Reliability Assessment of Power Distribution System Using Relative Customer Average Interruptions Duration Index Model

Ganiyu Adedayo Ajenikoko , Rafiu Itopa Enitan Sanni, Isaac Aina Omoyayo , Adebayo Wasiu Eboda, Samuel Olatinsu , Segun E. Oyebamiji, Peter Ojekunle
Department of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, P.M.B, 4000, Ogbomoso, Nigeria
Corresponding Email: ajeedollar@gmail.com

Abstract
Reliability assessment of power distribution system deals with the adequacy of overall system supply and indicates the system behaviour and response at the customer end. In order to attain satisfactory degree of reliability in electric power distribution system, there is the need to develop a model that will improve the three major system reliability indices via Systems Average Interruptions Duration Index (SAIDI), Systems Average Interruptions Frequency Index (SAIFI) and Customer Average Interruptions Duration Index (CAIDI). This research paper therefore, developed a Relative CAIDI model for assessment of reliability indices of electrical power distribution system. In this paper, ten (10) years outage data from selected distribution feeders of Ibadan, Ikeja and Port-Harcourt distribution systems were obtained and analyzed using curve fitting tools in MATLAB. The system reliability indices served as input parameters for the development of Relative CAIDI model. The best curves that fitted the relationship between the Relative CAIDI and the number of feeders were obtained using Lagrange polynomial functions, Newton polynomial functions and Chebyshev polynomial functions as performance evaluation metrics. The results showed that Ibadan, Ikeja and Port-Harcourt distribution systems had Relative CAIDI of 0.718, 0.3976 and 0.5279 respectively and the validation results produced by Largrange polynomial function, Newton polynomial function and Chebyshev polynomial function were 0.717, 0.3979 and 0.5278 respectively. The model developed is a polynomial of order six which depends majorly on the power requirements of the distribution systems. The developed model can be used for effective reliability assessment of electrical power distribution systems as well as forming a base-line information for system planning and maintenance strategies.
Keywords: Reliability Indices, SAIDI, SAIFI, CAIDI, Chebyshev Polynomial Function, Lagrange Polynomial Function, Newton Polynomial Function.
DOI: 10.7176/NCS/14-01
Publication date: August 31st 2022

I. Introduction

Power interruptions in electric power distribution system have been a great concern to both the service providers and the consumers of electricity. In a developing country such as Nigeria, satisfactory degree of reliability has not been attained in the power systems in which the average duration of interruptions that customers experience is very high especially in urban centers and the degree varies from place to place [1-5], [9].

Power system reliability is the ability of the system to provide adequate supply of electric power with satisfactory quality. However, the reliability of a power system is made up of both adequacy and security assessment. Adequacy assessment relates to the ability of the system to supply the energy requirements of customers in a satisfactory manner. Since adequacy assessment deals with static condition, it does not include the evaluation of the system response to transient disturbances [2]. Security assessment deals with the ability of the electric system to survive sudden disturbances such as electric short circuits or unanticipated loss of system elements. This includes the response of the system continuously to the loss of supply from generation and transmission lines [16], [20].

The Institute of Electrical and Electronic Engineers (IEEE) defines the generally acceptable reliability indices for distribution system in its standard number P1366, "Guide for Electrical Distribution Reliability Indices" as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI). When the relative CAIDI lie between 0.5 and 1, the distribution system has an average reliability level and when the relative CAIDI is less than 0.5, the system has a poor reliability level. The distribution system has an improved reliability level when the relative CAIDI is greater than 1 [6], [12].

A wide range of probabilistic techniques have been developed for system reliability assessment. These include technique for reliability evaluation, probability load flow and probabilistic transient stability [13]. The fundamental and common concept behind each of these developments is the need to recognize that power system behaves stochastically and all input, output state and event parameters are probabilistic variables. The probabilistic techniques have been developed which recognize not only the severity of state or an event and its impact on system behaviour and operation but also the likelihood of its occurrence [10], [14], [23]. However, one of the limitations to these techniques is that it did not improve all the three major system reliability indices (SAIDI, SAIFI and CAIDI) but instead, it improved the CAIDI for some of the feeders of the distribution systems concerned. Therefore, the need to develop a model which will improve the reliability of distribution systems is very imperative [7].

