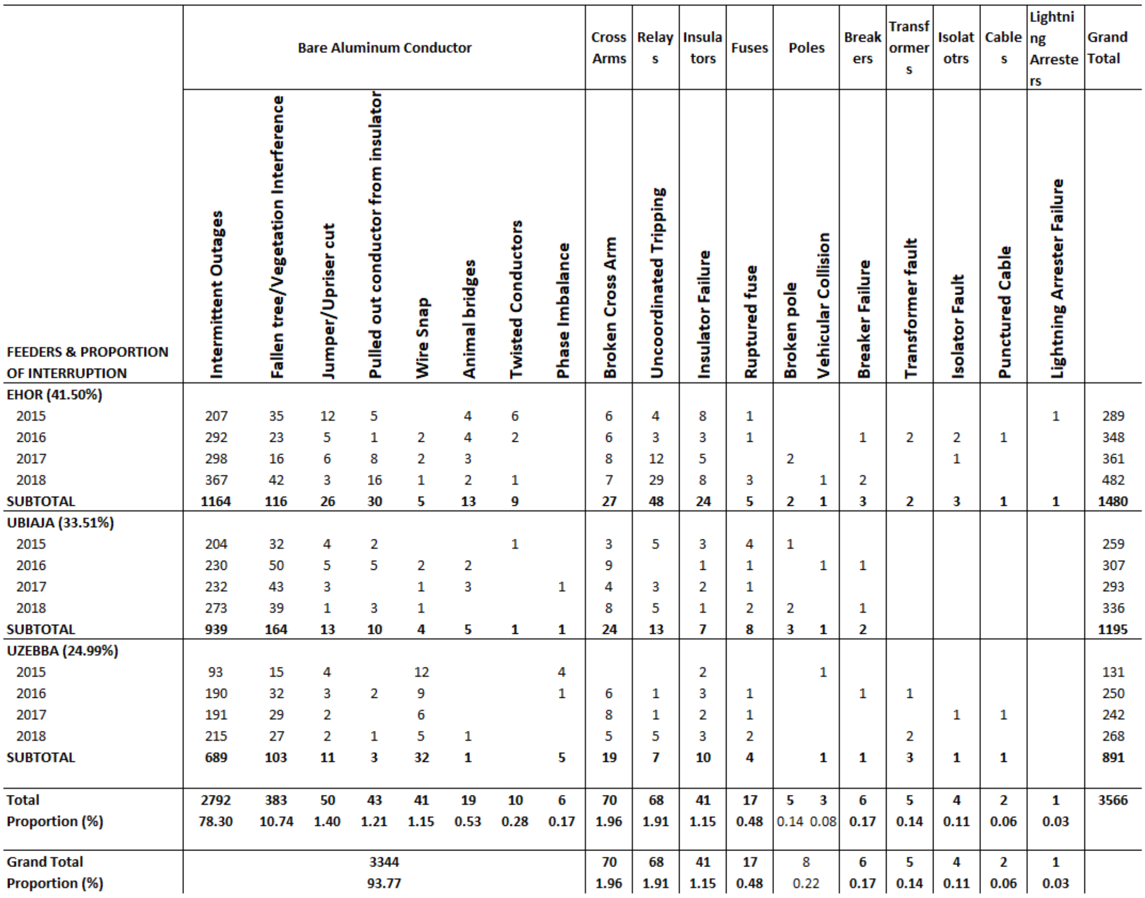
Table 3 represents the distribution system components and the identified causes of their failures/breakdowns.

Table 3: Components and their major causes of failure in the system (Source: TCN)

Serial Number	Components	Causes of failure
1	Bare Aluminum Conductor	Overgrown vegetation, Jumper/Upriser cut, detached conductor from support, wire snap, animal activities, twisted conductors.
2	cross Arms	Broken cross arms.
3	Relays	Poor calibration, poor selectivity, poor sensitivity.
4	Insulators	Insulation failure
5	Fuses	Ruptured fuses
6	Poles	Broken poles and vehicular collision.
7	Breakers	Breaker failure
8	Transformers	Transformer faults
9	Isolators	Faulty isolators
10	Cables	Punctured cables
11	Lightning Arresters	Arrester failure

Based on detailed analysis of the raw data, Table 4 shows the major components and equipment used in the power systems for the distribution of electric power and their level of susceptibility to failures. The grand total is the summation of total failure counts of each contributory cause of interruption to the equipment failures. For instance, according to Table 3, electric poles are susceptible to fault conditions such as broken pole and vehicular collision hence the grand total of outages comprises the count of failures from both scenarios.

