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IMPACT OF POWER DISTRIBUTION FEEDER'S CONTRIBUTIONS TO SYSTEM RELIABILITY INDICES

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ABSTRACT

System reliability is the ability of the power system to provide an adequate supply of electrical power at a desired time without interruption. Reliability indices are the parameters used for a comprehensive assessment of electrical power systems reliability. This study employed System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI) as reliability indices to analyze the impact of power distribution feeder's contribution to system reliability indices. Ten distribution feeders were selected from Kaduna and Kano distribution feeders and computed using appropriate mathematical relations. In addition, a comprehensive comparative analysis of these feeders were made to evaluate their reliability levels. The results show that mean SAIDI for Kaduna and Kano distribution systems were 0.0012 and 0.0007, respectively. This shows that Kano distribution systems is comparatively less reliable compared to Kaduna distribution systems due to prolonged period of interruptions recorded on most of the feeders attached to the systems. The mean SAIFI for Kaduna and Kano distribution systems were 0.0032 and 0.0.0016, respectively. This indicates that most of the customers attached to Kaduna distribution system feeders were served adequately compared to Kano distribution system feeders even though most of the faults recorded on Kaduna were cleared on time, thus making Kano distribution system to be relatively less reliable. Kaduna and Kano distribution systems have mean CAIDI contributions of 0.0054 and 0.0032, respectively. The result shows that fewer of the customers attached to Kano distribution system were adequately served, as a result of prolonged interruptions recorded on the system, while many of the customers attached to Kaduna distribution feeders were adequately served, which is evident from low level of faults on the distribution system. The findings from this study provide a basis for power system engineering for planning and maintenance strategies.

KEYWORDS: *Feeder's Contributions, Reliability Indices, SAIDI, SAIFI, CAIDI, Feeders, Distribution Systems*

INTRODUCTION

The major role of electric power system is to provide a reliable and continuous supply of electrical energy, so as to satisfy system load. However, for the proper realistic planning of an economic activity, the reliability of the power system must be taken into consideration by the entrepreneur. System reliability is the ability of the power system to provide an adequate supply of electric power with a suitable quality. In addition, the power system reliability assessment can assist power system operators in evaluating alternative facilities and to justify economically each of the additional facilities (Min *et al.*, 2009).

Reliability indices are a way of judging the performance of an electrical power system. Electric power system has three main components via generation, transmission and distribution systems. Electricity is generated and transferred through transmission line to distribution systems for supplying load demands. Both the generation and transmission systems are referred to as composite system or the bulk power system (Wang 2003, Singh and Billinton, 2005). However, distribution systems are normally designed in mesh, but the operation is always configured radially. The configuration of distribution system may be modified manually or by automatic switching operations for supplying the loads aiming at minimizing the cost of active power losses (Khodr *et al*, 2009).

For evaluation of reliability indices, the commonly operating systems are classified into two main categories: repairable and non-repairable. Repairable systems repair and put the system components back into operation after components failure, whereas a non-repairable system fails to repair system components after components' failure and it needs to be replaced by a new one. However, most of the electric power systems' failures are repairable systems. Therefore, effective reliability analysis is an essential factor in operational planning of electric power system (Meliopoulos *et al.,* 2017).

Accurate analysis of power system reliability will help power system engineering to predict future failure behavior of power system and also help in making appropriate maintenance plans (Endrenyi and Anders, 2006; Endrenyi *et al.,* 2018). Distribution power system reliability is greatly affected by outages caused by various environmental factors on overhead lines. Therefore, it is necessary to investigate this outage since animals cause most significant of the outages on overhead distribution systems (Min *et al.,* 2009).

This study therefore employed a Homogeneous Poisson Process (HPP) and inverse of exponential distribution function for non-aging model and for aging model, Power Law Process (PLP) model for a Non-Homogeneous Poisson Process (NHPP) was implemented. This model was able to accommodate data with zero positive or negative aging with proper choice of parameters.

