



Risk Assessment of Injection Substation within Kaduna Metropolis using FMECA

¹Airoboman, A. E., ²Salihu-Ango H., ³Ibrahim, S. O., ⁴Ahmed, H.

¹Department of Electrical/Electronic Engineering,
Nigerian Defence Academy Kaduna, Nigeria.

²Power Equipment and Electrical Machinery Development Institute,
National Agency for Science and Engineering Infrastructure, Nigeria.

³Transmission Company of Nigeria, Kaduna, Nigeria

⁴Department of Electrical/Electronic Engineering,
Kaduna Polytechnic, Nigeria

ABSTRACT

In recent times, poor systems reliability has characterized the power systems network in Kaduna, Nigeria. One of the causes of this drawback may be tied to the lack of effective maintenance practices and policies. Although there exists a maintenance department and a routine for carrying out various maintenance practices, however, the failure rate as a result of poor maintenance of the network is on the increase. In this study, therefore, risk assessment was carried out on Airport Feeder AF and Kikinau Feeder KF radiating from Kaduna metropolis using the Failure Mode Effect and Criticality Analysis FMECA. The results show that the critical components in the network requires attention. The results of this study, therefore, can be useful for system planning and operations.

ARTICLE INFO

Article History

Received: December, 2020

Received in revised form: January, 2021

Accepted: March, 2021

Published online: June, 2021

KEYWORDS

Feeder, FMECA, Kaduna, Maintenance.

INTRODUCTION

The main objective of a general power utility maintenance philosophy is to minimize the occurrence of failure and to ensure that the right staff can be sent to the right position with the right equipment at the right time to perform the right actions in the event of failure. Nevertheless, maintenance engineering will contribute to improving maintenance operations, reducing the volume and duration of maintenance, reducing the impact of complexity, deciding the scope of preventive maintenance to be performed, improving and making full usage of maintenance facilities, and improving the maintenance organization (Dhillon, 2002). One of the key causes of engineering system interruptions was described as inadequate maintenance (Sule, 2010; Airoboman et al., 2016). "Another weakness in the human character is that everyone wants to create and no one wants to do maintenance, according to (Kurt Vonnegut, Jr.)." Therefore, to reduce running costs and boost efficiency, more attention should be paid to maintaining an existing system rather than constructing a new one (Ahmed, 2019).

The Kaduna State (KS) injection substations are located in different locations, based on regional development; demand for supply, resources available and also the reduction in overloads of existing stations. Two (2) separated transmission stations with eleven (11) in the north, eight (8) in the southern part, and dedication stations comprise the remaining seven (7) are situated inside a total of twenty-six (26) injection substations. However, the location of these injection substations cannot be optimized and a significant percentage of losses can be generated (Wang et al, 2014). This study is therefore in the process of looking at the maintenance strategy currently adopted in two out of the twenty-six injection substations. The Airport Feeder is the station considered for this study (AF). The reason for choosing AF is because it feeds Nigeria's heart of the defense, i.e., the Nigerian Defence Academy (NDA), Kaduna International Airport (KIA) and the National Eye Centre (NES). These are vital assets of the Federal Government of Nigeria (FGN) that require a continuous supply of reliable power to ensure the maximum functioning of

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved

their service to the nation as a whole. The maintenance philosophy currently adopted by the system operators for the AF would therefore be reviewed and analyzed in this study to identify and determine grey areas in the maintenance strategy. A real-time MIS would then be developed that would remotely send information about the system to the mobile number of the operator of the system and otherwise. The benefit of this method is that it provides all operators with around-the-clock

evaluation of the station, in addition to prompt response in terms of clearing failures along with the network. The single line diagram indicating the network of interest is presented in Figure 1. It is observed from the figure that the AF draws its supply from the Mando Transmission Station (MTS). In this study, therefore, risk analysis would be carried out on AF and KF to determine the components/failure mode that contributes the largest amount of downtime within the network.

