A Model Unavailability Perspective of Existing Nigerian Township Electricity Distribution

Melodi Adegoke Oladipo, Temikotan Kehinde Olusesan
Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Nigeria

Article Info	ABSTRACT
	The study aimed to investigate and obtain model values of system unavailability and cost of energy not supplied in existing Nigerian township electricity distributions using a robust representative system. Outage data was obtained from system records for analysis using frequency distribution statistics to identify the causes of outages, and the contribution of each cause of outage to the overall system outage. The cost of energy not supplied (CENS) due to faults, was evaluated at a rate of NGN6 per kWHr. An analysis of the results shows that in a distribution feeder (and system) unavailability is mainly due to load shedding arising and faults; feeder unavailability involving load shedding is 0.25 and 0.1 without load shedding. Compared with standard UA value for well managed systems of less than or 0.01, the obtained unavailability values for a feeder show that downtime management was poor, and the corresponding cost – prohibitive. In view of the regular load shedding on the feeders and poor downtime management, this study recommends a need to obtain model loadflow perspective of township electricity distribution to ascertain load carrying capacity, and the application of distribution automation system or other effective strategies to mitigate downtime.

Corresponding Author:

Melodi, A. O.
Department of Electrical and Electronics Engineering,
Federal University of Technology, Akure,
PMB 704, Nigeria.
E-mail: melodiadegoke@yahoo.com

1. INTRODUCTION

The electric power distribution system is the most unreliable part of a national power supply system. For example, it contributes up to 81% of all customer outages in the UK [1]. The situation in Nigeria is similar as the distribution system is reported to be the most problematic of the three levels of power supply system. Distribution system unavailability in Nigerian electricity distribution is observed to be poor and aggravated after privatization and deregulation, a measure expected to mitigate electricity and system unavailability problems. This situation brings along with it a new perspective on system unavailability and especially cost of energy not supplied in the Nigerian electricity market; and causes of this unavailability.

Distribution voltages in Nigeria are 33 kV, 11 kV, and 0.4 kV. The most common arrangement for the distribution system is the radial system, in which 11kV feeders emanate from the 33/11 kV injection substation and feed 11/0.4 kV distribution transformers at 0.4 kV load centers. According to [2] and [3], the distribution system has posed a lot of problems to providing economic and reliable power supply in Nigeria due to random nature of growth of cities and poor planning. Generally, poor investment in the power system has been cited as one of the major causes of the poor quality of supply [4]; commensurate system development with township expansions was lacking. According to [5], lots of transformer failures were a major cause of fault outage problems in the distribution sytem. These failures were due to overloading,

insulation breakdown, poor maintenance arising from irregular inspection and reconditioning, and the use of inferior and obsolete protection facilities in distribution substations.

Under state owned operation, some studies had shown that the distribution system had poor reliability values [6-8]. According to [6] and [7], by deduction, the system unavailability was described as 0.36 and 0.32 respectively. These values were obtained on single 11 kV feeder-network composition in 2008 and 2011 time stages respectively. A review of these are necessary for effective planning after some years of operation under private control and new more-inclusive data. In this study the search for model values and conditions of unavailability and especially CENS is expanded to multiple feeder-networks.

According to [9], the Bureau for Public Enterprises declared that aggregate technical, commercial and collection losses sustained by the various privatized distribution companies were between 40 and 50 percent. This paper provide applicable value based unavailability review, assessment, and cost implication for these emerging distribution companies that have taken over the electricity distribution in Nigeria.

For this study, a test system was selected – 11 kV township distribution system of Akure metropolis ($7^0 15'00"$N, $5^0 11'42"$E), the capital of Ondo State in Nigeria. By political plan it became a Millennium City (supported by world agencies) in 2006 hence its current rapid expansion despite existing static capacity limits of power distribution transformers. Figure 1 shows the location of Akure and Ondo State in Nigeria.