Table 4: The frequencies, proportions and causes of components' failure induced outages



	Bare Aluminum Conductor								Cross Arms	Relays	Insulators	Fuses	Poles		Breakers	Transformers	Isolatotrs	Cables	Lightning Arresters	Grand Total
FEEDERS & PROPORTION OF INTERRUPTION	Intermittent Outages	Fallen tree/Vegetation Interference	Jumper/Upriser cut	Pulled out conductor from insulator	Wire Snap	Animal bridges	Twisted Conductors	Phase Imbalance	Broken Cross Arm	Uncoordinated Tripping	Insulator Failure	Ruptured fuse	Broken pole	Vehicular Collision	Breaker Failure	Transformer fault	Isolator Fault	Punctured Cable	Lightning Arrester Failure	
EHOR (41.50%)																				
2015	207	35	12	5		4	6		6	4	8	1							1	289
2016	292	23	5	1	2	4	2		6	3	3	1			1	2	2	1		348
2017	298	16	6	8	2	3			8	12	5		2				1			361
2018	367	42	3	16	1	2	1		7	29	8	3		1	2					482
SUBTOTAL	**1164**	**116**	**26**	**30**	**5**	**13**	**9**		**27**	**48**	**24**	**5**	**2**	**1**	**3**	**2**	**3**	**1**	**1**	**1480**
UBIAJA (33.51%)																				
2015	204	32	4	2			1		3	5	3	4	1							259
2016	230	50	5	5	2	2			9		1	1		1	1					307
2017	232	43	3		1	3		1	4	3	2	1								293
2018	273	39	1	3	1				8	5	1	2	2		1					336
SUBTOTAL	**939**	**164**	**13**	**10**	**4**	**5**	**1**	**1**	**24**	**13**	**7**	**8**	**3**	**1**	**2**					**1195**
UZEBBA (24.99%)																				
2015	93	15	4		12			4			2			1						131
2016	190	32	3	2	9			1	6	1	3	1			1	1				250
2017	191	29	2		6				8	1	2	1					1	1		242
2018	215	27	2	1	5	1			5	5	3	2				2				268
SUBTOTAL	**689**	**103**	**11**	**3**	**32**	**1**		**5**	**19**	**7**	**10**	**4**		**1**	**1**	**3**	**1**	**1**		**891**
Total	**2792**	**383**	**50**	**43**	**41**	**19**	**10**	**6**	**70**	**68**	**41**	**17**	**5**	**3**	**6**	**5**	**4**	**2**	**1**	**3566**
Proportion (%)	**78.30**	**10.74**	**1.40**	**1.21**	**1.15**	**0.53**	**0.28**	**0.17**	**1.96**	**1.91**	**1.15**	**0.48**	0.14	0.08	**0.17**	**0.14**	**0.11**	**0.06**	**0.03**	
Grand Total	**3344**								**70**	**68**	**41**	**17**	8		**6**	**5**	**4**	**2**	**1**	
Proportion (%)	**93.77**								**1.96**	**1.91**	**1.15**	**0.48**	0.22		**0.17**	**0.14**	**0.11**	**0.06**	**0.03**	

The proportion (%) of the grand total of the identified causes to the entire failure events (which is a measure of their level of relative susceptibility) is also presented. These proportions were determined using Equation 1 (Peter *et al*., 2011).

$$C_P = \frac{\sum C_O}{\sum O} x100 \quad (1)$$

C_p Percentage proportion of each component contribution to total outages (Vulnerability)
$\sum C_o$ Sum of outages cause as a result of failure of each component
$\sum O$ Sum of all outages caused by failure of components (3566)

The failure rates (λ) of each of the components were determined using Equation 2.

$$\boldsymbol{\lambda} = \frac{\sum F}{\sum D} \quad (2)$$

λ Failure Rate
$\sum F$ Sum of failure of each component
$\sum D$ Total duration of study