Related Works

Billinton (2014) illustrated a probabilistic technique to assess the operating reserve requirements in a distribution system. This technique combined deterministic criteria with probabilistic indices to monitor the system of well-being as designated by deterministic criteria. A risk index designated as the Generating System Operating State Risk (GSOSR) was defined as the probability of residing in an undesirable operating state. The technique together with the effect on the GSOSR and the system operating state probabilities of factors such as lead time, systems peak load, load forecast uncertainty and generating unit derated states were illustrated. The approach provides a basic framework, which could be extended to include other operating capacity reserve considerations.

Endrenyi *et al.*, 2018, proposed an efficient new approach for power system reliability evaluation using decomposition simulation approach. The interconnected system in this approach has been modeled by a probabilistic flow network, each area is denoted by a node in the network source, while loads are represented by additional nodes.

Mahmud and Saeed (2009) presented reliability analysis on electrical distribution system by considering preventive maintenance applications on circuit breakers. The impacts of failure rate variations caused by preventive maintenance were examined. This was considered as part of a Reliability Centered Maintenance (RCM) application program. A number of load point reliability indices are derived using the mathematical model of the failure rate, which was established using the observed data in a distribution system. The results of the preventive maintenance application were presented based on study and modeling of failure rates in breakers of electrical distribution system.

Billinton and Allan (2006) incorporated DC load flow model in the decomposition simulation method for multi-area reliability evaluation. State enumeration approach using topological analysis has been used to evaluate bulk power system reliability. System frequency, duration and availability indices have been obtained using topological enumeration. The method requires the use of AC or DC load flow to test the condition of contingency state.

Deng and Singh (2012) presented a methodology to evaluate the reliability and calculate interruption costs at the load bus level in the bulk power system. The methodology is based on a non-sequential Monte-Carlo simulation combined with a linear optimization model in which the load at every bus was represented by two components. Expected values of "not served energy", "not served demand" and LOLP are computed for the whole system.

Mirrasoul and Karen (2009) presented modeling and analysis of distribution reliability indices using Monte Carlo simulation method. The sensitivity of the reliability indices to the choice of model is presented. Finally, the impact of protection devices on the statistical distribution of SAIFI for a practical distribution feeder is presented.

MATERIALS AND METHODS

The performances of power system distribution feeders normally evaluate using mean values, variance and standard deviation of the relevant reliability indices. However, in most systems, reliability indices are the expected values normally indicated by the central tendency of a random variable and adequate primary index of system.

Monte Carlo Simulation technique, which is time consuming cannot be used to improve the reliability indices of distribution systems. In this work, the three major system reliability indices for the assessment of power distribution systems will be used for a comparative analysis of Kaduna and Kano feeders' contributions to system reliability indices. These indices are the System Average Interruptions Duration Index (SAIDI), System Average Interruptions Frequency Index (SAIFI) and Customer Average Interruptions Duration Index (CAIDI).

- National Control Center (NCC), Osogbo was visited to collect raw data.
- Ten years of outage information from Kaduna and Kano distribution feeders on Nigeria
- National Grid was collected from NCC Osogbo.
- The data collected from NCC, Osogbo include:
- Recorded faults on each of the selected distribution feeders' system from the study period.
- Recorded outage times on each of the selected distribution systems.
- Recorded number of customers served on each of the distribution systems.
- Recorded number of customers' interruptions on Kaduna and Kano distribution systems.

Mathematical Computation of Kaduna and Kano Distribution Feeders' Contributions

The contributions of Kaduna and Kano distribution feeders to the system reliability indices were computed using the notable reliability indices – SAIDI, SAIFI and CAIDI as follows:

System Average Interruption Duration Index, SAIDI is given by

$$SAIDI = \frac{Customer \ \text{int}\ erruption \ durations}{Total \ Number \ of \ Customers \ Served}$$

$$= \frac{\sum_{i=1}^{n} r_i N_i}{\sum_{i=1}^{n} N_T} \quad (1)$$

System Average Interruption Frequency Index, SAIFI is given by

$$SAIFI = \frac{Total \ number \ of \ customer \ \text{int}\ erruptions}{Total \ Number \ of \ Customers \ Served} = \frac{\sum_{i=1}^{n} N_i}{\sum_{i=1}^{n} N_T} \quad (2)$$

