American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-3, pp-168-175
www.ajer.org
Research Paper Open Access

Development of Outage Evaluation and Reliability Model for Benin City Power Distribution Network

Lazarus O. Uzoechi* and Etiebet Udo
Electrical/Electronic Engineering Department, Federal University of Technology Owerri (FUTO), Owerri, Nigeria.

Abstract: *This paper evaluated outages and assessed reliability in the Benin Electricity Distribution Network. The outage evaluation and reliability assessment was conducted using 2013 feeder outage data covering 8760 reliability hours from the network. The Electrical Transient Analyzer Program (ETAP) was employed in carrying out the reliability assessment on the network. The various reliability indices were obtained and analyzed. A comparison of the results with the mitigated system using distributed generators indicates substantial improvement over the existing system. The study established a linear relationship between the system annual outage duration, Expected Energy Not Supplied (EENS), and Expected Cost of Interruption (ECOST). The EENS was improved by 90.2% decrease while the ECOST improved by 90.5% in the mitigated system through the incorporation of distributed generators. The results obtained will assist power system regulators in setting distribution reliability benchmarks, future reliability prediction and performance standards for the Benin Electricity Distribution Company (BEDC).*

Keyword: *Benin Electricity Distribution Company, Reliablilty assessment, outage evaluation, expected energy not supplied, expected cost of interruption.*

I. INTRODUCTION

Reliability associated with a power distribution system is a measure of the overall ability of the power delivery system to satisfy the customer demand for electrical energy. Electrical power outages are responsible for the poor performance of a distribution network. Reliability assessment is an important concept in determining the performance of a power utility. Reliability indices are the parameters that help in calculating and analyzing the reliability of a distribution system. The distribution systems account for about 90% of all customer reliability problems and improving distribution reliability is the key to improving customer reliability and satisfaction [1].

Recent chaos in the electricity market in Nigeria attracted concerns of government regulators, businesses, and the general public regarding the reliability of their electricity supply [2]. Reference [3] observed that the power supply situation is never near satisfaction as Nigerians are not sure of up to 12-hour uninterrupted supply. Electricity plays an essential role in modern society and the importance of high quality and reliable electric services has increased with the advent of the internet - based economy. In the study in Ibadan, South-West Nigeria, [3] posited that the interruption of power system due to the occurrence of faults on the system constitutes a problem to electricity consumers in Nigeria. Several studies have been conducted in relation to electric power distribution system reliability. Most of the earliest methods relied heavily on analytical techniques. Analytical evaluation of raw and central moments of reliability indices has been addressed by [4], using the results for a posteriori evaluation of the probability distribution functions.

Reference [5] presented a computer programme for time- sequential Monte Carlo Simulation technique, which can be used in evaluation of complex distribution systems. General distribution system elements, operating models and radial configuration are considered in the programme. The results obtained using both analytical and simulation methods are compared. The mean values and the probability distributions for both local point and system indices are illustrated using a practical test system.

In [6], failures in overhead distribution systems caused by animals are examined. Occurrence of faults due to animals in different weather conditions as well as at different times of the year, are investigated. Based on this investigation, a mathematical cause and effect relationship is developed between weather and behavioral patterns of animals and animal-caused outages. A Bayesian model is built to represent the cause-effect relationship and for prediction of faults due to animals. If the observed number of faults in a period falls within the confidence bounds, the utilities don't need any action. However, if the observed number of faults is higher than the upper limit, the utilities need to do further examination to take corrective actions. Reliability indices are widely used for assessing the effectiveness of continuity of supply in distribution systems. Their use is essential in setting up performance standards for the continuity of supply regulation. According to [7], the reliability indices calculation is generally performed using uncertain variables or parameters, uncertain quantities could be the number of fault occurrences and the restoration times, for which a stochastic model of the system operation can be used. Availability of the probability distributions makes it possible to easily assess the probability, that any reliability index exceeds a specified limit imposed by an authority. The classical reliability analysis performed with the Markov approach assumes times to failure and repair times of the system components to be exponentially distributed, so that failure and repair times of the system components are constant. However, the use of exponential distribution in some cases is not realistic. In particular, [8] described that the exponential distribution of restoration times does not properly represent their random nature so that lognormal, normal and gamma probability distribution functions have been proposed in different papers. Monte Carlo methods have been used for evaluating the probability distributions of reliability indices.