In order to obtain the proportion (%) of the failures recorded in the system as a result of the any component like aluminum conductor, the following steps were taken;

i. The total counts of failure events that have anything to do with aluminum conductors were identified. These information which can be found in Table 4 include;
    a. Intermittent outages (2792 cases)
    b. Fallen trees/vegetational encroachment (383 cases)
    c. Jumper/upriser cut (50 cases)
    d. Pulled out conductors from insulators (43 cases)
    e. Wire snap (41 cases)
    f. Animal bridges (19 cases)
    g. Twisted conductors (10 cases)
    h. Phase imbalance (6 cases)

ii. These numbers of cases were then substituted into equation 1 as follows

$$C_p = \left(\frac{2792 + 383 + 50 + 43 + 41 + 19 + 10 + 6}{3566}\right) * 100$$
$$= \frac{3344}{3566} * 100$$
$$= 93.77$$

These steps were replicated for the other component and the results are presented in Table 5.

3.0. Results and Discussion

Table 5 shows that there were 3566 outages as a result of equipment and components failures, the failure distribution are: the bare aluminum conductors accounted for 93.77% of the failures, cross arms (1.96%) as a result of manufacture defects or old age, relays (1.91%) due to improper relay coordination of the 11kV protection zones which do result to trippings of the 33kV protection schemes by faults that occurred on the 11kV networks, insulators (1.15%) due to manufacture defects or old age, fuses (0.48%) in response to a fault condition or overloading condition in the system, poles (0.22%) due to old age or accidental vehicular collision. Also, outages could occur due to faults on the breakers (0.17%), transformers (0.14%), isolators (0.11%), cables (0.06%) and lightning arresters (0.03%). Figure 6 gives a graphical depiction of these realities.

Table 5: Vulnerability report of component in the distribution power system

Components	Total Failures	Proportion of contribution to total forced outages in the system (%)
Bare Aluminum Conductor	3344	93.77
Cross Arms	70	1.96
Relays	68	1.91
Insulators	41	1.15
Fuses	17	0.48
Pole	8	0.22
Breakers	6	0.17
Transformers	5	0.14
Isolators	4	0.11
Cables	2	0.06
Lightning Surge Arresters	1	0.03
Total	3566	100