Figure 1. Map of the Study Area, Akure, Ondo State, Nigeria

From a survey in the data period, the radial test system consisted of four 33/11kV substations fed from a 132/33kV transmission substation (with three transfomers). The total capacity of the 33/11kV substations was 70MVA. Figure 2 shows the Akure feeder arrangement.
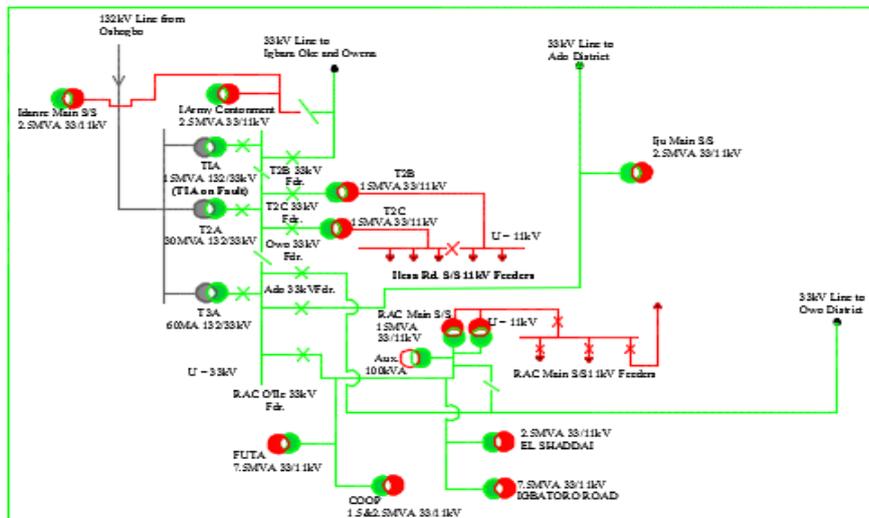
Figure 2. Updated Akure Feeder Arrangement (Source: Author)

Distribution transformer (DT) population and distribution in the test-network are presented in Figure 3 the DTs feed from seven 33/11kV power transformers, which in turn feed from 3x132/33 power transformers. There are eight 11 kV feeders (Fdrs) or delivery areas, denoted alphabetically as A (Oba-ile fdr), B (Ijapo fdr), C (Alagbaka fdr), D (Ilesha rd fdr), E (Isinkan fdr), F (Ondo fdr), G (Oke eda fdr), and H (Oyemekun fdr). Feeder DT population distribution vary from 25 to 144; DT nominal capacities range from 50kVA to 500kVA (144x500kVA, 146x300kVA, 110x200kVA, 80x100kVA and 14x50kVA); Total installed capacity was 146500kVA. The largest contributor is Feeder C (29%). In 2012, this feeder was alleviated by introducing four more feeders into the delivery area, which were powered by newly installed 33/11 kV power transformers (TFs) located at different areas of the delivery area. These include a 2.5MVA (feeding 7 DTs), and a 7.5MVA TF (feeding two feeders). However, their DT populations are still grouped under their parent feeder C in this study.
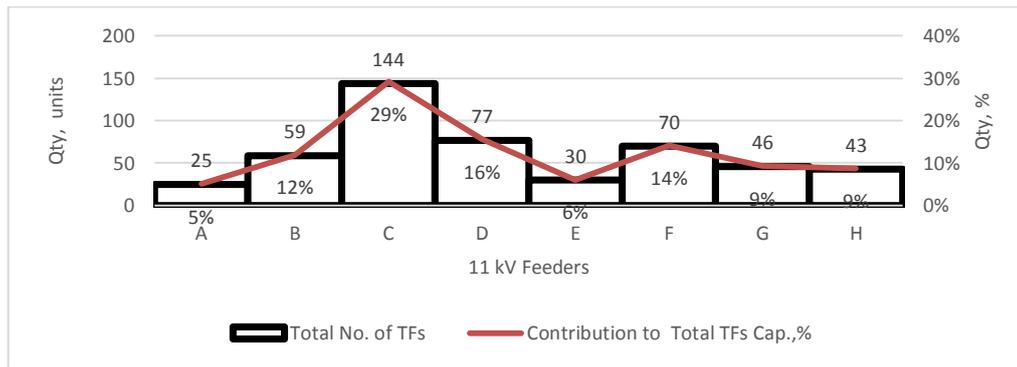
Figure 3. No of Distribution Transformers per Feeder

Basic power system reliability concepts discussed in literature as [1], [6], [7], [10] were considered in deriving an effective algorithm for obtaining model values for Nigerian township system in spite of load shedding events and without need for direct consideration of connected customers. The obtained results would enhance justification for investment in planned off-line and on-line network maintenance to obtain quality service, which is also a requirement by regulations [11], [12].