Customer Average Interruption Duration Index, CAIDI is given by

$$CAIDI = \frac{Customer \ \text{int}\ erruption \ durations}{Total \ Number \ of \ Customers \ Interruption}.$$

$$= \frac{\sum_{i=1}^{n} r_i N_i}{\sum_{i=1}^{n} N_i} \quad (3)$$

where

r_i = Restoration time for each interruption for the i[th] customer.

N_i = Number of interrupted customers for each interruption event during reporting period.

N_T = Total number of customers served for area being indexed.

$$SAIFI = \sum_{i=1}^{n} \left(SAIFI^{c} \right) \quad (4)$$

$$SAIDI = \sum_{i=1}^{n} \left(SAIDI^{c} \right) \quad (5)$$

$$CAIDI = \sum_{i=1}^{n}\left(CAIDI^{c}\right) \tag{6}$$

where

$SAIFI^c$= Contribution to SAIFI from the feeders

$SAIDI^c$= Contribution to SAIDI from the feeders

$CAIDI^c$= Contribution to CAIDI from the feeders

$$SAIFI^{c} = \frac{\lambda_i I_i}{n_i} \tag{7}$$

$$SAIDI^{c} = \frac{\lambda_i\left(\sum_{j=1}^{I_i} d_{ij}\right)}{n_i} = \frac{\lambda_i D_i}{n_i} \tag{8}$$

$$CAIDI^{c} = \lambda_i\left(\frac{D_i}{I_i}\right) \tag{9}$$

where

λ_I = Failure rates of feeders i.

$_{Ii}$ = Number of customers experiencing sustained interruptions

due to a failure of feeders i.

d_{ij} = Interruption duration for customer *j* due to a failure of feeder *i*.

n_i = Total number of customers on a feeder i.

D_i = Sum of customers interruption duration due to a failure of

DISCUSSION OF RESULTS

Case Study 1: Kaduna Distribution System.

FDR 3 feeder of Kaduna distribution system had the highest mean SAIDI of 0.1064 with a standard deviation of 0.0516 and a SAIDI contribution of 0.0010, as shown in Fig. 1. Customers connected to this distribution feeder were exposed to long time of interruption leading to complete period of darkness. Junction Road feeder recorded the least mean SAIDI of 0.0704 with a standard deviation of 0.0384 and a SAIDI contribution of 0.0010. Customers on this feeder experienced intermittent interruption.

St. Gorald feeder had the highest mean SAIFI of 0.2727, a standard deviation of 0.0958 and a SAIFI contribution of 0.0053, as shown in Fig. 2. This feeder also recorded the least mean CAIDI of 0.2770, a standard deviation of 0.1968 and a CAIDI contribution of 0.0054, as displayed in Fig. 3.

The contribution to total system reliability indices for Kaduna distribution system is shown in Figure 4, while Figure 5 illustrates the contribution to mean total system reliability indices for Kaduna distribution system.