Reference [9], presented a practical reliability assessment algorithm for distribution systems of general network configurations. The algorithm is an extension of analytical simulation approach for radial distribution systems. The algorithm is efficient for large-scale radial/meshed distribution systems, and can accommodate the effects of fault isolation and local restoration. Further, [10] proposed a method to analyze the economic feasibility of a new order acceptance in a scenario of unit costs variability. It describes that the simulation is an attempt to replicate a real system through the construction of a model as similar to reality as possible.

Power system distribution reliability efforts in Nigeria are still at a nascent stage. One of such efforts is the reliability analysis of distribution transformers conducted at Gwiwa Business Unit, Sokoto [11]. Also, a reliability assessment of Power Transmission and Distribution Systems employed statistical tools for the analysis of fault data from Power Holding Company of Nigeria (PHCN) [3]. Both works involved historical techniques and therefore, the practical applications of the results are not as extensive. On the whole, the literature on distribution system reliability in Nigeria is rather scanty and to the best of the author's knowledge, it appears very little work has been done to assess the reliability of power distribution. However, the work in [12] found that the Benin City, one of the main distribution areas in Edo State, Nigeria has suffered a great deal of irregular power supply in the last few decades. This has attracted sustained outcry by customers connected to the Benin Distribution Network. This work is an attempt to measure the reliability performance of the Benin Electricity Distribution Network using defined reliability indices. The results obtained will assist power system regulators in setting distribution reliability benchmarks and performance standards for the Benin Electricity Distribution Company (BEDC).

II. METHODOLOGY

The primary technique employed is the historical analysis approach. Historical analysis involves the collection and analysis of actually observed reliability performance such as customer interruption frequency and durations ideally at a feeder level. The reliability assessment involved the analysis of outage data obtained from the Benin Electricity Distribution Company (BEDC). The Electrical Transient Analyzer Program (ETAP) is used as the analytical tool. ETAP employs an analytic algorithm to assess the reliability of the distribution network. The distribution feeders which are radial in nature are represented by means of one-line diagrams. The output reports generated showed the reliability indices results.Table 1 shows the seven injection substations used for the reliability assessment of the Benin City Electricity Distribution network. The rated power specifies the power output of the injection substation transformers or normal operating conditions. Table 2 shows the estimated total load on each of the feeders connected to the injection substations.The distribution reliability assessment was carried out using the ETAP software. ETAP uses outage data in Table 3 and employs an analytic algorithm to calculate the failure rate ( ), average outage duration ( ) and annual outage time (U_s) of an n-component series system given by

(1)

(2)

Table 1: Rated Power and Voltage Ratios of Injection Substation Transformers

S/No	Name of Injection substation	Rated Power	Rated Voltage Ratio
1	Etete	20.5MW	33/11kV
2	Nekpenekpen	13.5MW	33/11kV
3	Ugbowo	13.5MW	33/11kV

4	Ikpoba Dam	6.6MW	33/11kV
5	Guinness	12.3MW	33/11kV
6	Siluko	20.5MW	33/11kV
7	GRA	13.5MW	33/11kV

(3)

In analyzing load points in the Benin City distribution system, Equations (1), (2) & (3) have been altered to fit the indices defined below. The analysis is done using the simulation capabilities of ETAP. The following reliability parameters are defined:
Average Failure Rate at Load Point *i*, λ_i *(f/yr)*

(4)

where $\lambda_{e,j}$ is the average failure rate of element *j*; N_e is the total number of the elements whose faults will interrupt load point *i*.