2.   RESEARCH METHOD

From the system records, 288 serial measurements of outage data were obtained simultaneously for each of the following variables on eight feeders: monthly outage events (E) due to load shedding ("LS"), earth fault ("EF"), open-circuit ("OP"), and others ("O") respectively (Figure 4); and corresponding outage durations (Figure 5) and power loss during outage. Each serial measurement is obtained for a month. The derived data were further grouped into two categories: events and durations with load shedding and without load shedding. These measurements were considered as data for a dummy feeder, representative of the feeders in the network, since the study is about obtaining values for a non-specific feeder in the network.
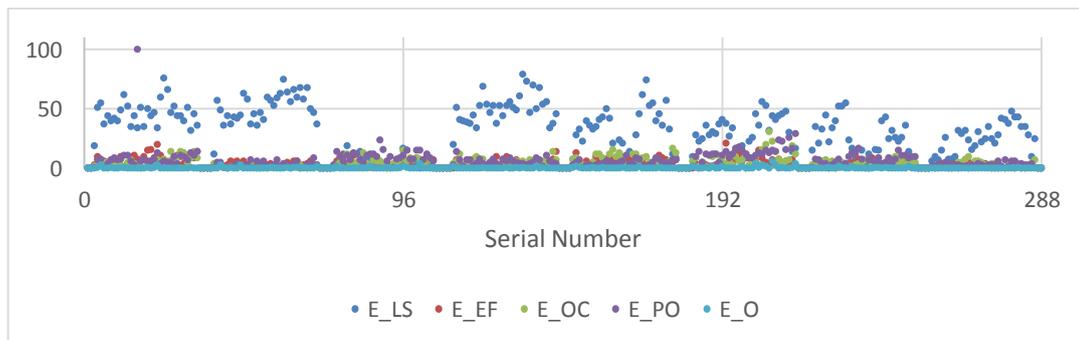
Figure 4. Scatter Plot of Obtainable Outage Events for Various Outage Causes for a Feeder in a Month
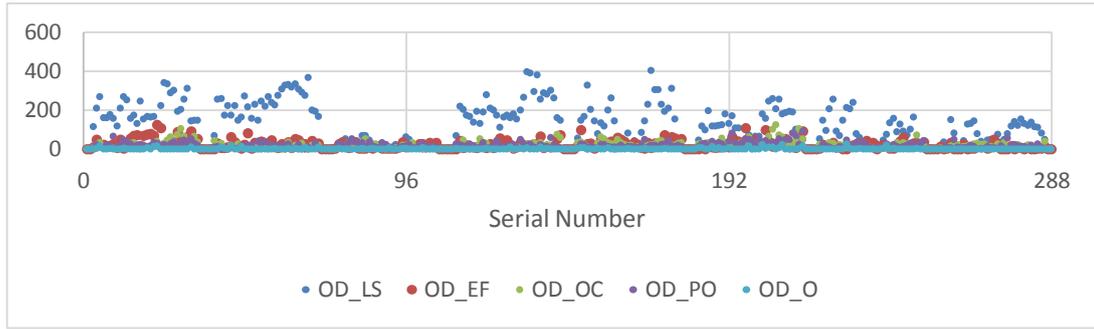
Figure 5. Scatter Plot of Obtainable Monthly Outage Durations for various Outage Causes for a Feeder

The cost of energy not supplied (CENS) on each feeder arising from faults and system failures for the period of the study was evaluated using the following algorithm. From system records outage causes were identified, and the number of outage events and their respective durations for i-th category of outage events in m-th month-measurement were extracted:

$$E_{m,i} = \sum [e \in (m, i)] \, ; i = (\text{"LS", "EF", "OC", "PO", "O"}) = (1, 2, 3, 4, 5) \tag{1}$$

$$OD_{m,i} = \sum OD_{m,i,e} \tag{2}$$

where e and $OD_{m,i,e}$ are simple outage event and duration respectively for i-th outage cause, in m-th measurement; "LS", "EF", "OC", "PO", "O" are 'load shedding', 'earth fault', 'open circuit', 'planned outage', and 'others' categories respectively. Unavailability of feeder in the system for m-th measurement is evaluated as:

$$UA_{m,i} = \frac{OD_{m,i}}{T_m}; \tag{3}$$

where T_m is number of hours in corresponding measurement month, when outage due to load shedding is considered. When outage due to "LS" is not considered, effective number of hours in m-th measurement is considered as T'_m:

$$T'_m = T_m - OD_{m,1} \tag{4}$$

where $OD_{m,1}$ is outage due to load shedding.
        Overall outage of system and unavailability in m-th measurement for a feeder:

$$OD_m = \sum OD_{m,i} \, ; \, UA_m = \frac{OD_m}{T_m} \tag{5}$$

Average unavailability index (AUA) was created and proposed to evaluate feeder UA for M measurements:

$$AUA_M = \frac{\sum_{m=1}^M UA_m}{M} = \frac{1}{M} \sum_{m=1}^M \left(\frac{OD_m}{T_m} \right) \tag{6}$$

Also 96 measurements correspond to one year data. The energy not supplied due to i-th outage cause for m-th month ($ENS_{m,i}$) is evaluated as:

$$ENS_{m,i} = \sum_{e=1} P_{m,i,e} OD_{m,i,e} \tag{7}$$

where $P_{m,i,e}$ and $OD_{m,i,e}$ are outage power and duration respectively for e-th outage event, i-th outage cause, and m-th measurement; data of these variables are extracted form system records for the considered period.