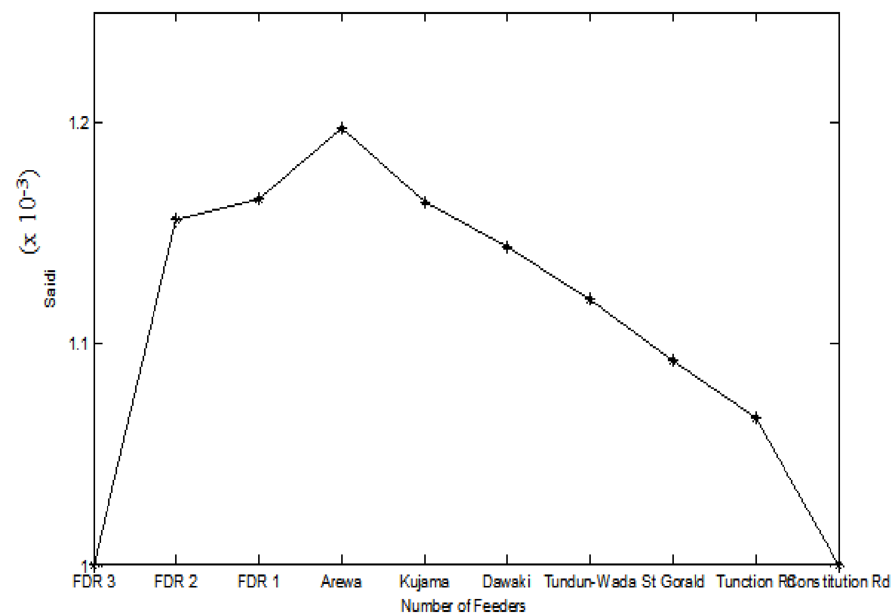

Figure 1: Contribution to SAIDI for Kaduna Distribution System.

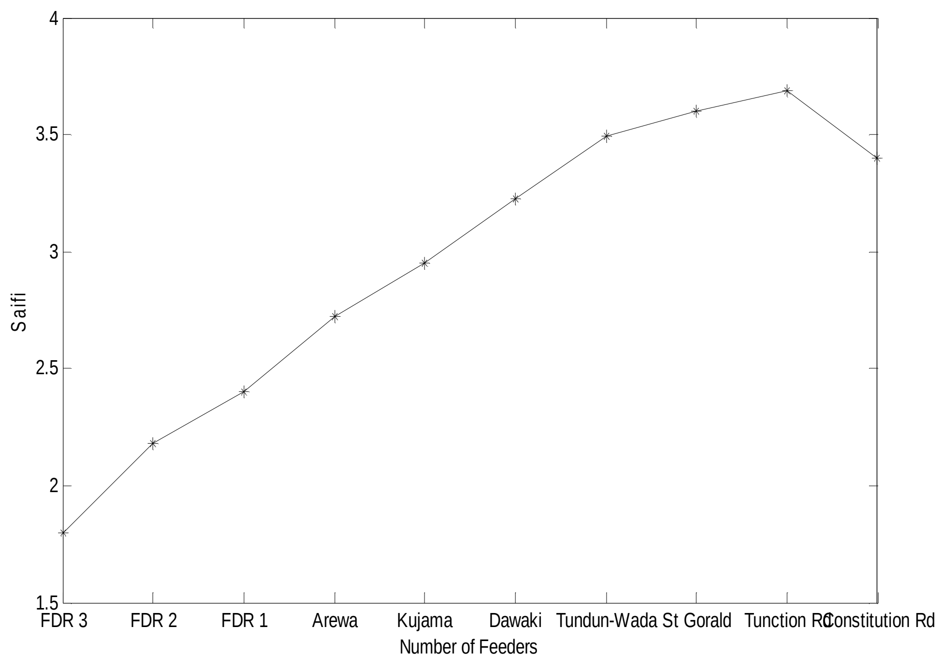

Figure 2: Contribution to SAIFI for Kaduna Distribution System.

