FREQUENCY AND DURATION METHOD RELIABILITY ANALYSIS: CASE STUDY OF BAMA AND UNIVERSITY 33KV DISTRIBUTION FEEDER MAIDUGURI

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Abstract: Failures in distribution systems not only reduce reliability of power system but also have significant effects on power quality since one of the important components of any system quality is reliability of that system. To enhance utility reliability, failure analysis and its frequency must be studied. This paper describes a case study of the reliability of 33Kv distribution feeders (Bama and University) .The information obtained from Transmission Company of Nigeria along Baga Road. Reliability indices such as the MTBF and MTTR are determined, analytically, by using outage information gathered from the Transmission Company. The study generally shows that the distribution feeders have not been adequately maintained leading to frequent and delayed forced outage indicating unreliable performance of the individual units and the entire station.

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POWER SYSTEM RELIABILITY

The probability of an electric power equipment or system to deliver uninterrupted electrical power of prescribed quality to its customers for a given period of time is usually designated by the term power system reliability. The function of an electric power system is to satisfy the system load requirement with a reasonable assurance of continuity and quality. The concept of power system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements (Billinton and Allan, 2011).

SUB-DIVISIONS OF POWER SYSTEM RELIABILITY

The power system reliability can be sub-divided into several aspects based on different considerations. The first sub-division based on technical capacities comprises of two basic aspects: system adequacy and system security.

System Adequacy: This relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points.

System Security: This relates to the ability of the system to respond to disturbances arising within that system. Security is therefore, associated with the response of the system to perturbations. The second sub-divisions of power system reliability based on the scope of considerations of the analysis are: Composite and Component System Reliability.

The Sub-Station Network

This section starts from the termination transmission networks. The section comprise power transformers that step down voltages typical of transmission systems (132KV for Nigerian network) to lower voltages (33 kV for Nigerian network). The power at this voltage level (33 kV for Nigeria network) was fed to the primary distribution networks through radial lines known as outgoing feeders. It is at this voltage level that some customer load point connections start. The research will focus on this level of the network.

The Primary Distribution Network

This comprises of long 3-phase feeders (in-comers) that receive supply from the substation network and in turn feed the secondary distribution networks after stepping down to lower voltage level via large power transformers (from 33 kV to 11KV for Nigerian networks). The feeders here are either overhead lines or underground cables. Overhead lines are supported by poles that are mounted with insulators to hold the lines. Underground cables are connected with elbows and splices. There are protective equipments like fuses, re-closers and circuit breakers at appropriate points according to design requirement of the network. Also in the network are the switches and sectionalizes that are used to isolate faulted areas thus help in restoring power to at least the unaffected customers while repair is carried out.

The Secondary Distribution Network

This network typically has pole-mounted or pad- mounted power transformers that step down voltage to feed customer load points (from 11kV to 415V line-to-line or 220V phase-to-neutral for Nigerian network). Customers are generally connected to the nearest transformers using short lines or cables. In a whole, the distribution systems have numerous components that are dispersed over large geographical regions with varying load and weather patterns.

LITERATURE REVIEW

Reliability Analysis is done on other segments of the Nigerian Power System in the 1990's (Abdu, D. 2012), (Yusuf, S.O 2010). Also, studies have been done on reliability assessment of 33 kV distribution feeders. However, there are still open questions such as need to use a wider range of parameters of consideration especially in the current situation of the Nigerian power system. Thus, the reliability and outage cost assessment of the 33 kV feeders in Maiduguri 132/33 kV transmission substation was carried out. A couple of Research works conducted on similar subject are as follows: (Abdu, D. (2012) carried out reliability assessment on the Distribution System Reliability Study in the five Northern States of Nigeria and showed that Kano and Kaduna distribution networks exhibit lower availability value compared to Bauchi, Jos and Sokoto networks.

Another related work is that of Ogujor and Kuale, (2010) on Fault Events Reduction in Electric Power Distribution Reliability Assessment Using Pareto Analysis. Pareto analysis was carried out on outages of some feeders of a selected portion of the Nigerian electric power distribution system, Ugbowo injection substation. The study revealed the significant few fault types that when solved will result in remarkable increase in the electric power distribution reliability. Also, Igbalo et al, (2010) conducted their research on the Electrical Power failures in Nigeria, A case study of the 33 kV feeders in Benin District. Fault analysis results for availability, partial availability and non availability of some 33 kV feeders in Benin district are obtained. In addition, Ilochi et al, (2012) worked on; Frequency and Duration method in Reliability Assessment of three 33 kV primary distribution feeders in Enugu State of Nigeria. The feeders are analyzed and discovered that there are more frequent delayed forced outages during rainy and hot seasons and also showed the most and least available feeders. Furthermore, Yusuf, S.O (2010) worked on the Adequacy and Reliability Evaluation of the 330/132kV Nigerian National Power Transmission Network. The reliability evaluation carried out showed that the average availability for any 330/132kV line of the Nigerian Power Transmission System was over 99% (Adebayo et al, 2011) which indicates a reliable system at the time research was conducted.