The distribution system ENS for m-th measurement is obtained as:

$$ENS_m = \sum_{i=1} ENS_{m,i} = \sum_{i=1}\sum_{e=1} P_{m,i,e}\, OD_{m,i,e} = \sum_{i=1}\sum_{e=1} P_{m,i,e} \sum_{i=1}\sum_{e=1} OD_{m,i,e} = P_m OD_m \qquad (8)$$

where P_m and OD_m are equivalent active power not supplied (MW) and total outage duration for the system for m-th measurement. Average power loss per feeder for m-th measurement:

$$P_{m(av)} = \frac{P_m}{E_m} \qquad (9)$$

ENS for M-th interval is defined as:

$$ENS_M = \sum_{m=1}^{M} P_m\, OD_m \qquad (10)$$

Cost of energy not supplied for period M is evaluated as:

$$CENS_M = \beta \cdot 10^{-3} ENS_M = \beta \cdot 10^{-3} \sum_{m=1}^{M} P_m OD_m \qquad (11)$$

where β is unit cost of energy, 6 NGN per kWHr. The expected monthly ENS and CENS for period M are denoted $AENS_M$, and $ACENS_M$:

$$AENS_M = M^{-1} \sum_{m=1}^{M} P_m\, OD_m; \quad ACENS_M = \beta \cdot 10^{-3} M^{-1} \sum_{m=1}^{M} P_m OD_m \qquad (12)$$

3. RESULTS AND ANALYSIS

An analysis of outage data reveals the causes of power outages and the frequency at which each factor contributed to power outages in the network on feeder by feeder basis. Unavailability UA on the 11kV feeders comprises the contributions from load shedding (Ls), earth fault (Ef), open circuit (Oc), planned outages (Po) and others (O). Table 1 is a summary of outage frequency and duration distribution statistics of obtained data. Out of 12,961 events, load shedding contributed 66%. Load shedding also accounted for 58% of total outage hours during the study period.

Table 1. Summary of Obtained Outage Data

FEEDER	E					OD, hrs					Total E	Total_OD, hrs
	LS	EF	OC	PO	O	LS	EF	OC	PO	O		
A	817	42	103	100	1	1155	257	419	365	0	1063	2196
B	796	125	130	232	11	863	592	472	508	50	1294	2485
C	1001	196	279	437	35	1667	993	1169	1224	106	1948	5159
D	1459	259	181	329	13	6122	1454	801	770	39	2241	9186
E	1634	104	47	104	16	7095	774	326	369	30	1905	8594
F	1604	133	154	177	9	2764	697	577	565	35	2077	4639
G	148	147	163	313	15	517	442	505	519	21	786	2004
H	1064	171	250	152	10	2172	1051	830	490	29	1647	4571
Total	8523	1177	1307	1844	110	22354	6260	5100	4810	311	12961	38834