1.1 Distribution System

Distribution systems are built as interconnected networks concerned with the conveyance of power to consumers by means of lower voltage network. The design of distribution network is such that normal operation is reasonably close to balance three-phase system and often, a study of the electrical conditions in one phase is sufficient to give a complete analysis. Equal loading on all three phase of a network is ensured by allotting equal domestic loads to each phase of the low-voltage distribution feeders [5], [8].

The representation of typical radial distribution network is depicted in Figure 1. The system consists of primary and secondary feeders. The primary feeder transfers the electrical power from substation to several service transformers while the secondary system consists of a service transformer and transfers the electrical power to the various houses through the secondary conductors. The 110 kV system is primarily a transmission voltage and connections at this voltage level are normally dealt with by the transmission system operator (TSO) [11], [16].

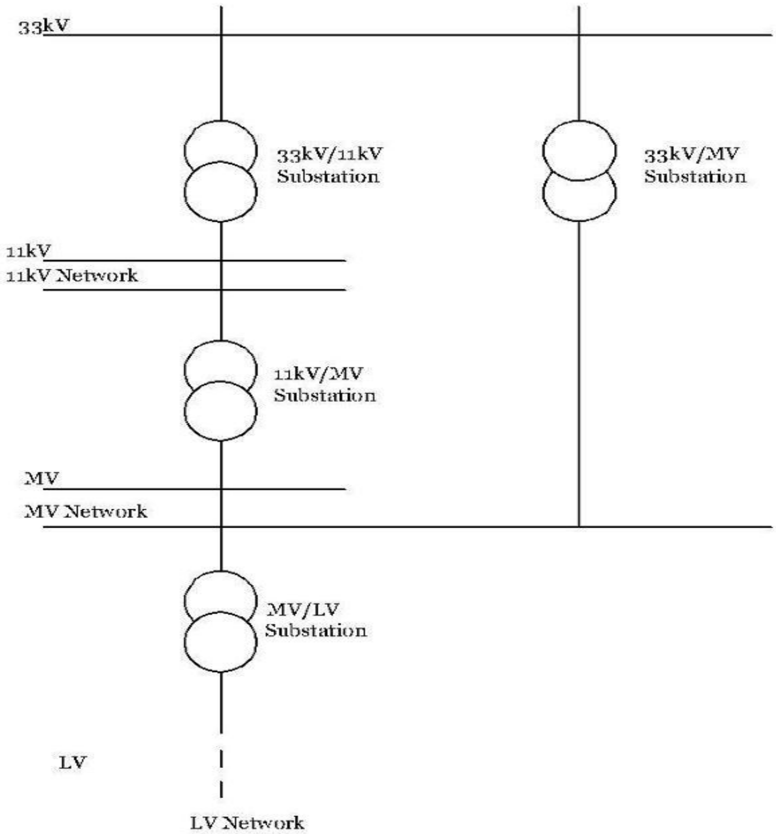

Figure 1: Typical Radial Electrical Distribution Network

A distribution system consists of the secondary mains, primary mains, distribution centers, and the feeders as [6], [9], [11], [16], [19]:

i. **Secondary Mains:** Secondary mains are conductors which originate from the secondary winding of the distribution transformers and are extended along the streets. The secondary mains in residential area may be two wires, three wires or four wires system. The commonly used secondary voltage in Nigeria is single phase or 415V, 3 – phase system.
ii. **Primary Mains:** These are circuits which originates from the distribution centers. They are usually connected to the main distribution feeders. The primary mains are operated at the same voltage as the main distribution feeder circuit. In industrial areas, the primary mains are often connected into what is known as the primary ring. In primary main loop, a number of sectionalizing switches are inserted in the loop at the distribution transformer locations. In such a loop, power can flow around the loop in

either one or two directions. However, if there is a fault in the system, the sectionalizing switches on one side of the loop is opened and service is maintained on the other side of the loop.