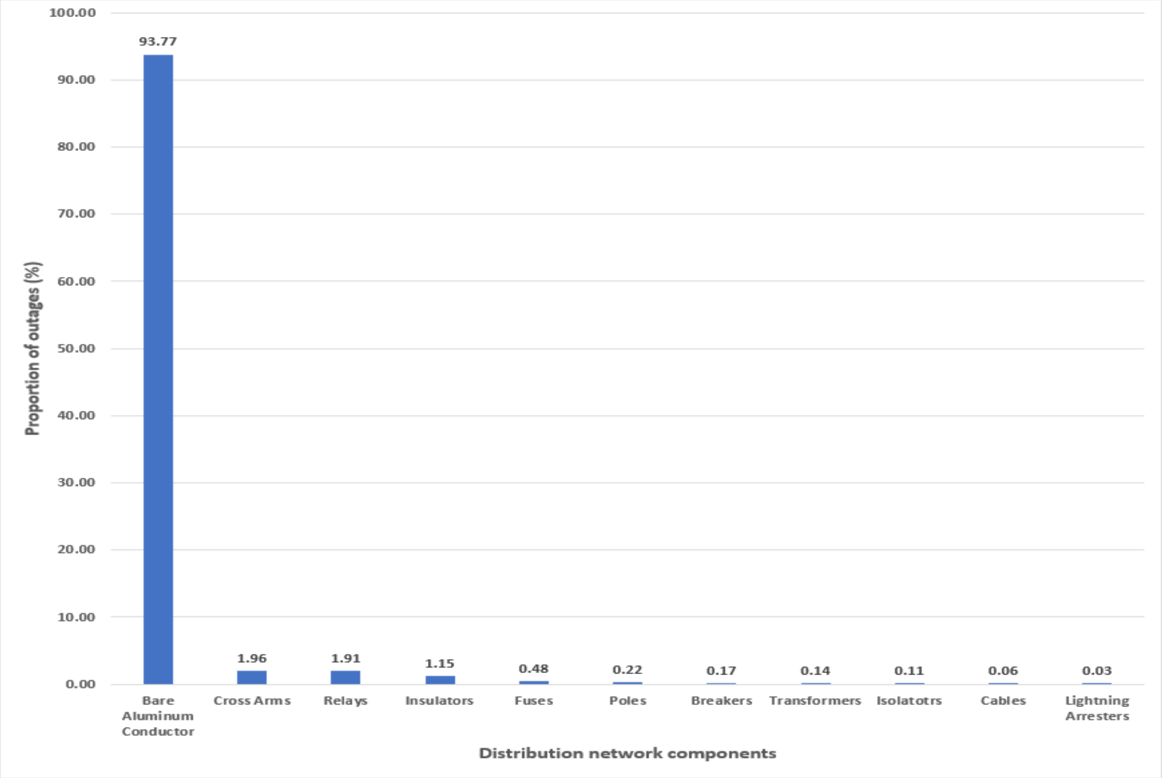


Figure 6: Contribution of major components to the forced outage incidences

The most visible reason for line fault is fallen trees that rest on the network and this account for 10.74% of all the faults as presented in Table 4. This result agrees with the earlier findings of Short (2004) and Okorie and Abdul (2015) which stated that vegetation issues are the major causes of faults on the distribution network resulting in overcurrent earth fault.

Components like insulators, cross arms and poles are very important supports for the conductors have been found to be prone to failures at varying degrees resulting to power outages to the customers. This agrees with the findings of Adegboye and Dawal (2012). Sometimes, weak and obsolete cross arms can also cause power outages when they break and make the live conductors to be earthed.

Considering the grand total of 3,344 outage events connected to aluminum conductor out of 3,566 events in Table 5, it is evident that 93.77% of the faults in the power sector in Nigeria are connected to the susceptible nature of the aluminum conductors that are used for the distribution of power to the

various load points. This high level of bare aluminum related faults is due to many factors such as the high vegetation density of the environments where these feeders transverse.
Overloading increases the thermal characteristics of the conductors which leads to snapping of the lines (including jumpers and uprisers), while other incidents that affect the bare aluminum conductors include detachment from supports, animals bridging the lines (Brown, 2009), phase imbalance due to disconnected phase and twisted conductors' issues.

From Table 5, transformer failure is very minimal in the network (about 0.14%). This is due to the high level of protection given to it by the fuses, relays, breakers and lightning arresters in the design stage. However, it is found to fail more than the circuit breakers.

Equation 2 was used to determine the failure rate of each of the component on hourly, daily, monthly and yearly basis as presented in Table 6. The table shows that the aluminum conductors had issues 3,344 times during the period of study (2015 - 2018) within the studied distribution system. Consequently, this resulted to a failure rate of 0.09537 per hour, 2.2888 per day, 69.667 per month and 836 per year for the component.

Table 6: Failure rate of each component

Components	Total Failures	Failure Rate			
		Hourly	Daily	Monthly	Yearly
Bare Aluminum Conductor	3344	0.09537	2.2888	69.667	836.0
Cross Arms	70	0.00200	0.0479	1.458	17.5
Relays	68	0.00194	0.0465	1.417	17.0
Insulators	41	0.00117	0.0281	0.854	10.3
Fuses	17	0.00048	0.0116	0.354	4.3
Pole	8	0.00023	0.0055	0.167	2.0
Breakers	6	0.00017	0.0041	0.125	1.5
Transformers	5	0.00014	0.0034	0.104	1.3
Isolators	4	0.00011	0.0027	0.083	1.0
Cables	2	0.00006	0.0014	0.042	0.5
Lightning Surge Arresters	1	0.00003	0.0007	0.021	0.3

Furthermore, the yearly failure rate of cross arms, relay, insulators, fuses, electric poles, breakers, transformers, isolators, cables lightning surge arresters are 17.5, 17.0, 10.3, 4.3, 2.0, 1.5, 1.3, 1.0, 0.5 and 0.3 respectively. These values are other ways of conveying the information on Table 5 and Figure 6 with regards to the measurement of each component hazard/failure/susceptibility rates relatively to one another with regards to proportion, causes and effects which have been discussed.