In a study by William, (2007) on Cost-Benefit. Analysis of Power System Reliability: Two utility Case Study, used the cost benefit approach to evaluate alternative designs for proposed addition to a transmission station for Duke Power Company and to evaluate three options for maintaining reliability in a major load center — two involving local generation, and the third, a new 330kV transmission connection for Pacific Gas and Electric Company. Lastly, Shalini, (2006) performed a Cost-Benefit Assessment of Power System Reliability. The research illustrates the basic concepts and procedures in the evaluation of cost-benefit analysis in power system. Reliability analysis techniques have been gradually accepted as standard tools for the planning, design, operation and maintenance of electric power. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and reliability (Adegboye et al 2012). (S.T Lotery 2011); developed an adaptive-fuzzy k model to predict the failure rate of overhead distribution feeders based on factors such as tree density, tree trimming, lightning intensity and wind index. A gradient descent method was used to train the fuzzy model. They observed the root mean square error (RMSE) and absolute average error (AAE) to check performance of the model and discussed the variations of failure rate to various factors obtained from the sensitivity analysis used. Modern automation technologies can reduce contingency margins, improve utilization and economy of operation and even provide improved scheduling and effectiveness of maintenance and service. However, they must be applied well, with the technologies selected to be compatible with systems need and targeted effectively. On the other hand, non-electric method such as vegetation management, system improvements, crew placement and management, maintenance practices plays an important role in improving reliability in the system. It was discovered that the peak frequent and delayed forced outages occur during the rainy season and the harmattan season. The causes are attributed to heavy winds, thunder strike, and other reasons such as vehicular accident, animal cause outages, and simultaneous use of weather sensitive devices. Adegboye et al (2012) carried out a study and analysis of outages on the 33 kV primary distribution feeders in Zaria. It was found out that outage rates are higher in the rainy seasons than in the dry seasons due to failures associated with damages on the transmission line equipment during heavy rain falls. Similar observations are made when the study was extended to the 11kV primary distribution feeders. The consequences of an interruption are highly dependent on the characteristics of the interruption as well as that of the customer concerned. Interruption characteristics include frequency, duration, time of occurrence, advance warning, and the extent of the interruption. Customer characteristics include the type of customer, size of operation, demand and energy requirements and advance preparation for the outage. Additional factors such as the outside temperature or the occurrence of the interruption during special events also affect the impact. The level of reliability the users have experienced in the past and expect in the future may have a significant effect on the interruption costs. Adegboye et al (2012), Abdu, D. (2012), Ogujir and Kuale (2010), each conducted his reliability analysis. Most of them also focus on historical assessments rather than the predictive analytical method used in this study. The Analytical approach is used to acquire input data from utilities and calculations used to obtain useful reliability indices which can then be used for comparison with the historical assessments. Moreover, analytical methods are more enhanced to providing useful and higher accuracy of results. The result of analytical method depends on the quality of input data.

The 33 kV Distribution Network Feeders

Based on the standards of the Nigerian power system network that is managed and controlled by the various distribution companies (DISCOS) in Nigeria the 33 kV feeders are the substation outgoing feeders and primary distribution network incoming feeders. The feeders supply power from the substation network to the primary distribution network. Outage of any 33 kV feeders causes outage to all other downstream feeders tapping from the same 33 kV feeder branches. The 33 kV feeders' voltage level is the highest voltage level that conveys power directly to some particular consumers (usually industries with heavy loads through far distances) and then all other lower voltage customer- type (i.e. 11KV, 415V phase to phase, 220V phase to ground load points) down, the stream through step-down power transformers. Data such as the load interrupted, time period and energy losses as a result of outage of the 33 kV feeders sufficiently cover all other downstream network feeders. The 33 kV feeders are chosen for the outage analysis because of the availability of data and the highlighted reasons mentioned. The Maiduguri 132/33 kV T/S is comprised of the following 33 kV feeders namely: Damasak 33 kV feeder, Benisheikh 33 kV feeder, University 33 kV feeder, Bama 33 kV feeder, Monguno 33 kV feeder.