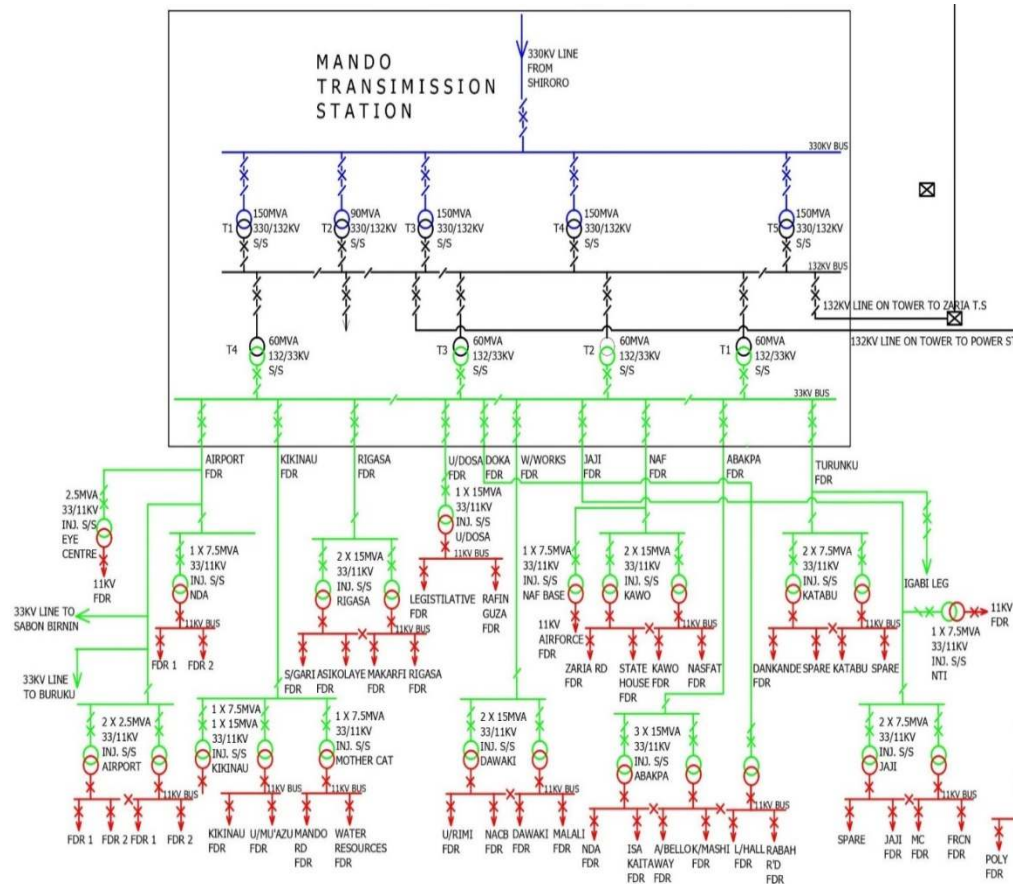


Figure 1: Single Line Diagram of Mando Transmission Station Showing Airport Feeder and Nine others

LITERATURE REVIEW

The ability of a system, upon removal of failed components or items, to return to its normal working condition is referred to as system maintenance. The ineffective maintenance strategy and philosophy were one of the causes of poor system network reliability (Lundgren, et al., 2018).

The rational human manager is more concerned with building new systems instead of preserving existing ones, according to Kurt-Vonnegut, Jr. Link this statement to the Nigerian network of power systems where importance on the generation of power is considered, while minimal effort has been made to maintain the current network and systems properly.

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved

Ironically, a considerable improvement in the overall reliability of the network can be achieved with the presence of an effective maintenance technique and strategy. Poor system network reliability due to poor maintenance continues to persist, according to (Ewulum, 2008), even with the presence of a maintenance department within the utility. Therefore, a successful maintenance scheme is mindful of the system's fiscal, technological and physical importance (Schutz et al., 2006). Before maintenance action is carried out, a system should not be allowed to malfunction because the former raises the maintenance expense (Airoboman et al., 2019). Therefore, the secret to successful operations of the network of systems is to include an efficient maintenance plan to improve service delivery.

Maintenance can be generally categorized into four philosophies: Corrective Maintenance, Preventive Maintenance (PM), Predictive Maintenance (PdM), and Reliability Centered Maintenance (RCM) Over fifteen years ago, vast numbers have increased and various assets of physical science in the field of maintenance have activated (Dimitris et al., 2007). Reliability is the possibility that an object can perform a required function without failure for a period under specified conditions, while RCM is a technique that determines any reliable physical equipment operations and provides a preventive maintenance plan by evaluating functional failures (Chulho et al., 2009). RCM contributes to a maintenance program that focuses on a particular failure mode likely to occur with preventive maintenance (PM). If its breakdowns account for more than 20–25 per cent of the overall maintenance workload, any organization may benefit from RCM. RCM offers comprehensive access to achieve a balance between preventive and corrective maintenance (Yssaad et al., 2014). The inefficiency and enormous maintenance costs in minimizing system outages made it possible to implement a systematic and more reliable maintenance strategy, a strategy focused on the need to understand interrelationships and track the reliability of the network between maintenance costs and reliability. Such criteria progressively led to the tendency of maintenance strategies towards reliability-centred strategies and away from time-based strategies (Mansour et al., 2015).