Annual Outage Duration at load point *i*, U_i *(hr/yr)*

$$U_i = \sum_{j \in N_e} \lambda_{e,j} r_{ij} \tag{5}$$

where r_{ij} is the failure duration at load point *i* due to a failed element *j*.

Average Outage Duration at Load Point *i*, r_i *(hr)*

$$r_i = \frac{U_i}{\lambda_i} \tag{6}$$

Expected Energy Not Supplied Index at Load Point *i*, $EENS_i$ *(MWhr/yr)*

$$EENS_i = P_i U_i \tag{7}$$

where P_i is the average load of point *i*.

Expected Interruption Cost Index at Load Point *i*, $ECOST_i$ *(k\$/yr)*

$$ECOST_i = P_i \sum f(r_{ij}).\ \lambda_{ej} \tag{8}$$

where $f(r_{ij})$ is the sector cost damage f unction (SCDF)

Interrupted Energy Assessment Rate Index at Load Point *i*, $IEAR_i$ *(\$/kWhr)*

$$IEAR_i = \frac{ECOST_i}{EENS_i} \tag{9}$$

System Average Interruption Frequency Index, *SAIFI(f/customer.yr)*

$$SAIFI = \frac{\text{Sum of customer interruptions}}{\text{Total number of customers served}}$$

$$= \frac{\sum \lambda_i N_i}{\sum N_i} \tag{10}$$

Where N_i is the number of customers at load point *i*; the symbol $\sum$ means the summation for all load points.

System Average Interruption Duration Index, *SAIDI(hr/customer.yr)*

$$SAIDI = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customers served}}$$

$$= \frac{\sum U_i N_i}{\sum N_i} \tag{11}$$

Customer Average Interruption Duration Index, *CAIDI(hr/customer interruption)*

$$CAIDI =$$

(12)

Table 2: Estimated Total Load of the 11kV feeders

S/No	Injection substation	Feeders	Load (kVA)
1	Etete (A)	Sapele road (A1) Ihama road (A2) Ugbor road (A3) Dumez road (A4)	7300 13315 700 1200
2	Nekpenekpen (B)	Feeder 1 (B1) Feeder 2 (B2) Feeder 3 (B3) Feeder 4 (B4)	5400 7900 9750 3600
3	Ugbowo (C)	Federal Girls (C1) Uselu Road (C2) Egua Edaken (C3) Ugbowo (C4)	2900 5400 2500 8400
4	Ikpoba Dam (D)	Okhoro road (D1) Upper lawani (D2) Dam (D3)	2300 2300 9000
5	Guinness (E)	Brewery (E1) New Benin (E2) Auchi Road (E3) Asaba road (E4)	7500 5760 2650 7115
6	Siluko (F)	Uwelu road (F1) Edo textile (F2) Upper Siluko (F3) Oliha (F4)	1900 7000 4100 7900
7	GRA (G)	Palace (G1) Sapele Road (G2) GRA (G3) Reservation (G4)	7650 800 9000 7400

Table 3: Outage Data for the 33kV Feeders

S/No	Feeder	Outage Duration (hr)	No. of Failures
1	Etete	372.71	367
2	Nekpenekpen	410.32	247
3	Ugbowo	376.41	354
4	Ikpoba Dam	625.05	371
5	Guinness	732.21	405
6	Siluko	536.66	354
7	GRA	210.63	278

Average Service Availability Index, *ASAI (pu)*

$$AS$$

(13)

where 8760 is the number of hours in a calendar year.

Average Service Unavailability Index, *ASUI (pu)*

(14)

System Expected Energy Not Supplied Index, *EENS(MWhr/yr)*

(15)

Average Energy Not Supplied Index, *AENS (k$/yr)*

$$AENS = \frac{T_t}{} \quad = \tag{16}$$

The indices defined above were used to assess the overall behavior of the distribution system. Equations (7) to (16) are system reliability indices calculated in order to capture the severity of a system outage.

III. RESULTS AND DISCUSSIONS

This section provides the results obtained from the simulation of the distribution network. The test system consists of seven major 33/11kV injection substations in Benin City and their associated feeders.