In laying distribution systems, the territory to be served is divided into a number of districts. This is done so that consumers in each district are equidistance to the distribution centers. The reason is that the length of the mains should be as short as possible in order to limit the voltage drop between the centers and the consumers at the end of the mains.

iii. **Distribution Centers:** These are locations at which the feeders are connected to the primary main switches. The switches and the automatic cut-out from control and protection of the primary mains are grouped at the distribution centers. The voltage at the distribution centers should be maintained practically constant from no load to full load. This is always accomplished by means of voltage feeder regulators at the substation.

iv. **The Feeders:** These are conductors in a distribution system which extends the substation to the various distribution centers.. The connection of the feeder could be overhead or underground.

Also, distribution system can be classified as ring type distribution system and the radial type [7]. The ring type distribution system is one which forms a complete loop. This is operated on the principle of circular distribution in which any substation is fed from two different directions. A fault on the system can be disconnected without loss of power supply to other consumers without faults. The feeders used on ring distribution depend on the nature of loading, the total length of the ring distributor and the allowable voltage drops. For maintaining continuity of service, ring distribution system is usually employed [11], [18]. The radial type of distribution operates such that the substation transformers are fed only in one direction. One major disadvantage of this system of distribution is that the consumers have to depend on one feeder only. So if there is any fault or breakdown occurs on the feeder, the supply of power is completely taken off until the fault is rectified and the line is restored. Hence, there is no guarantee for continuous power supply [21].

1.2 Distribution System Voltage Level

There are a number of standard voltages used on the distribution system and customers are connected at one of these levels. Voltage levels at which a connection can be provided are depicted in Table 1 [12], [22].

Table 1: Distribution System Voltage Level

Voltage Levels	Normal Voltage
	230 V(Single Phase)
Low Voltage (LV)	415 V(3-Phase)
Medium Voltage (MV)	11kV
	33kV
High Voltage	132kV
	330kV

1.3 Classification of Power Interruption

Power interruption has the general consequence of throwing the electricity consumer into period of lack of electricity supply which may result in both material and economic loss. According to PHCN (2012) power interruption could be forced, emergent or planned interruption [24].

i. **Forced Interruption:** Forced Interruption is primarily as a result of faulty situations in the network which are normally initiated by electrical sensing devices called relays. It could also be as a result of over loading in a particular branch of the network which the relay is overseeing.

ii. **Emergency Interruption:** As the name implies, this type of power interruption is initiated by qualified personnel under emergency situations to avert any danger which may be as a result of temporary removal of load (load shedding) or as a result of poor supply from generation.

iii. **Planned Interruption:** This is power interruption deliberately initiated for the purpose of maintenance work on equipment or to connect new extensions to the existing ones. Similarly, in transmission stations, the bulk transformers, circuit breakers, isolators, protective and their communication equipment are often time scheduled for over hauling so as to enhance their efficiency.

2. Reliability Indices in Distribution System

A system reliability index deals with the adequacy of overall system supply and indicates the system behaviour and response. The performance indices express interruption statistics in terms of the customers [15]. A customer here can be an individual, firm, or organization who purchases electric services at one location under one rate classification, contract or schedule. If service is supplied to a customer at more than one location, each location shall be counted as a separate customer [15], [17].

Managing bulk system reliability for utility is essential. Measurement of actual system reliability provides feedback to the planners on the performance of executed plans. It gives feedback to operation personnel on reliability effects of operating and maintenance practices [1]. Reliability assessment helps in system planning for long and short terms. System reliability can be grouped into two distinct aspects i.e. in terms of system security and system adequacy [9].

System security involves the ability of the system to respond to disturbances and remain in secured operation and meeting the customer demand. In order to maintain the desired level of adequacy and to avoid excessive shortages, additional reserve must be maintained. System adequacy deals with the existence of sufficient generation, transmission and distribution facilities within the system to satisfy customer load demand. It is associated with the system steady state conditions and system planning for long and short terms. In case of adequacy and security, the higher the reserve margin the higher the system reliability but at a substantial economic cost [9].

In addition, the reliability of a network could be judged on the basis of reliability indices. Sustained Interruption system reliability indices are considered over the distribution side of the power network [19]. System reliability indices include: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Expected Energy Not Supplied (EENS) and Average Energy Not Supplied (AENS) [2]. However SAIFI, SAIDI and CAIDI imply how often an average customer experiences sustained interruption over a predefined time of year and they are the most used reliability indices for distribution system [20].