Figure 6 shows that, in a feeder, monthly unavailability due to LS could reach 0.54. Whereas UA due to earth fault and OC causes can reach 0.22 and 0.23 respectively. In addition, Figure 7 shows that the monthly unavailability of the system could reach 0.62. Without load shedding, the unavailability of a feeder would reduce to approximately 0.36. In essence, this is the effective unavailability (UA') of a feeder in the system. As M increases to maximum data interval, Figure 8 shows that the average UA of a feeder returns a steadied value of approximately 0.25; and without load shedding, it reduces to 0.10. Average UA of a feeder due to load shedding, earth fault, open circuit faults, planned outage, and others are approximately 0.17, 0.04, 0.03, 0.03, and 0.02 respectively. These values establish that a feeder in the system is in blackout on aggregate period of 36 days annually due to faults and planned outages. Prevailing load shedding increases the expected blackout days to about 91 days. Clearly, the highest contributor to UA is load shedding, and the next in rank is earth fault. This high unavailability values imply that downtime management is substandard. In well run power distribution, UA should be less than 0.01 [1]. Comparatively, the obtained value of 0.1 for the test system is very high and indicates poor downtime management. This finding underscores a need for feeder automation, that is, automated fault location isolation and service restoration (FLISR) system.
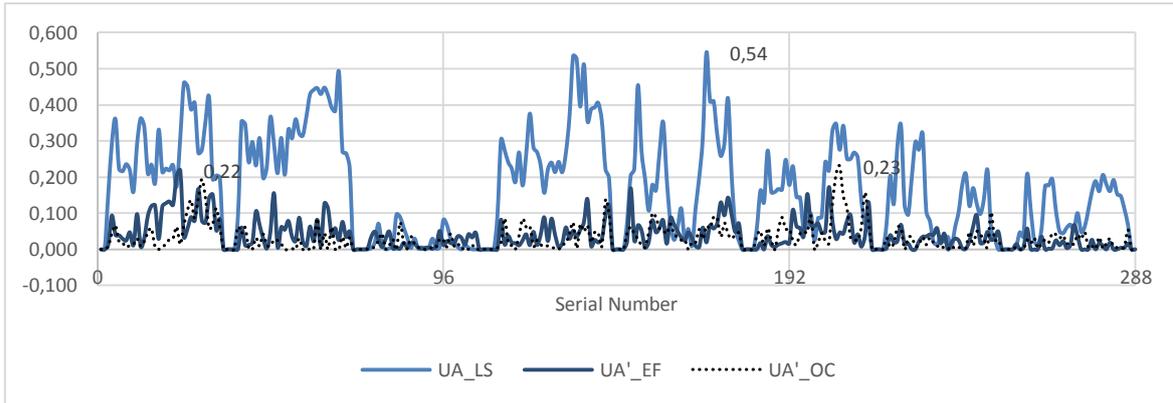
Figure 6. Variations of Feeder Unavailability due to LS, EF, and OC
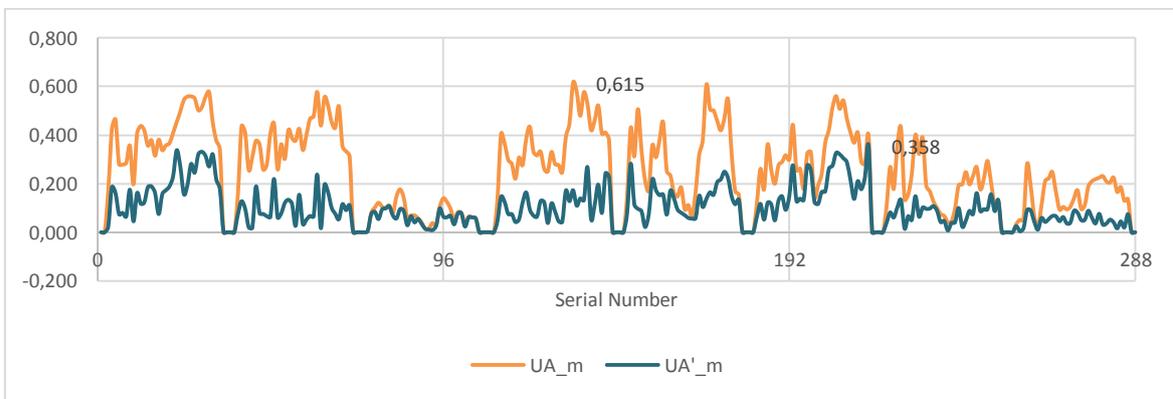
Figure 7. Variations of Feeder Unavailability Overall Downtime
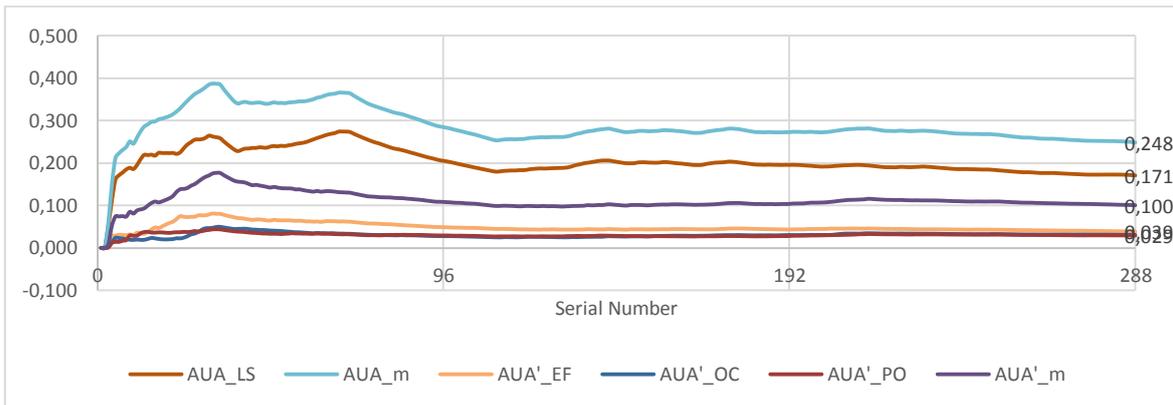
Figure 8. Obtainable Feeder AUA Due to LS, EF, PO, and Overall Downtimes