In reality, recommended maintenance cycles are often difficult to implement (even if we can

decide optimal intervals in RCM). It would be inevitable to give priority to failures of critical infrastructure, postpone long-planned operations, and build a backlog. This backlog will add up to the maintenance section and create a difficult situation and ruin the entire RCM program as well (Marvin, 1998). Therefore, maintenance workers are advised to provide a thorough study of the behavioural pattern of their system network to know the best time to change and refurbish a failed part of the system; if it is recognized either before or after a failure (Airoboman et al., 2017). The four main objectives are to achieve efficient maintenance of any electrical equipment(s) or device(s); to ensure the safety of staff who come into contact or use the machinery; to increase the service life of the machinery; to gain full returns on investment by ensuring that there is no unplanned disruption during manufacturing, and to ensure availability and readiness. Therefore, maintenance should be an ongoing proactive process by responding instantaneously once a failure is detected (Rukijkanpanich, 2019). A maintenance phase involving a planning stage, followed by implementation, is presented in Figure 2 to see the result that is then evaluated for improvement purposes.

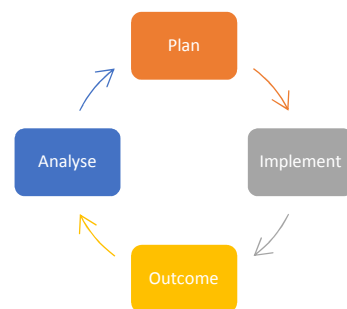


Figure 2. Simple Maintenance Process

Because failure(s) that are supposed to be cleared by maintenance intervention remain inherent in the network, the maintenance philosophy applied to the power system network in recent times has been controversial. In the contextual operations of the network, this avoidable action(s) has triggered too many demerits, such as downtime, loss of load, financial loss, technological loss, etc. Therefore, reliability improvement and risk detection should be adopted to assess how stable a system network is, how significant the future of the system will be, and

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



then utilize the obtained findings to determine the finest system maintenance strategy. Therefore, the maintenance strategy currently followed in the AF and the Nigerian Power Sector NPS as a whole could be either planned or unplanned, not exploring other optimal maintenance strategies that could have helped the system work effectively. Research by (Obamwonyi, 2009) found that inadequate management and capability growth of maintenance workers often leads to the ineffectiveness of utility maintenance activities. A disruption monitoring framework was proposed as a method for predictive maintenance management and operation to enhance maintenance performance and reduce maintenance costs (El-Hadidy and Helmi, 2009), but not all other forms of maintenance strategy other than predictive maintenance were included in the paper. Furthermore, the Taguchi method was used to analyze engineering systems (Emovon and Norman, 2019). The paper argues that the new approach is OK computationally in comparison to other procedures. However, the timing of a swift response before a failure should be removed from the network did not provide any justification. The paper offered a multi-objective model to resolve the mathematical problem of optimization, the reliability centralized maintenance planning of an electric power distribution system (EPDS) by (Diego et al. 2016), the main objectives of the method is to reduce preventive maintenance and to improve the whole system reliability index. Approach to the reliability evaluation of the power system fault tree analysis (Mohammad et al., 2011) uses the Boolean Algebra as the starting point for this modeling of engineering reliability evaluation to identify all possible means, starting from the top event called an undesired potential event (accident).

This analysis is used primarily to quantify the likelihood of the safety hazard in engineering safety. Not only does the proposed MPI consider the physical conditions of overhead lines, but it also shows the significance of system reliability to achieve cost-effectiveness. The model (Igweonu & Joshua 2011) produced by Igweonu & Joshua is a five-step algorithm that encompasses planning, organization, operation, and management of the network system. 80% of the prototype functionality was allocated from the presentation to preventive maintenance, and the remaining 20% allocated to corrective maintenance. But the design does not

include other maintenance indices, such as predictive, reactive and Proactive maintenance, which may make it difficult to ensure the process's effectiveness. The more complex a system becomes, the stronger the maintenance strategy is required since maintenance is a continuous process (Moubray, 2007). Apparent maintenance process or philosophy other than equipment, personnel, and systems safety, etc. also takes into consideration environmental safety in its design process. It is therefore necessary for all arms of Nigero's NPS power sector to design an effective maintenance scheme to increase reliability (Ismaila, 2000). It is therefore apparent from the review carried out in this study that literature has to deal with the timing at which an operator is provided with information about a failure system due to the analog methods currently available in Nigeria in particular. The longer a failure is required, the more downtimes and the more losses the economy is imposed. This study, therefore, tends to develop a real-time MIMS that will ensure prompt response by maintenance operators to addressing a failed item, component, system in a network.