2.1. System Average Interruption Frequency Index

System Average Interruption Frequency Index (SAIFI) indicates the average frequency of sustained interruptions per customer over a predefined area [27]. The number of customers and the interruptions experienced by them vary from time to time. For instance, feeder SAIFI indicates the average number of interruptions a customer experience on a particular feeder in a year. Similarly SAIFI reported that a substation or a distribution system encloses the total customers in the service area [30]. The System average interruption frequency index (SAIFI) is given by [8]

$$SAIFI = \frac{TotalNumberofCustomersinterruptions}{TotalNumberofCustomersServed} \quad (1)$$

In order to calculate the index, data of individual sustained interruptions in a year are required. For each of these interruptions, the number of customers affected comprises the customer interruptions for the particular outage. The denominator is the total number of customers in the service area under consideration. Thus, the SAIFI is represented by [21]:

$$SAIFI = \frac{\sum N_i}{N_T} \quad (2)$$

N_i is the number of interrupted customers for each interruption event during the reporting period and N_T is the total number of customers served in the area.

2.2 System Average Interruption Duration Index

System Average Interruption Duration Index (SAIDI) indicates the average time a customer has an interruption during a time cycle (1 year). It is usually specified in customer minutes or customer hours of interruption per year. SAIDI is the average interruption duration per customer served and it is determined by dividing the sum of all customer interruption durations during a year by the number of customers served. SAIDI is given by [26], [28],[29].

$$SAIDI = \frac{\sum CustomerInterruptionDurations}{TotalNumberofCustomersServed} \quad (3)$$

SAIDI can be improved by reducing the number of interruptions or the duration of the interruptions. For a given service area, system average interruption duration index SAIDI is represented as given by

$$SAIDI = \frac{\sum r_i N_i}{N_T} \quad (4)$$

where; N_i is the number of interrupted customers for each interruption event during the reporting period, N_T is the total number of customers served in the area and r_i is restoration time for each interruption event. The number of customers affected and the time it took for the restoration for each interruption event are the parameters required to estimate the system average interruption duration index. The restoration time includes, the time taken to notice an outage, the time taken to locate and reach the location and the time to repair the fault [23], [27].

2.3 Customer Average Interruption Duration Index

Customer Average Interruption Duration Index (CAIDI) is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the number of customers experiencing one or more interruptions over a year period [18], [25].The index is the ratio of SAIDI to SAIFI as given in equations (2) and (4) respectively. It represents the average time taken to restore service to the customers when a sustained interruption occurs. CAIDI is given by [13].

$$CAIDI = \frac{\sum CustomerInterruptionDurations}{TotalNumberofCustomerInterruption} \quad (5)$$

The value of CAIDI for a given service area is given as:

$$CAIDI = \frac{\sum r_i N_i}{\sum N_i} \quad (6)$$

where; N_i is the number of interrupted customers for each interruption event during the reporting period and r_i is restoration time for each interruption event.

3. Materials and Method

In this study, power distribution network which is narrowed down to 33 kV and 11 kV for Ibadan, Ikeja and Port-Harcourt distribution systems were used. Ten years of outage data were collected from the records of the system operators and analyzed. The data collected include the recorded faults, outage times, number of customer's interruptions and the number of customers served. Relative CAIDI Model for reliability assessment of the selected power distribution feeders was develop using the three major reliability indices (SAIDI, SAIFI and CAIDI) as input parameters and validated by subjecting the model to Lagrange polynomial functions, Newton polynomial functions and Chebyshev polynomial functions to determine and compare their coefficients.

The following assumptions were made In the development of the model.

i. The reliability of the distribution system feeders does not vary with time.
ii. Adequate and prompt maintenance and repair actions make the distribution feeders as good as new and
iii. The time between faults on the distribution feeders has an exponential distribution.