Figure 9 presents data of obtainable average active power losses in a feeder due to downtime. It shows that the unsupplied MW during downtime can be as high as 11 MW in exceptional cases of LS, but normally clusters around a mean value of approximately 5 MW. Figure 10 shows the ENS obtainable on a feeder for a month, which could be as high as 186,199,754 kWH with consideration for downtime through load shedding. Figure 11 shows that the obtainable ENS due to fault only could only be as high as 26,979,357 kWH, which is a lot lesser in comparison when there is load shedding. Figure 12 shows that the corresponding CENS are approximately 1117 million naira and 162 million naira respectively.
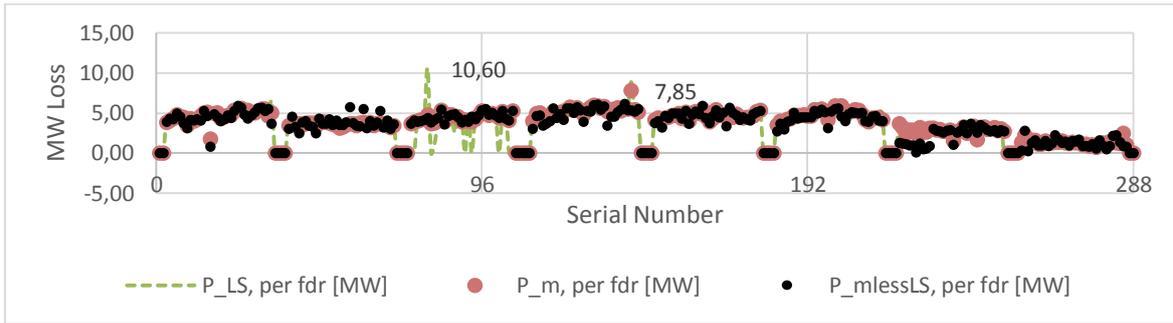
Figure 9. Obtainable Average Active Power Losses in a Feeder in a Month Due to downtime
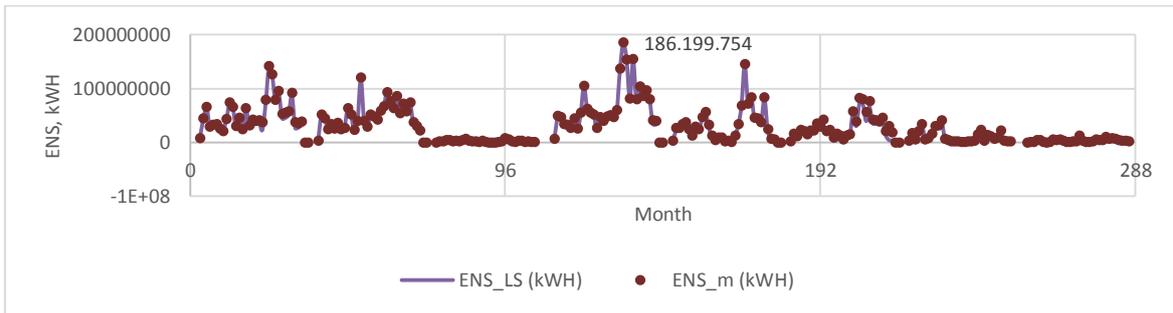
Figure 10. Obtainable Values of ENS in a feeder in a month due to downtime
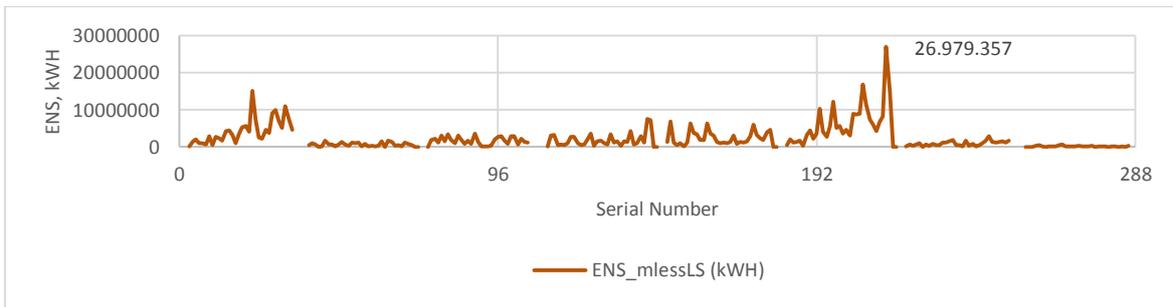
Figure 11. Obtainable Values of Feeder ENS in a month without LS
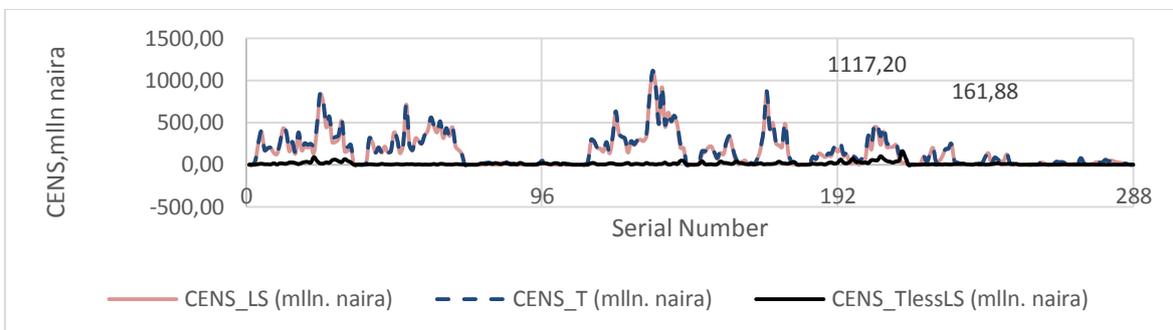
Figure 12. Obtainable Values of Feeder CENS in a month due to LS, without LS, and Overall Downtime