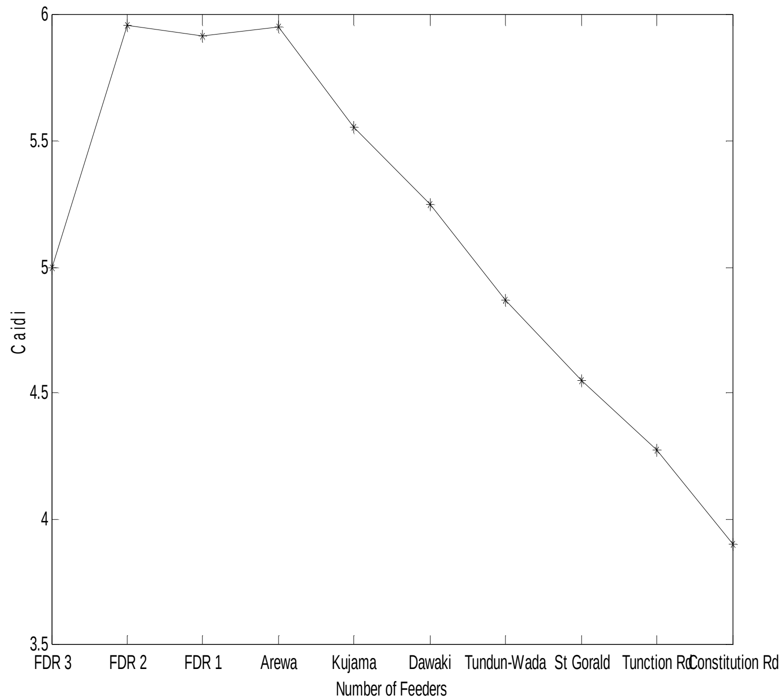

Figure 3: Contribution to CAIDI for Kaduna Distribution System.

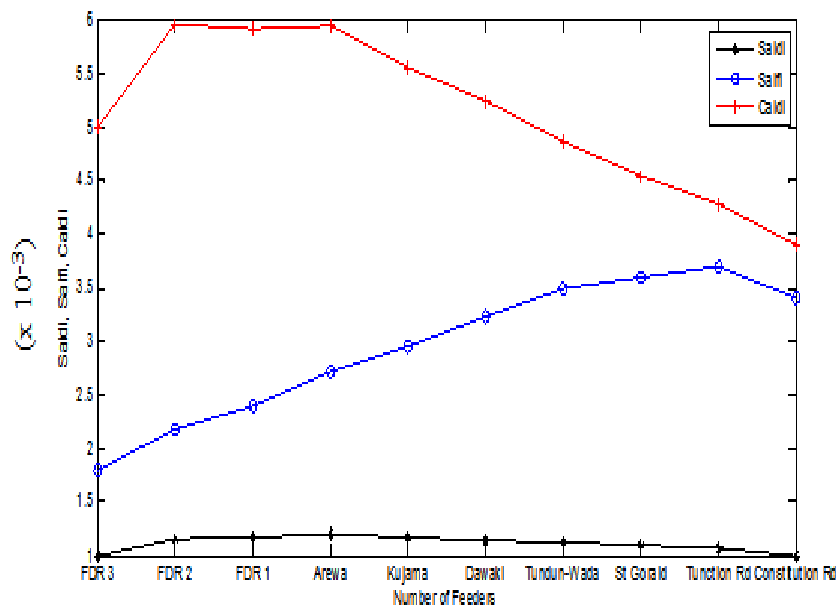

Figure 4: Contribution to Total System Reliability Indices for Kaduna Distribution.