Frequency and Duration Reliability Indices

The data used for the calculation of frequency and duration method was obtained from the Transmission Company of Nigeria Maiduguri 132/33 kV T/S, interruption and outage report from (O.F 53).Outage data of the 33 kV feeders in the Maiduguri 132/33 kV transmission station, comprising of date of occurrence, time-out, time-in, duration of outages, relay indication and load interrupted are extracted. The "emergency" and "forced" outage types for the various feeders are sorted and grouped. Also under the forced outages, the adverse and normal weather outages are sorted and re-grouped for each feeder. From the subgroup of the data the frequencies and durations of outage are calculated and made available in tabular form as shown below in Table(1).below. The following data are needed for the frequency and duration method indices for each of the 33 kV feeder:

a) Period of study
b) Outage time
c) Forced outage time
d) Planned outage time
e) Adverse weather outage time
f) Normal weather outage time
g) Number of forced outages
h) Number of planned outages
i) Number of normal weather outages

j) Number of adverse weather outages

k) Normal weather period

l) Adverse weather period

m) Service time

From the above data, the following indices are computed:

$$1. Planned\ outage\ rate = \frac{Number\ of\ planned\ outage}{Service\ time} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.0$$

$$2. Forced\ outage\ rate = \frac{Numbr\ of\ forced\ outage}{Service\ time} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots..3.2$$

$$3. Normal\ weather\ outage\ rate = \frac{No.of\ outages\ during\ normal\ weather}{Normal\ weather\ service\ time} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

$$4. Adverse\ weather\ outage\ rate = \frac{No.of\ outage\ during\ adverse\ weather}{Adverse\ weather\ service\ time} \ldots 3.4$$

$$5. Mean\ time\ to\ failure\ (MTTF) = \frac{Service\ time}{Number\ of\ outages} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.5$$

$$6. Mean\ time\ to\ repair\ (MTTR) = \frac{Forced\ outage\ time}{Number\ of\ outages} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

$$7. Mean\ time\ between\ failure\ (MTBF) = MTTF + MTTR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

$$8. Failure\ rate\ (X) = \frac{1}{MTTF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots.3.8$$

$$9. Rapiar\ rate\ (\mu) = \frac{1}{MTTR} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots..3.9$$

10. $Availability = \frac{\mu}{\mu + \lambda} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.10$

11. $Unavailabilty = \frac{\lambda}{\mu + \lambda} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.11$

Table 1: Data for the Calculation of Frequency and Duration Method Reliability Indices for the 33 kV Bama Feeder

	DATA	EXPRESSION	UNIT VALUE
1.	Period of study	366 days x no. of Hrs in a day	8784 hrs
2.	Total outage time		638.417 hrs
3.	Emergency outage time		398.533 hrs
4.	Forced outage time		239.883 hrs
5.	Adverse weather forced outage time		38.517 hrs
6.	Normal weather forced outage time		201.367 hrs
7.	Total no. of outages		384
8.	No. of emergency outages		290
9.	No. of forced outages		94
10.	No. of normal weather forced outages		80
11.	No. of adverse weather forced outages		14
12.	Adverse weather period	April + May + June + Jul + Aug. + Sept. + Oct. (30 + 31 + 3 + 31 + 31 + 31 + 31 days x 24hrs	5160 hrs
13.	Normal weather period	Jan + Feb + March. + Nov. + Dec. (31 + 29 + 31 + 30 + 31) days x 24 hrs	3648 hrs

Calculation of Frequency and Duration Method Reliability Indices

Using the formulae discussed above for the calculation of the various indices of the frequency and duration method reliability analysis and the data extracted above the respective indices are obtained. The formulae and results of the calculation procedure for the Frequency and Duration Method Reliability indices of all the 33 kV feeders are as shown below:

Calculation of Frequency and Duration Method Reliability indices of 33 kV Bama feeder

$$a. Emergency\ outage\ rate = \frac{Number\ of\ Emergency\ Outage}{Service\ time}$$

$$Emergency\ outage\ rate = \frac{290}{8145.58} = 0.35602117$$

$$Service\ time = No. of\ Hrs\ in\ year - total\ outage\ time\ in\ hrs$$
$$= 8784 - 638.417 = 8145.58hrs$$

$$b. Forced\ outag\ Rate = \frac{Forced\ outage\ time}{Service\ time + forced\ outage\ time}$$
$$= \frac{239.833}{8145.58 + 239.883} = 0.028607007$$

$$c. Normal\ weather\ outage\ rate$$
$$= \frac{Number\ of\ normal\ weather\ forced\ outages}{Normal\ weather\ period - Normal\ weather\ forced\ outage\ time}$$
$$= \frac{80}{3648 - 201.367} = \frac{0.03431}{078}$$

$$d. Adverse\ weather\ outage\ rate$$
$$= \frac{Number\ of\ adverse\ weather\ forced\ outages}{Aderve\ weather\ period - Adverse\ weather\ force\ outage\ time}$$

$$e. Mean\ time\ to\ failure = \frac{Service\ time}{Total\ No. of\ outages} = \frac{8145.58}{385}$$
$$= 21.2124479$$

$$f. Mean\ time\ to\ repair = \frac{Forced\ outage\ time}{Total\ No.of\ outages} = \frac{239.883}{384}$$
$$= 0.624695312$$

$$g. Mean\ time\ between\ failure$$
$$= Mean\ time\ to\ failure + Mean\ time\ to\ repair$$
$$= 21.83714323$$

$$h. Failure\ Rate = \frac{1}{Mean\ time\ to\ failure} = \frac{1}{21.21244792} = 0.047142131$$

$$i. Repair\ Rate = \frac{1}{Mean\ time\ to\ repair} = \frac{1}{0.624695312} = 1.60078038$$

$$j. Availability = \frac{Repair\ rate}{Failure\ rate + Repair\ rate} x\ 100\% = \frac{1.60078038}{1.64792251} x\ 100$$
$$= 97.1392993$$

$$k. Unavailability = \frac{Failure\ rate}{Failure\ rate + Repair\ rate}\ x\ 100 = \frac{0.047142131}{1.64792251}$$
$$= 2.8607007$$

Table 2: Data for the Calculation of Frequency and Duration Method Reliability Indices for the 33 kV University Feeder

	DATA	EXPRESSION	UNIT VALUE
1.	Period of study	366 days x no. of Hrs in a day	8784 hrs
2.	Total outage time		559.47 hrs
3.	Emergency outage time		195.81hrs
4.	Forced outage time		363.66 hrs
5.	Adverse weather forced outage time		236.38hrs
6.	Normal weather forced outage time		127.28hrs
7.	Total no. of outages		394
8.	No. of emergency outages		139
9.	No. of forced outages		256
10.	No. of normal weather forced outages		90
11.	No. of adverse weather forced outages		166
12.	Adverse weather period	April + May + June + Jul + Aug. + Sept. + Oct. (30 + 31 + 3 + 31 + 31 + 31 + 31 days x 24hrs	5160 hrs
13.	Normal weather period	Jan + Feb + March. + Nov. + Dec. (31 + 29 + 31 + 30 + 31) days x 24 hrs	3648 hrs

Calculation of Frequency and Duration Method Reliability Indices of 33 kV University Feeder

$$a. Emergency\ outage\ rate = \frac{Number\ of\ Emergency\ Outage}{Service\ time}$$

$$Where\ service\ time = No. of\ hrs\ in\ a\ yr - TOtal\ outage\ time$$
$$= 8784 - 559.47hrs = 8224.53hrs$$

$$Emergency\ outage\ rate\ = \frac{138}{8224.53} \quad = 0.016779074$$

$$b. Forced\ outag\ Rate = \frac{Forced\ outage\ time}{Service\ time + forced\ outage\ time}$$
$$= \frac{363.66}{8224.53 + 363.66} = 0.042344195$$

$$c.\,Normal\ weather\ outage\ rate = \frac{Number\ of\ normal\ weather\ forced\ outages}{Normal\ weather\ period - Normal\ weather\ forced\ outage\ time}$$

$$= \frac{90}{3648 - 127.28} = 0.025562953$$

$$d.\,Adverse\ weather\ outage\ rate = \frac{Number\ of\ adverse\ weather\ forced\ outages}{Aderve\ weather\ period - Adverse\ weather\ force\ outage\ time}$$

$$= \frac{166}{5160 - 236.338} = 0.03371503$$

$$e.\,Mean\ time\ to\ failure = \frac{Service\ time}{Total\ No.of\ outages} = \frac{8224.53}{394} = 20.8744162$$

$$f.\,Mean\ time\ to\ repair = \frac{Forced\ outage\ time}{Total\ No.of\ outages} = \frac{363.66}{394} = 0.922994923$$