A. Implementation and Simulation Results

The simulation is carried out in two stages using two case scenarios, thereby giving rise to two sets of results.

1) Case 1

Case 1 involves simulation using the data obtained from the existing system. The load input data are fed into the distribution reliability module of ETAP. The distribution network realized in ETAP environment consists of the grid, injection substation transformers, high voltage breakers and lumped loads. The results of the reliability indices for the Case 1 scenario are outlined in Table 4.

2) Case 2

Case 2 considered the improved system scenario. In this case, seven distributed generators, not exceeding 30MW capacity, are added to the Benin Electricity distribution network to improve the reliability of the system. Here, it is assumed that the major problems leading to poor reliability of the distribution system have been eliminated. Also, the manual fuses were replaced with automatic reclosers. The results of the reliability indices for the Case 2 scenario are outlined in Table 5.

Table 5 shows the quantitative values of the improved indices with the application of distributed generators. The employment of the mini plants close to the point of consumption has greatly reduced the outage duration and frequency associated with centralized distribution.

Figure 3 compares two quantitative variables; the expected energy not supplied (EENS) and the annual outage duration. The relationship between the two quantitative variables is represented by a scatter plot graphical display.

Table 4: System Indices for Case 1

Index	Value
SAIFI	0.3360 f / customer.yr
SAIDI	7.2001 hr / customer.yr
CAIDI	21.426 hr / customer interruption
ASAI	0.9992 pu
ASUI	0.00082 pu
EENS	959.624 MW hr / yr
ECOST	6,717,668.00 $ / yr
AENS	0.0063 MW hr / customer. yr
IEAR	7.000 $ / kW hr

Table 5: System Indices for Case 2

Index	Value
SAIFI	0.0185 f/customer.yr
SAIDI	0.6414 hr/customer.yr
CAIDI	34.609 hr/customer interruption
ASAI	0.9999 pu
ASUI	0.00007 pu
EENS	85.162 MWhr/yr
ECOST	555,314.30 $/yr
AENS	0.0006 MWhr/customer.yr
IEAR	6.521 $/kWhr

The EENS on the y-axis serves as the response variable while the annual outage duration on the x-axis represents the predictor variable.

B. Linear Model Derivation

The general equation of a straight line is used to model the relationship dependent variable Y and an explanatory variable X.

Therefore, the relationship between the annual outage duration and the expected energy not supplied (EENS) can be defined by a linear equation whose general form is:

(17)

where a = slope of the line, b = y intercept, and u = annual outage duration

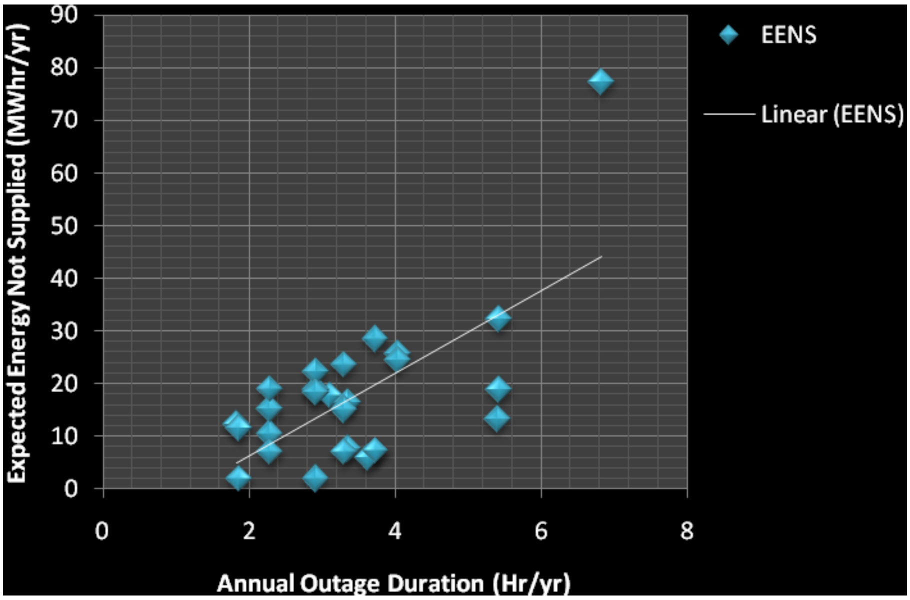

Fig. 3: Correlation between the Annual Outage Duration and the Expected Energy Not Supplied