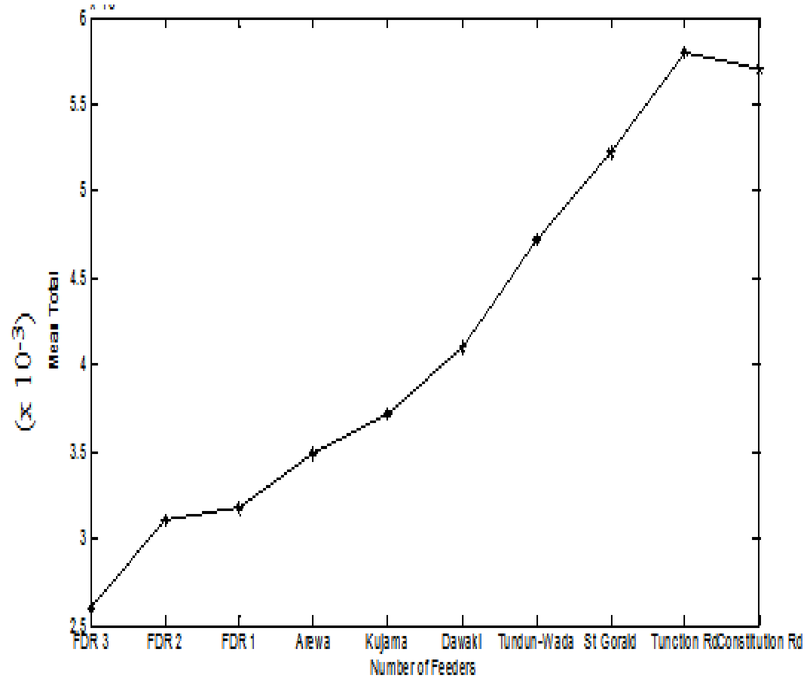

Figure 5: Contribution to Mean Total System Reliability Indices for Kaduna Distribution System.

Case Study 2: Kano Distribution System

Bangauda feeder of Kano distribution system recorded the highest mean SAIDI of 0.1462 with a standard deviation of 0.0128 as well as the highest mean CAIDI of 0.6263 with a standard deviation of 0.1170. Bangauda had SAIDI and CAIDI contributions of 0.0031 and 0.0132, respectively. This is because the prolonged period of interruption had put the customers on this feeder in a complete darkness since the faults were not cleared.

The least mean SAIDI of 0.0497, a standard deviation of 0.0153 and a SAIDI contribution of 0.005 were recorded on spare feeder of this distribution system, as shown in Fig. 6. Spare feeder also had the highest mean SAIFI of 0.2384, a standard deviation of 0.0144 and a SAIFI contribution of 0.0023, as shown in Fig. 7. Customers on this feeder experience frequent interruptions, while only few of them were adequately served. Waterworks feeder had the least mean SAIFI of 0.1989, a standard deviation of 0.0101 and a SAIFI contribution of 0.0020. Many of the customers attached to this feeder were adequately served.

Spare feeder of Kano distribution system recorded the least mean CAIDI of 0.2083, a standard deviation of 0.0631 with a CAIDI contribution of 0.0020, as illustrated in Fig. 8. Many customers connected to this feeder experienced a short period of interruptions. The contribution to total system reliability indices for Kano distribution system is shown in Figure 9, while Figure 10 illustrates the contribution to mean total system reliability indices for Kano distribution system

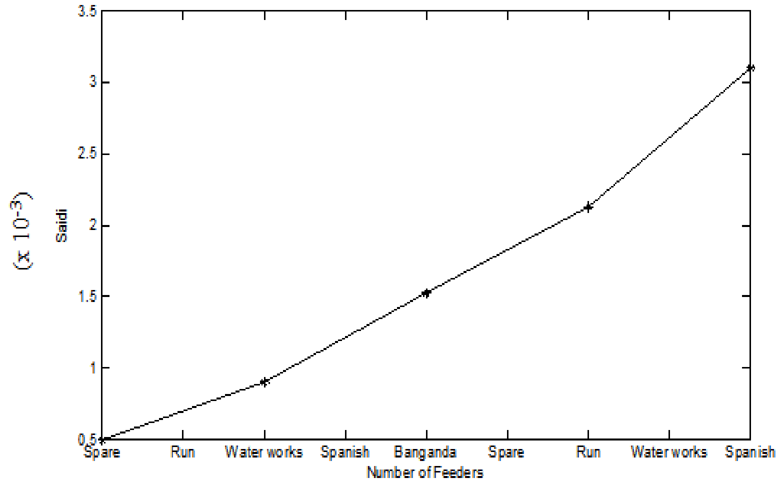

Figure 6: Contribution to SAIDI for Kano Distribution System.