$$g.\,Mean\ time\ between\ failure = Mean\ time\ to\ failure + Mean\ time\ to\ repair = 20.87444162 + 0.922994923 = 21.79743654$$

$$h.\,Failure\ Rate = \frac{1}{Mean\ time\ to\ failure} = \frac{1}{20.87444162} = 0.047905473$$

$$i.\,Repair\ Rate = \frac{1}{Mean\ time\ to\ repair} = \frac{1}{0.922994923} = 1.083429578$$

$$j.\,Availability = \frac{Repair\ rate}{Failure\ rate + Repair\ rate}\ x\ 100\%$$

$$= \frac{1.083429578}{0.047905473 + 1.83429578}\,x\ 100 = 95.7655804$$

$$k.\,Unavailability = \frac{Failure\ rate}{Failure\ rate + Repair\ rate}\ x\ 100$$

$$= \frac{0.047905473}{0.047905473 + 1.083429578} = 4.2344195$$

TABLE 3: Frequency and Duration Method Reliability Indices of Bama and University 33 kV Feeders in Maiduguri

	INDICES	BAMA	UNIVERSITY
1.	Emergency outage rate (hours	0.035602117	0.01677907
2.	Forced outage rate	0.028607007	0.0423442
3.	Normal weather outage rate (hours)	0.023211078	0.02556295
4.	Adverse weather outage rate (hrs)	0.02746453	0.03371503
5.	Mean time to failure (hrs)	21.21244792	20.87444162
6.	Mean time to repair (hrs)	0.624695312	0.9229949
7.	Mean time between failure (hrs)	21.83714323	21.7974365
8.	Failure Rate (hrs)	0.047142131	0.04790547
9.	Repair rate(hrs)	1.60078038	1.08342958
10.	Availability%	97.1392993	95.7655804
11.	Unavailability%	2.8607007	4.2344195

Results for Frequency and Duration Method Reliability Analysis

The 33 kV Bama feeder has the highest emergency outage rate of (0.035602117) and the lowest mean time to repair of (0.624695312) implying that the feeder is the most affected in terms of load shedding and must be given priority whenever there is improvement in the load allocation status of the station. The 33 kV University feeder has the second highest forced outage rate of (0.0423442) and the second highest Adverse weather outage rate of (0.03371503) meaning that the feeder should be given the second highest preventive maintenance attention in order to improve on its performance. Generally, the result revealed that, the two feeders recorded the Forced Outage Rates (FOR) of 0.35% and 0.16% respectively, which depends on other factors such as customer's size and age of equipment. The result obtained shows the good performance of both Bama and University feeder with availability of 97% and 95% respectively. Maintenance which is the backbone of successful performance has been properly done for both feeders. with total number of outages of 94 that correspond to the total outages time of 638.447hrs indicates that Bama feeder experience higher outage time than university feeder, whose force outages was 256 times, has outage time of 559.47hrs experience less outage hours, this is simply because university feeder is located in the town but Bama feeder is located outside the town as most of the poles are affected by animals, strong wind and erosions. The indices also indicate that, the MTTR, MTBF, MTTF and FR were obtained as 0.625,21.83,21.21,0.047 and 0.928, 21.79,20.87 ,0.048 for Bama and university feeder respectively. However, in terms of emergency outages, Bama feeder recorded the highest number of emergency outages of 290, which actually double that University which occurred 139 times within the year.

Indicating that the feeder has the highest value of energy interruption per customer served. Given the increasing volatility and violent nature of societies, the indices above should serve as an indicator to the electricity distribution company's management to be conscious and sensitive to the consumers by putting extra efforts to reduce outage duration of the customers served by the 33 kV University feeder. This can be done through preventive maintenance or operational procedures to balance the impression of unfair treatment that can be developed among the customers.

CONCLUSION

The availability indices obtained from the frequency and duration method reliability. Analysis carried out shows that 33 kV Bama is the most available feeder while 33 kV University is the least available feeder. This indicates that 33 kV University feeder is having more outage problem than all other feeder. Given that resources are scarce, these indices give the management of electricity distribution companies (DISCOS) a basis for relative preferential maintenance attention on the 33 kV University feeder with respect to the 33 kV feeder in order of their availability index. That is 33 kV

University feeder should be attended to first before the other more available feeders. This treatment also applies to operational load shedding exercise. Further load shedding should be carried out on more available 33 kV feeders. This means greatest priority attention be given to the 33 kV University feeder during load shedding and preventive maintenance activities in order to improve on its performance.

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