METHODOLOGY

To determine the rate of failure, Mean Time Between Failure (MTBF) and Mean Time To Failure (MTTF) in the network, equations (1) - (3) were used. This is to show if the failure rate in particular for each feeder is decreasing or increasing or constant. In determining the Feeders' risk, the FMECA approach with emphasis on the feeders' function, functional failure, failure mode, failure effect, and failure consequence of salient components in the feeders of interest was defined under Table 12. Thereafter, the components are arranged concerning their rate of occurrence of faults, duration of faults, and ability to detect fault within a given interval as presented in Tables 1-6. Finally, the ranking of these events is done. The ranking is such that, the faults with the lowest rate of occurrence are given the lowest ranking (1) and vice versa. Similarly, Faults with a longer duration before the closure of a feeder are given the highest ranking (10) and vice versa. Finally, faults with difficulty to detect are equally ranked high (10) while those with easier detectability were ranked (1). Using equations (4) & (5), therefore, the RPN of the individual failure types was gotten. The value of the RPN gotten in each case signifies the level of risk or criticality of that

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



feeder. These values were eventually normalized using (7)

$$\text{Failure Rate, } \lambda = \frac{\sum F_{oi}}{\sum_{i=1}^N T_{OHi} - T_{DTi}} \quad (1)$$

$$\text{MTBF} = \frac{\sum_{i=1}^N T_{DTi}}{F_{oi}} + \frac{\sum_{i=1}^N T_{UTi}}{F_{oi}} \quad (2)$$

$$\text{MTTF} = \frac{\sum_{i=1}^N T_{UTi}}{F_{oi}} \quad (3)$$

$$\text{RPN}_{AF} = \begin{pmatrix} O_{AF1} \\ O_{AF2} \\ \vdots \\ O_{AFn} \end{pmatrix} \times \begin{pmatrix} S_{AF1} \\ S_{AF2} \\ \vdots \\ S_{AFn} \end{pmatrix} \times \begin{pmatrix} D_{AF1} \\ D_{AF2} \\ \vdots \\ D_{AFn} \end{pmatrix} \quad (4)$$

$$\text{RPN}_{KF} = \begin{pmatrix} O_{KF1} \\ O_{KF2} \\ \vdots \\ O_{KF_n} \end{pmatrix} \times \begin{pmatrix} S_{KF1} \\ S_{KF2} \\ \vdots \\ S_{KF_n} \end{pmatrix} \times \begin{pmatrix} D_{KF1} \\ D_{KF2} \\ \vdots \\ D_{KF_n} \end{pmatrix} \quad (5)$$

$$\text{Cumulative Frequency} = \frac{F}{\sum O_f} \times 100 \quad (6)$$

$$F = F_o + F_i$$

where F is the frequency, O_i is the outage of feeder, F_o = initial frequency, and F_i is the final frequency

$$N = \frac{C_i}{C_M} \quad (7)$$

N is the normalized RPN determinant/dependent value

C_i is the actual value in an array of RPN-dependent numbers.

C_M is the maximum value in an array of RPN dependent

TABLE 1: Faults Occurrence for Airport Feeder

FAILURE ELEMENT	RATE OF OCCURRENCE	RANKING
Line	ONCE IN A WEEK	10
Disk / pot insulator	ONCE IN 2 WEEKS	9
	ONCE IN A MONTH	8
Fuse	ONCE IN 3 MONTHS	7
Circuit breaker	ONCE IN 6 MONTHS	6
Cable	ONCE IN 9 MONTHS	5
Transformer	ONCE IN A YEAR	4
Isolator	ONCE IN 2 YEARS	3
Busbar	ONCE IN 3 YEARS	2
Arresters	ONCE IN 4 YEARS	1

TABLE 2: Faults Detectability for Airport Feeder

FAILURE ELEMENT	ABILITY TO DETECT FAILURE	RANKING
	IMPOSSIBLE	10
Cable	VERY DIFFICULT	9
Arrester	VERY LATE	8
Busbar	NOT SURE	7
Transformer	OCCASSIONAL	6
Disk / pot insulator	LOW	5
Line	LATE	4
Isolator	EASY	3
Breaker	IMMEDIATE	2
Fuse	ALWAYS	1

TABLE 3: Faults Severity for Airport Feeder

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



FAILURE ELEMENT	DURATION	RANKING
Cable	FAILURE GREATER THAN 8HRS	10
Arresters	FAILURE GREATER THAN 7HRS	9
Busbar	FAILURE GREATER THAN 6HRS	8
	FAILURE GREATER THAN 5HRS	7
Circuit Breaker	FAILURE GREATER THAN 4HRS	6
Line	FAILURE GREATER THAN 3HRS	5
Transformer	FAILURE GREATER THAN 2HRS	4
Disk / pot insulator	FAILURE GREATER THAN 1HRS	3
Fuse	FAILURE GREATER THAN 30MINS	2
Isolator	FAILURE LESS THAN 30MINS	1