Table 7 represents a comparison of findings from this study and a similar one conducted by Akintola and Awosope (2017). To make up for the observed nomenclature variances amongst the network components in the two studies, some of the names were reconciled as follows: switches were taken as isolator, overcurrent and earth relays were presented as relays, incoming and outgoing feeders were named as aluminum conductors. Both studies showed that the line conductors are responsible for most of the forced outages. Also, both studies showed that the least failure prone component in the distribution system is the lightning arresters. The proportion of feeder conductor was 30.12% in Akintola and Awosope (2017) as against 93.77% found in this study. It was observed that the proportions (%) of failures reported in both studies (This Work : Akintola and Awosope, 2017) for relays (1.91 : 1.56), fuses (0.48 : 27.41), circuit breakers (0.17 : 3.07), transformers (0.14 : 13.93) and isolators (0.11 : 2.06) varied. This is likely due to the fact that both studies were conducted in different power systems, environments, duration and time. The difference in urbanization level in both studied areas is another key factor in the observed disparity in the obtained results. The network used in this study are mainly in rural location with a lot of vegetation on its corridor as against the other study which was done in Ayetoro I Substation located in the heart of Lagos state. It is therefore established from this study that networks in the rural areas are more susceptible to forced outages than those in the urban areas. Some of the components were not studied in each work hence no values were found for them and these are presented as NA (Not Available).

Table 7: Comparison between the findings from related work and this study

S/N	Components	Percentage relative failure proportion (%)	
		This work	Akintola and Awosope (2017)
1	Bare Aluminum Conductor	93.77	30.12
2	Cross Arms	1.96	NA
3	Relays	1.91	1.56
4	Insulators	1.15	NA
5	Fuses	0.48	27.41
6	Poles	0.22	NA
7	Circuit Breakers	0.17	3.07
8	Transformers	0.14	13.93
9	Isolators	0.11	2.06
10	Cables	0.06	NA
11	Lightning Surge Arresters	0.03	0.00
12	Switch gear	NA	19.77
13	Bus bars	NA	2.08

4.0. Conclusion

In this article, the failure of components in a typical distribution system in Nigeria was analyzed to measure the proportions of vulnerability of each component to failure. Such information is useful in identifying the key components responsible for forced outages thereby assisting the utility providers to apply the appropriate maintenance methods.

The results showed that almost all the forced outages (93.7%) in the distribution network occur as a result of temporary and permanent current leakage to earth from the aluminum conductors (feeders). The rest proportion of outages are as a result of the failure of other components such as cross arms (1.96%), relays (1.91%), insulators (1.15%), fuses (0.48%), poles (0.22%), breakers (0.17%), transformers (0.14%), isolators (0.11%), cables (0.06%) and lightning arresters (0.03%). The failure rate of each of these components was also determined on hourly, daily, monthly and yearly basis to give insight to their hazard rates. Based on the findings, it is therefore recommended that proper trace clearing should be regularly carried out on the distribution networks to avoid the intermittent tripping of the lines. There should be legislation for the enactment of laws prohibiting the use of wooden cross arms and wooden poles in future power network construction in Nigeria. This will help to reduce failures of these components to the barest minimum in the network. The use of protective equipment should be sustained and improved upon to eliminate the failure of vital and expensive network component such as transformers. The appropriate wire gauge should be selected for the conductor sizes used for network construction to avoid wire snap due to overloading of conductors. Proper component inventory should be kept so as to help identify the obsolete component to effect replacement before they finally fail. Any policy or technique (such as condition monitoring (CM), predictive and reliability centered maintenance (RCM) techniques) that could reduce component failures in the network will go a long way to enhance the reliability, cut maintenance cost and reduce probable hazards in the system.

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Cite this article as:

Omoroghomwan A. E., Igbinovia S. O. and Odiase F. O., 2021. Vulnerability Assessment of Components in a Typical Rural Nigerian Power Distribution System. *Nigerian Journal of Environmental Sciences and Technology*, 5(1), pp. 32-46. https://doi.org/10.36263/nijest.2021.01.0237