To derive the linear mathematical model, quantitative values for a and b were calculated. From the plot in Fig. 3, we obtained a = 8, b = - 10, Therefore,

(18)

Hence, for any value of X, the dependent variable Y can be calculated for the Benin City distribution network.
The Figure 3 gives a correlation coefficient of 0.660963062. There is an almost direct correlation between the annual outage duration and the expected energy not supplied. The longer the outage duration, the more the expected energy not supplied.
The scatter plot in Fig. 4 compares the linear relationship between the expected cost of interruption (ECOST) and the annual outage duration (u)

Using a first order polynomial equation adaptation

(19)

Using values from the scatter plot and solving simultaneously we obtain a = 90,000, b= -180,000
Therefore,

(20)

Hence, Equation (20) represents a mathematical model for calculating the relationship between the expected cost of interruption (ECOST) and the annual outage duration (u) for the Benin Electricity Distribution Network.
Figure 4 gives a correlation coefficient of 0.590108. This represents a positive relationship between the annual outage duration and the expected cost of interruption. An increase in outage duration leads to a corresponding increase in the cost of interruption.
The system improvement yielded a promising result. Table 6 is a comparison of the obtained system indices in the existing network and the improved system.

The application of distributed generation has significantly helped to improve the reliability of the Benin electricity distribution network. The 94.4% improvement in SAIFI is amazing as the frequency of interruption has drastically reduced. Also, the expected energy not supplied has decreased by 90.2% thereby reducing the expected cost of interruption.

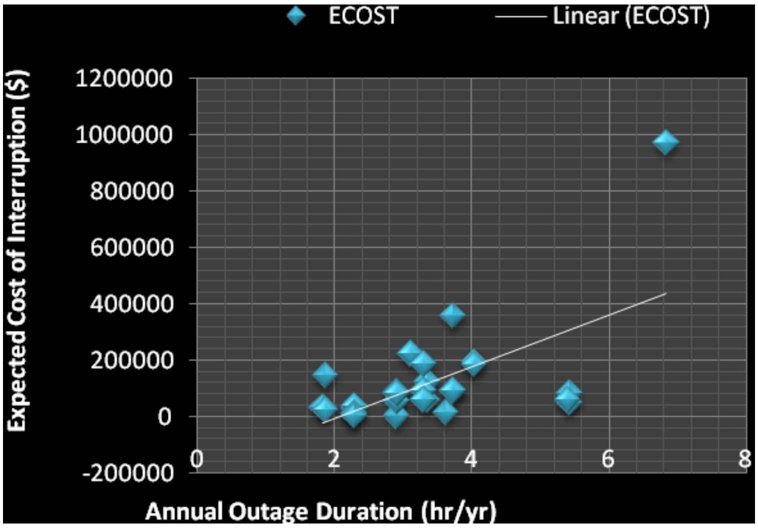

Fig.4.: Correlation between the annual outage duration and the expected cost of interruption (ECOST)

Table 6: Comparison between Existing and Improved System Indices

Index	Existing Value	Improved Value With DG	%	Remark
SAIFI	0.3308	0.0185	94.4	Decrease
SAIDI	6.5236	0.6414	90.2	Decrease
CAIDI	19.718	34.609	75.6	Increase
ASAI	0.9993	0.9999	0.06	Increase
ASUI	0.00074	0.00007	90.5	Decrease
EENS	866.316	85.162	90.2	Decrease
ECOST	5828136	555314.3	90.5	Decrease
AENS	32.0858	0.0006	99.9	Decrease
IEAR	6.727	6.521	3.06	Decrease