Considering varying data interval M, Figure 13 provides obtained cumulative CENS for the data interval; at a scale of 92 serial data corresponding to one year data. Figure 5 shows, by deduction, an average

loss of 1,197 million naira per annum due to downtime without load shedding, and an average loss of 16,082 million naira per annum due to downtime with load shedding in a feeder.

Following the M concept explained above, Figure 14 provides plots of obtained ACENS for a feeder. Figure 14 shows obtained and corresponding average CENS as 12.52 million naira per feeder per month due to downtime without load shedding and 167.52 million naira per feeder per month with load shedding.
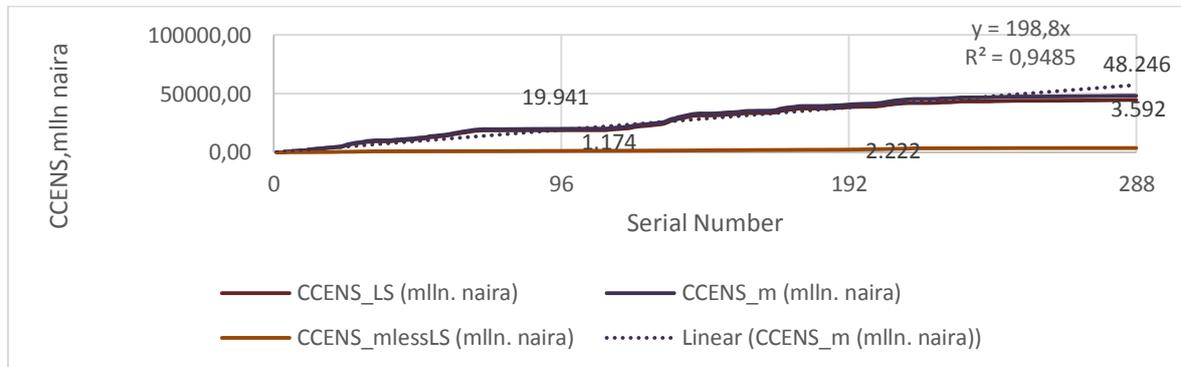
Figure 13. Variation of Feeder Cumulative CENS
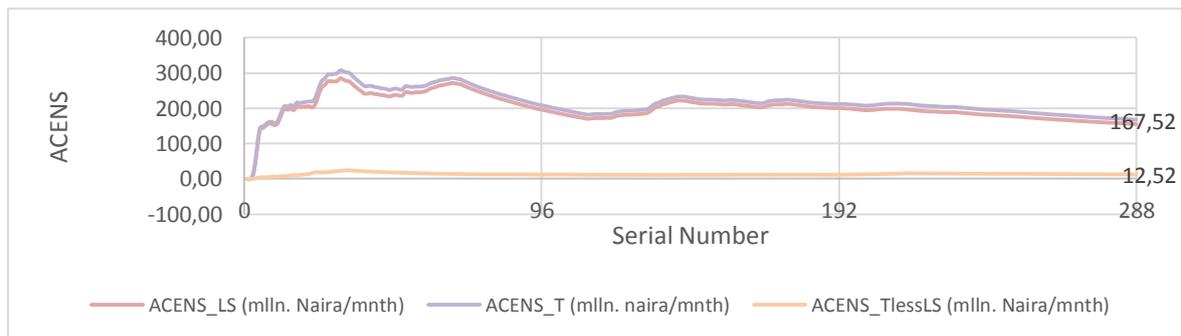
Figure 14. Variation of Feeder Average Cost of Energy not Supplied (ACENS)

From the analyses above, this study provides descriptive values for the distribution system useful for characterizing its prevailing unavailability constraint and reliability, and justifying technical-economical needs for system upgrading schemes, especially automation.