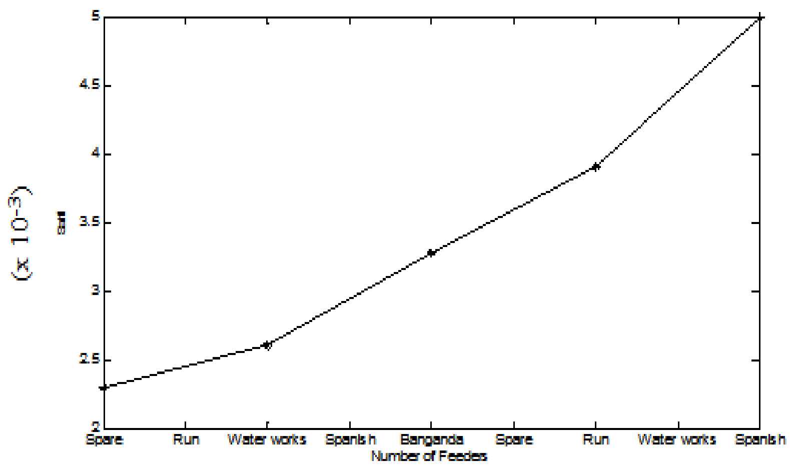

Figure 7: Contribution to SAIFI for Kano Distribution System.

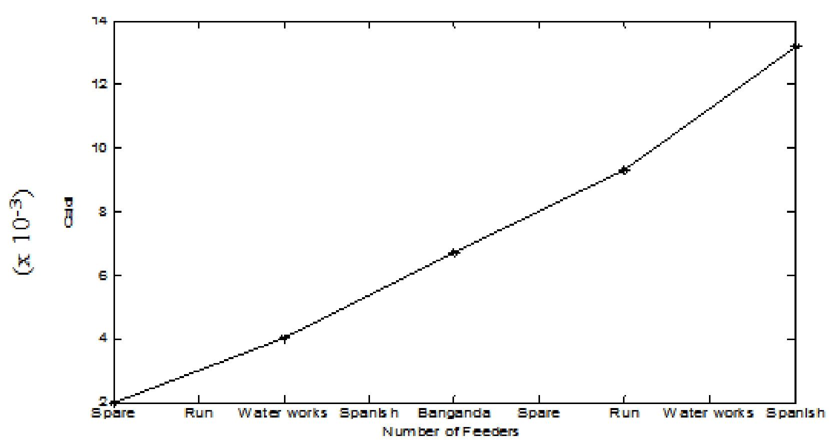

Figure 8: Contribution to CAIDI for Kano Distribution System.

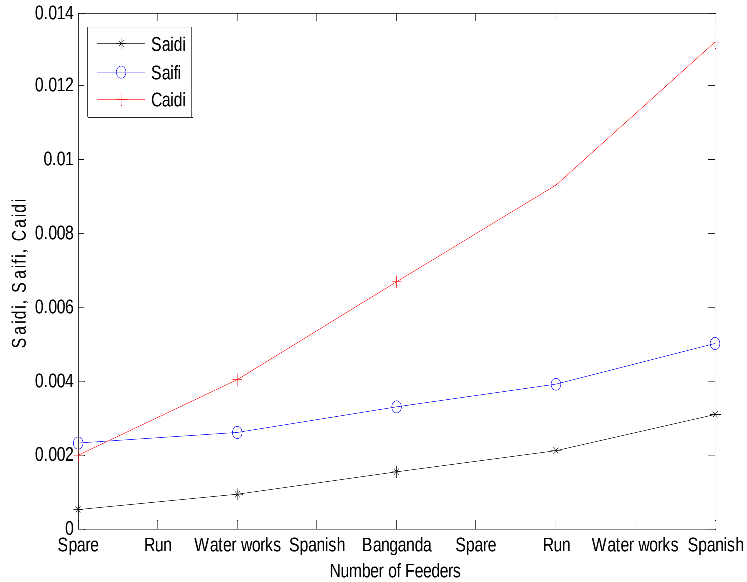

Figure 9: Contribution to Total System Reliability Indices for Kano Distribution System.