IV. CONCLUSION

This paper evaluated outages and assessed reliability in the Benin Electricity Distribution Network. The primary objective of the research was to establish the distribution reliability performance of the Benin City Distribution Network. The feeder outage data assisted in the determination of the duration and frequency of interruptions. The outage data assisted in the calculation of the reliability indices which serve as the parameter for measuring the reliability behaviour of the Benin City Distribution Network.The interpretation of the results provides a means of assessing the state of health (reliability) of the distribution network. Through this effort, it is obvious that outages that arise in distribution systems are responsible for the low level of reliability of the Benin City Distribution Network as expressed by the calculated indices. The reliability performance indices evaluated are useful in determining the severity of the outages experienced by the considered network.

The mathematical analysis of the distribution reliability data offered useful insight into the relationship between the variables. Results established a linear relationship between the annual outage duration and the Expected Energy Not Supplied (EENS). This same trend is also observed between the annual outage duration and the Expected Cost of Interruption (ECOST). Based on the results, it is observed that frequent outages are found to be responsible for the high rate of energy not supplied to the customers and also for the soaring cost of interruption.In order to improve the reliability of the Benin City Distribution Network, distributed generators have been employed. The incorporation of the distributed generators has proved to be an effective strategy in the improvement of the reliability of the distribution system.

REFERENCES

[1]. R. Billinton and L. Wenyaun, *Reliability Assessment of Electrical Power System by Using the Monte Carlo Methods*, New York: Plenum Press, 1994.

[2]. J.J. Popoola, A.A. Ponnle and A.O. Ale, "Reliability worth assessment of electric power utility in Nigeria: Residential Customer Survey results," *AU J.T.*, pp. 217-224, 2011.

[3]. [3] K.H. Adebayo, A.V. Adebayo and I.O. Oladejo, "A reliability assessment of power transmission and distribution systems; Ibadan South-West Nigeria as a case study," *Journal of Research and Development*, vol. 1, no. 2, June 2001.

[4]. [4] R. Billinton and R. Goel, "An analytical approach to evaluate probability distributions associated with the reliability indices of electric distribution systems", *IEEE Trans. Power Delivery*, vol. PWRD-1, pp. 245–251, July 1986.

[5]. [5] R. Billinton, and W. Peng, "Teaching distribution system reliability evaluation using Monte Carlo simulation," *IEEE Trans. on Power Systems*, vol. 14, no. 2, May 1999.

[6]. [6] S. Swati and A. Pahwa, "*A Probabilistic Approach for Animal-Caused Outages in Overhead Distribution Systems*," in Proc. 9th International Conference on Probabilistic Methods Applied to Power Systems, KTH, Stockholm, Sweden – June 11-15, 2006.

[7]. [7] J. Endrenyi, *Reliability Modeling in Electric Power Systems*, New York:Wiley, 1978.

[8]. [8] R. Billinton and W. Li, *Reliability Evaluation of Electric Power Systems Using Monte Carlo Methods*. New York:Plenum, 1994.

[9]. [9] Wang Zhuding, Shokooh Farrokh *and* Qiu Jun, *"*An efficient algorithm for assessing reliability indexes of general distribution systems," *IEEE Trans. on Power Systems*, vol. 17, no. 3, Aug. 2002.

[10]. [10] A. Prado, "Monte Carlo Simulation Applied to Order Economic Analysis," Abstract No: 011-0744, *POMS 20th Annual Conference Orlando*, Florida U.S.A. May 1 – 4, 2009.

[11]. [11] K. Suleiman and U.A. Ali, "Reliability Analysis of Distribution Transformer: A Case Study of Gwiwa Business Unit, Sokoto," *Greener Journal of Science, Engineering and Technology,* vol. 3, issue 3, Feb. 2013.

[12]. [12] A.O. Odior, F.A. Oyawale and G.C. Ovuworie, "Some operations of electric power supply system in Benin City area of Nigeria", American Journal of Scientific and Industrial Research, 2010.