Table 4: Faults Occurrence for Kinkinau Feeder

FAILURE ELEMENT	RATE OF OCCURRENCE	RANKING
Line	ONCE IN A WEEK	10
Isolator	ONCE IN 2 WEEKS	9
Fuse	ONCE IN A MONTH	8
	ONCE IN 3 MONTHS	7
Cable	ONCE IN 6 MONTHS	6
Disc/Pot insulator	ONCE IN 9 MONTHS	5
Transformer	ONCE IN A YEAR	4
Circuit Breaker	ONCE IN 2 YEARS	3
Arrester	ONCE IN 3 YEARS	2
	ONCE IN 4 YEARS	1

TABLE 5: Faults Severity for Kinkinau Feeder

FAILURE ELEMENT	RATE OF OCCURRENCE	RANKING
Cable	FAILURE GREATER THAN 8HRS	10
Arrester	FAILURE GREATER THAN 7HRS	9
Disc/Pot Insulator	FAILURE GREATER THAN 6HRS	8
Transformer	FAILURE GREATER THAN 5HRS	7
	FAILURE GREATER THAN 4HRS	6
Circuit Breaker	FAILURE GREATER THAN 3HRS	5
Busbar	FAILURE GREATER THAN 2HRS	4
Line	FAILURE GREATER THAN 1HRS	3
Isolator	FAILURE GREATER THAN 30MINS	2
Fuse	FAILURE LESS THAN 30MINS	1

TABLE 6: Faults Detectability for Kinkinau Feeder

FAILURE ELEMENT	RATE OF OCCURRENCE	RANKING
	IMPOSSIBLE	10
Cable	VERY DIFFICULT	9
Arresters	VERY LATE	8
Circuit Breaker	NOT SURE	7
Disk/Pot Insulator	OCCASSIONAL	6
Transformer	LOW	5
Busbar	LATE	4
Fuse	EASY	3

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



Isolator	IMMEDIATE	2
Line	ALWAYS	1

RESULTS AND DISCUSSIONS

The results showing the failure indices for AF and KF are presented in Tables 7-8 and represented graphically using Figures 4-6. Thereafter, the value of the criticality of the feeders otherwise known as the risk summary is presented in Table 9. Tables 10-11 show the failure, relative, and cumulative frequency used for the Pareto Analysis. This result was represented graphically as shown in Figures 3-4.

Table 7: Failure Indices for AF

Year	outage	Downtime	MTBF	MTTR	FR
2017	112	179	76.6161	1.5982	0.0131
2018	59	646	137.5254	10.9492	0.0073
2019	95	417	87.8211	4.3895	0.0084
2020	74	198	115.7027	2.6757	0.0075

Table 8: Failure Indices for KF

Year	outage	Downtime	MTBF	MTTR	FR
2017	367	1864	18.79019	5.0790	0.0532
2018	574	2263	11.31882	3.9425	0.0883
2019	624	2876	9.429487	4.6090	0.1061
2020	475	2122	13.97474	4.4674	0.0716

Table 9: Risk Summary

Faults Elements	AF Risk Value	KF Risk Value
Line	200	30
Insulator	135	240
Fuse	14	24
Breaker	72	105
Cable	450	540
Transformer	96	140
Isolator	9	36
Busbar	112	112
Arresters	72	144

Table 10: Pareto Chart for AF

Failure Element	Failure Frequency	Relative Frequency	Cummulative Frequency
Cable	450	450	38.8
Line	200	650	56.0
Insulator	135	785	67.7
Busbar	112	897	77.3
Transformer	96	993	85.6
Breaker	72	1065	91.8
Arrester	72	1137	98.0
Fuse	14	1151	99.2
Isolator	9	1160	100.0

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



Table 11: Pareto Chart for KF

Failure Element	Failure Frequency	Relative Frequency	Cumulative Frequency
Cable	450	450	35.1
Insulator	240	690	53.9
Arresters	144	834	65.1
Transformer	140	974	76.0
Busbar	112	1086	84.8
Breaker	105	1191	93.0
Isolator	36	1227	95.8
Line	30	1257	98.1
Fuse	24	1281	100.0