4. CONCLUSION

Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

In this study an analytical algorithm was deployed to evaluate system unavailability and cost of energy not supplied in a Nigerian township electric power distribution. From an analysis of the results obtained, the following conclusions and contributions are made:

i. Distribution Feeder (and system) unavailability is mainly due to load shedding arising (possibly from low generation and insufficient distribution capacity) and faults; feeder unavailability involving load shedding is 0.25, and 0.1 without load shedding. Compared with standard UA value for well managed systems of less than or 0.01, the obtained unavailability values for a feeder show that downtime management was poor.

  ii. The frequency of planned outages, 1,844 times in 32 months and the high number of hours (4,810 hours) spent on them, an average of 2.6 hours per planned outage, are an indication of a weak or aging infrastructure and a lack of redundancy in the network.

  iii. The loss of revenue due to poor downtime management was approximately NGN168 million per month (at NGN 6 per kWHr), provided collection rate was adequate and there was no energy theft; approximately, 92% of this amount is due to daily load shedding schemes.

In view of these conclusions, it is recommended that model loadflow perspective should be obtained for the township feeders to ascertain capacity to accommodate prevailing load; and downtime mitigating technologies such as automation systems should be installed in the existing electricity distribution infrastructure to mitigate fault detection duration and downtime. A saving, by the utility, of about ten percent of obtained CENS or revenue loss on downtime could fund the implementation of system reinforcements through automation and/or other effective downtime mitigation strategies.

REFERENCES

[1] R. Billinton and R. N. Allan, Reliability Evaluation of Power Systems, 2nd edition, New York: Springer Private Limited, 2008.

[2] L. A. Amu and S. F. A, The Development of The Nigerian Electric Power System (1973 – 1990), Lagos: University of Lagos Press and Bookshop Limited, 2015.

[3] A. O. Melodi and S. R. Famakin, "A Review of Solar PV-Grid Energy Cost Parity in Akure, South-West Nigeria," *International Journal of Electrical and Computer Engineering,* vol. 5, no. 5, pp. 879-886, 2015.

[4] A. Iwayemi, "Investment in Electricity Generation and Transmission in Nigeria: Issues and Options," International Association for Energy Economics, 2008. [Online]. Available: www.iaee.org.

[5] S. O. Adeyemo and E. Abutu, *Transformer Failures in the National Grid-Engineers Experience and Challenges,* vol. II, Lagos: Electrical Division of the Nigeria Society of Nigeria, Lagos, 2004.

[6] A. O. Melodi and K. O. Temikotan, "Problems of Nigerian Local Electric Distribution Networks: A Case Study of a University Environment in the South West Region," *Journal of Sustainable Technology (JoST),* vol. II, no. 2, pp. 82-95, 2011.

[7] A. O. Melodi and P. T. Ogunboyo, "Power Distribution Problems on 11 kV Feeder Networks in Akure, Nigeria. IEEE Xplore, 292-300," *IEEE Xplore,* pp. 292-300, 2013.

[8] J. J. Popoola, A. A. Ponnle and T. O. Ale, "Reliability Worth Assessment of Electric Power Utility in Nigeria: Residential Customer Survey Results," *AUJ.T,* pp. 217-224, 2011.

[9] O. Olaniyan, "Power Reforms Enter Crucial Stage," *Electrical Engineering and Telecommunications Magazine (ee + T),* vol. VII, no. 1, pp. 5-7, 1 October 2013.

[10] M. Al-Muhaini, G. T. Heydt and A. Huynh, "The Reliability of Power Distribution Systems as Calculated Using System Theoretic Concepts," *IEEEXplore Digital Library,* pp. 1-8, 2010.

[11] Nigerian Electricity Regulatory Commission (NERC), *The Distribution Code for the Nigeria Electricity Distribution System (Version 01, Section 4.3.1),* Abuja: Nigerian Electricity Regulatory Commission, 2006, p. p.31.

[12] S. Afshar and M. F. Firuzabad, "Reliability and Cost Model of P.M. in A Component of an Electrical Distribution System Considering Ageing Mechanism," *International Journal of Electrical and Computer Engineering (IJECE),* vol. IV, no. 2, pp. 193-199, 2014.