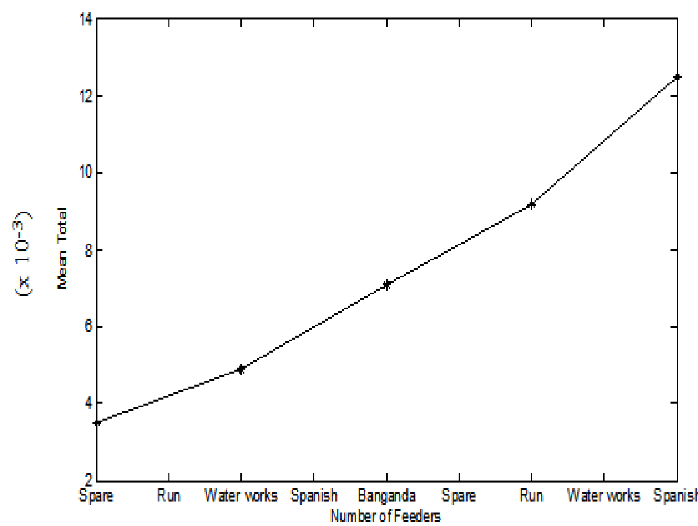

Figure 10: Contribution to Mean Total System Reliability Indices for Kano Distribution.

Comparative Analysis of Kaduna and Kano Distribution Feeders' Contributions to System Reliability Indices

Table 1 shows a comparative analysis on Kaduna and Kano power distributions/contributions to system reliability indices.

Observation shows that Kaduna distribution system has an average SAIDI contribution of 0.0012, while the SAIDI contribution of Kano is 0.0007 suggesting the fact that a prolonged period of interruptions was recorded on most of the feeders on Kano distribution system. The interruptions remain uncleared for a long time, thereby placing all the customers attached to those feeders in a complete blackout. The faults recorded on Kaduna distribution systems feeders were cleared at intervals of occurrence even though they were not as prolonged as in Kano distribution system, thus making customers attached to some of the feeders to have a comparatively reliable power supply.

The mean SAIFI contributions to system indices were 0.0032 and 0.0016 for Kaduna and Kano power distribution systems, respectively, indicating that Kaduna distribution system has contributed as much as twice the SAIFI contributions of Kano to system reliability indices. This is because fewer number of customers were served adequately on Kano distribution system as a result of persistent record of faults on most of the feeders attached to it, which is evident from numerous customers that were interrupted on these feeders compared to Kaduna distribution system, which is relatively reliable.

Kaduna and Kano distribution systems have mean CAIDI contributions of 0.0054 and 0.0032 to systems' reliability indices. Many customers were interrupted for a long time on most of the feeders attached to Kano distribution system, while fewer of the affected customers were fairly served unlike Kaduna distribution system, which had most of the customers attached to its feeders adequately served.

Table 1: Comparative Analysis of Kaduna and Kano Distribution Feeders' Contributions

S/N	Distribution Systems	$SAIDI^C$	$SAIFI^C$	$CAIDI^C$
1	Kaduna	0.0012	0.0032	0.0054
2	Kano	0.0007	0.0016	0.0032

CONCLUSIONS

The impact of power distribution feeders' contribution to system reliability indices has been presented. The analysis started with the identification of system reliability indices for Kaduna and Kano distribution systems. The mean contributions of Kaduna and Kano distribution systems were also determined using appropriate mathematical relations. The mean SAIDI contributions to system reliability indices for Kaduna and Kano distribution systems were 0.0012 and 0.0007, respectively, due to the fact that a prolonged period of interruptions was recorded on most of the feeders attached to Kano distribution systems, making it comparatively less reliable compared to Kaduna distribution systems.

The mean SAIFI contributions to system reliability indices for Kaduna and Kano distribution system were 0.0032 and 0.0.0016, respectively. Most of the customers attached to Kaduna distribution system feeders were served adequately compared to Kano distribution system feeders, even though most of the faults recorded on Kaduna were cleared promptly, thus making Kano distribution system to be relatively less reliable.

Kaduna and Kano distribution systems have mean CAIDI contributions of 0.0054 and 0.0032, respectively. Fewer of the customers attached to Kano distribution system were adequately served as a result of prolonged interruptions recorded on this distribution system, while many of the customers attached to Kaduna distribution feeders were adequately served, which is evident from low level of faults on the distribution system.

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