TABLE 12: FEEDERS' FMECA

Components	Function	Functional Failure	Failure Mode	Failure Cause	Failure Effect	Detectability	Normalize AF/KF	Remark AF/KF	Action
Transformer	Step up or step down voltage level	Failed test results	Low oil level, ageing etc	Contamination, vibration etc	Loss of load, overheating etc	Visual; Noise, relay operation	21.3/25.9	II	Visual Inspection, Preventive maintenance etc.
Busbar	Transfers power from one point to another	Mechanical failure	Snapping, deformation	Over loading	Partial/total Loss of supply,	Visual	24.8/20.7	II	Visual Inspection, Preventive maintenance
Breaker	Protects electrical circuit from damage caused by fault	Mechanical and electrical failure	Low SF6 gas, burnt coils	Gas leak, mechanism failure, interrupter failure, burnt trip or close coils	Damage to the protected equipment	Visual	16/19.4	II	Visual Inspection, Preventive maintenance
Transmission line	Transmit power to a distance location	Mechanical stress	Broken conductor	External cause	Loss of supply	Visual, Relay operation	44.4/5.5	II	Line Patrol/Visual Inspection
Fuse	Protects the transformer from fault caused by overload or short circuit	Incorrect fuse rating	Fuse blown out	Short circuit	Loss of supply to the transformer	Visual	3.1/4.4	L/L	Visual Inspection
Cable	Connecting supply from the feeder pillar to the line	Mechanical stress, incorrect size	Insulation failure	Overcurrent,	Loss of supply	Visual, testing	100/100	H/H	Overhauling
Arresters	Protects transformers against lightning or surge	Failed test	Dielectric breakdown	Moisture entering its interior	Short circuit inside its housing	Testing	16/26.6	II	Visual Inspection
Insulator	Insulating the line from the electric pole during transmission	Mechanical failure	Crack or shattering	Mechanical stress	Short circuit to ground	Visual	30/44.4	II	Visual Inspection

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved

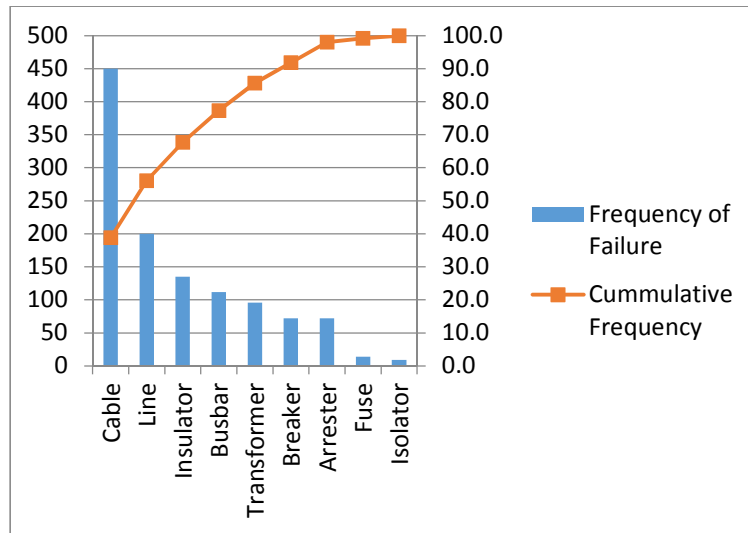


Figure 3: Pareto Plot for AF

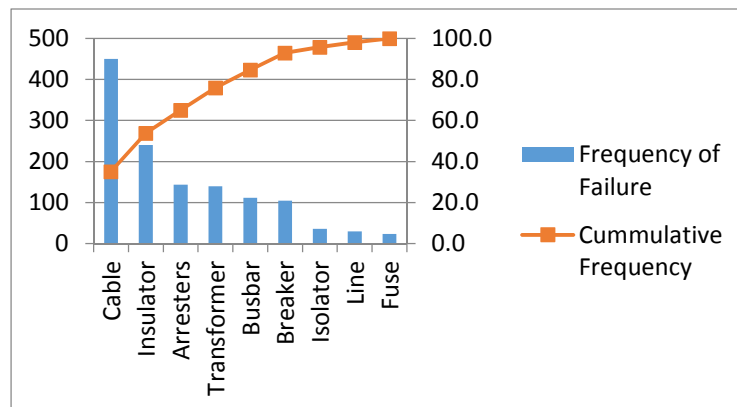


Figure 4: Pareto Plot for KF

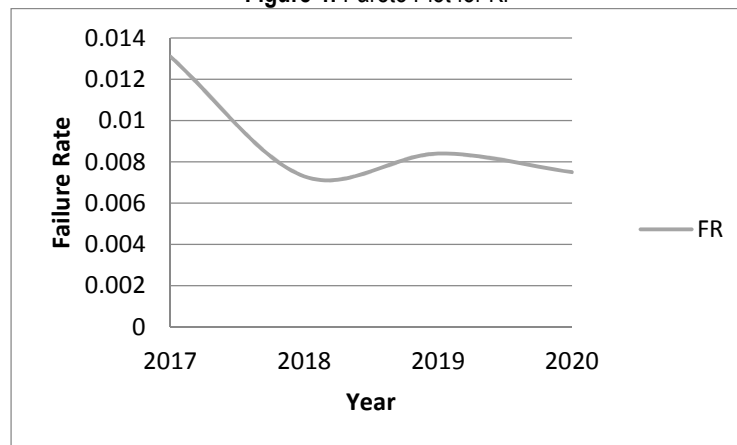


Figure 5: AF Failure Rate

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved

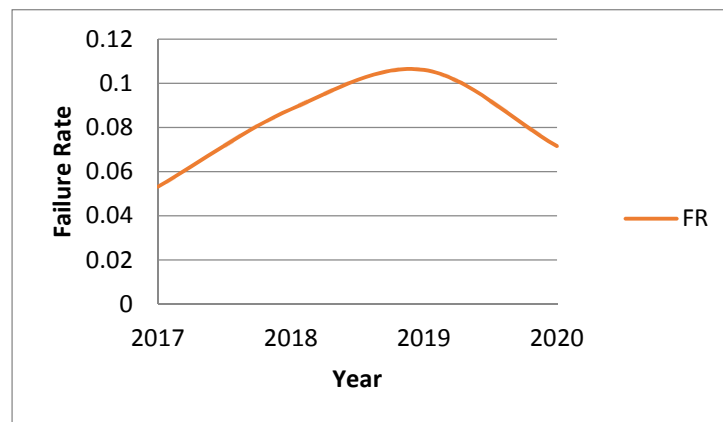


Figure 6: KF Failure Rate

The results in Tables 7-8 show a decreasing failure rate for the AF between 2017–2018 and a fairly constant one between 2018-19. This indicates therefore that only random external events could lead to failure along the line. However the KF shows an increasing failure rate between 2017-18 and eventually the failure rate drops in 2020. This is indication also that the feeder might have been affected by ageing. In both cases however, FR was said to reduce in the year 2020. This may be unconnected to the fact that since many industries were not up during this time as a result of the COVID, hence the reduction in FR. In Table 10, the summary of the risk value using FMECA approach has been determined. In both cases, cables have the highest risk value of 540 and 450 for KF and AF respectively. According to (Airoboman, 2018), a feeder's risk level is low if the risk level is between 0 - 12.5%, intermediate if the risk level is between 12.5% - 50% of and high if it ranges from 50.1% - 100%. This information was therefore used in assigning remarks to the individual feeders. Furthermore, the PARETO analysis was used to determine the components in each network that falls outside the 80% margin and hence require more attention. From Figure 3-4, the following; Cable, Line Insulator and Busbar were identified as the critical equipment that required urgent attention in the AF while Cable, Insulators, Arresters and Transformers were identified as the critical components that required urgent attention in the KF.

CONCLUSIONS

In this paper, risk assessment on Airport and Kikinau feeders radiating from the Transmission Company of Nigeria have been carried out. The objective of the study is fully met after the determination of the failure rate of the feeders, the determination of the risk values attached to each particular component in the network, the identification of the vital few components and finally the ranking of the faults. This study, therefore, would be a useful guide for maintenance operators either within or outside Kaduna metropolis for proper system planning.

ACKNOWLEDGEMENTS

This research was sponsored by the Federal Government of Nigeria under the Tertiary Education Trust Fund (TETFUND) Institutional Based Research Grant TETF/DR&D/CE/NDA/IBR/2016/VOL. 1

REFERENCES

- Ahmed, M.N. (2019), "The use of performance-based contracting in managing the outsourcing of a reliability-centered maintenance program: A case study", *Journal of Quality in Maintenance Engineering*, Vol. 26 No. 4, pp. 526-554.
- Airoboman A.E, Ogujor E.A and Edokpia, R. (2019) "Using Markov Indices to Determine Feeders Stationary Point in the 33kV Feeders Emanating from TCN Benin City. *IEEE PES/IAS Power Africa Conference. Abuja, Nigeria.* pp. 285 – 290.

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



- Airoboman, A.E and Ogujor, E.A (2018) "Risk assessment of feeders in power system network using FCT" *International Journal of Advanced Engineering and Technology* Volume 2; Issue 2; May 2018; pp. 33-39
- Airoboman, A.E, Oriafio, P. and Ogujor, E.A (2017) "A Maintenance Framework in Power System Network Using RCM. *IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON)* November 7-10, Federal University of Technology, Owerri, Imo State pp.893-897.
- Airoboman, A.E. Ogujor, E.A Okakwu, I.K. (2016) "On the Centralization of Reliability in Maintenance Practices in the Nigerian Power System Network: A Review". *International Journal of Engineering Works*.Vol. 3, Issue 9, pp. 68-72.
- Chulho, B., Taeyoon K., Youngtak S., Kyjun P., Jongdeok J., Seokyouon H. and Myungwon S., (2009), "A study on reliability centered maintenance planning of a standard electric motor unit subsystem using computational techniques", *Springerlink.com, Journal of Mechanical Science and Technology* vol. 23, pp. 1157-1168.
- Diego, P., André, A.P. B., Fábio, B. L., Roberto, S. M. (2016), "A new approach for reliability-centered maintenance programs in electric power distribution systems based on a multiobjective genetic algorithm", *Elsevier Science Limited, Electric Power Systems Research*. vol. 137, pp. 41–50.
- Dimitris, C. T., Theodore N. C., George J. A., and Ioannis S. Z. (2007), "A Cost-Efficient Application of the Reliability-Centered Maintenance Method for Small-Scale Usage", *2nd International Conference on Experiments/Process/System Modelling/Simulation/Optimization*, pp. 1-9.
- Dhillon, B.S. (2002) "Engineering Maintenance A modern Approach" CRC Press., Boca Raton New York London Washington D.C.
- EL-Hadidy, M.A & Helmi, D.H (2013) "Predictive Maintenance Strategy Based on Disturbance eorders" *The Online Journal on Power and Energy Engineering (OJPEE)* Vol. 1, No. 3, pp. 99-105.
- Emovon, I. and Norman, R. (2019), "Risk analysis of engineering systems for sustainable industrial development using the Taguchi approach", *Journal of Quality in Maintenance Engineering*, Vol. 26 No. 4, pp. 611-624.
- Ewulum, O.K (2008) "A new maintenance strategy for Power Holding Company of Nigeria to contest the current Power Demand Problem" *Asset Management and Maintenance Journal*.
- Igweonu, E.I and Joshua, R.B (2011) "A Maintenance Paradigm for the Power Infrastructure in the 21st Century Nigeria" *Continental J. Engineering Sciences* Vol. 6, No. 1 pp 1-7.
- Ismaila, O.S (2010) "Lecture note on Mechanical Maintenance" Federal University of Agriculture, Abeokuta, Ogun State. http://unaab.edu.ng/attachments/470_mce%20509%20lecture%20note.pdf. Accessed 20/8/16, 12:23pm.
- Lundgren, C. Skoogh, A and Bokrantz, J. (2018) "Quantifying the effects on Maintenance-a literature review of maintenance models. 51st CIRP Conference on Manufacturing Systems. Pp.1305-1310.
- Mansour, H.-F. and Noradin, G. (2015), "Financial Planning for the Preventive Maintenance of the Power Distribution Systems' Critical Components Using the Reliability-Centered Approach", *International Journal of Physical Sciences*, Vol. 10(3), pp. 123-132.
- Marvin, R. (1998), "Reliability Centered Maintenance", *Elsevier Science Limited, Reliability Engineering and System Safety*, vol. 60, pp.121 – 132.
- Mohammad, S., J., A., Ali, M., (2011), "Fault Tree Analysis Approach in Reliability Assessment of Power System", *International Journal of Multidisciplinary Sciences and Engineering*, Vol. 2, No. 6, pp. 46-50.
- Moubray, J. (2007) "Introduction to Reliability-centered Maintenance" *Plant*

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved



- Maintenance Resource Center. pp. 1-13.
- Obamwonyi, M. (2009) "Improving Maintenance Perception in Developing Countries - A Case Study" Linnaeus University School of Engineering Department of Terotechnology.
- Rukijkpanich, J. and Mingmongkol, M. (2019), "Enhancing performance of maintenance in solar power plant", *Journal of Quality in Maintenance Engineering*, Vol. 26 No. 4, pp. 575-591.
- Schutz, J., Chelbi, A., Rezg, N. and Ben Salem, S. (2019), "Production and maintenance strategies for parallel machines with load transfer in case of failure", *Journal of Quality in Maintenance Engineering*, Vol. 25 No. 4, pp. 525-544.
- Sule, A.H. 2010 "Major Factors Affecting Electricity Generation, Transmission and Distribution in Nigeria" *International Journal of Engineering and Mathematical Intelligence*. Vol. 1, pp. 161-162.
- Wang, S. Lu, Z. Ge, S. and Wang, C. (2014) "An Improved Substation Locating And Sizing Method Based On The Weighted Voronoi Diagram And The Transportation Model", *Hindawi Publishing Corporation, Journal of Applied Mathematics*, vol. 2014, pp. 1-9.
- Yssaad, B., M. Khat, M., and Chaker, A. (2014), "Reliability centered maintenance optimization for power distribution Systems", *Elsevier Science Limited, Electrical Power and Energy Systems*, vol. 55, pp. 108-115.

*Corresponding author: Airoboman, A. E. ✉ airobomanabel@nda.edu.ng ✉ Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna. © 2019 Faculty of Technology Education, ATBU Bauchi. All rights reserved