Graphs of relative CAIDI for the case studies areas were potted and curve fitting tools in MATLAB were used to develop the Relative CAIDI model. Relative CAIDI was computed using MATLAB with the aid of the expression:

$$\text{Relative CAIDI} = \frac{\text{Mean Value of SAIDI}}{\text{Mean Values of SAIFI}} \quad (7)$$

3.1 Algorithm for Relative CAIDI Model

A Pseudo code was written using MATLAB program for electrical distribution system reliability analysis using curve fitting tools to obtain the Relative CAIDI Model. The following steps were followed in the development of the Relative CAIDI model.

i. Identification of the system reliability indices for the selected power distribution systems under study. These indices are SAIDI, SAIFI and CAIDI.
ii. The identified system reliability indices were computed using ;

$$SAIDI = \frac{\sum CustomerInterruptionDurations}{TotalNumberofCustomersServed} \quad (8)$$

$$= \frac{\sum r_i N_i}{N_T} \quad (9)$$

Hence, the Pseudo code for calculation of SAIDI is given as;

```
BEGIN
    For feeder = 1 to last_feeder
        For year = 1 to last_year
            Saidi_per_feeder = interruption_duration per year/served_per_year
        End For
    End For
        END
```

$$\text{SAIFI} = \frac{TotalNumberofCustomersinterruptions}{TotalNumberofCustomersServed} \quad (10)$$

$$= \frac{\sum N_i}{N_T} \quad (11)$$

Also, the Pseudo code for calculation of SAIFI is given as;

```
BEGIN
    For feeder = 1 to last_feeder
        For year = 1 to last_year
            Saifi_per_feeder = interruption_per_year/served_per_year
        End For
    End For
```


END

$$CAIDI = \frac{\sum CustomerInterruptionDurations}{TotalNumberofCustomerInterruption} \quad (12)$$

$$CAIDI = \frac{\sum r_i N_i}{\sum N_i} \quad (13)$$

where; N_i is the number of interrupted customers for each interruption event during the reporting period, N_T is the total number of customers served for area being indexed and r_i is restoration time for each interruption event.

3.2 Models Validation

The Relative CAIDI model was validated using Lagrange polynomial functions, Newton polynomial functions and Chebyshev polynomial functions as performance metrics. Pseudo code programs were written using MATLAB for each of the performance metrics.

i. Lagrange polynomial function:

By considering a given set of N+1 data points, $\{(x_0,y_0), (x_1,y_1),\dots(x_N,y_N)\}$, the Lagrange polynomial equation is given as:

$$L_{N,m}(x) = \frac{\prod_{k=m}^{N}(x-x_k)}{\prod_{k=m}^{N}(x_m-x_k)} = \prod_{k=m}^{N} \frac{x-x_k}{x_m-x_k} \quad (14)$$

where; N-degree polynomial function matching the given N+ 1 point is unique.

The Pseudocode for calculation of Lagrange polynomial functions is given as:

BEGIN
Input coordinates x and y
Set m = N+1; l=0;
***For** each m*
P=1
***For** each order k*
***If** k is not m*
P = [convolve P and x (k)] / [x (m) – x (k)];
End If
End For
L(m) = P
*l = l + y(m) * P*
End For
END

ii. Newton polynomial function:

The N^{th} coefficient of the Newton polynomial function is given as:

$$a_N = \frac{D^{N-1}f_1 - D^{N-1}f_0}{x_N - x_0} \equiv D^N f_0 \quad (15)$$

The Pseudocode for calculation of Newtonpolynomial functions is given as:

BEGIN
Initialize the divided difference DD to zero
Input coordinates x and y
Set DD = y coordinates
***For** each order k*
d = (next DD – current DD) / (next x – current x)
End For
END

iii. Chebyshev polynomial function:

The Chebyshev coefficient polynomial is defined as

$$f(x) \cong C_N(x) = \sum_{n=0}^{N} d_m T_m(x') \quad (16)$$

$$x' = \frac{2}{b-a}\left(x - \frac{a+b}{2}\right)$$

where

$$d_0 = \frac{1}{N+1}\sum_{k=0}^{N} f(x_k)T_0 x_k = \frac{1}{N+1}\sum_{k=0}^{N} f(x_1) \quad (17)$$

$$d_1 = \frac{2}{N+1}\sum_{k=0}^{N} f(x_k)T_m(x_k) = \frac{2}{N+1}\sum f x_k cos\frac{m(2N+1-2k)}{2(N+1)}\Pi$$

for $m = 1,2,.N$ (18)

The Pseudocode for calculation of Chebyshevpolynomial functions is given as:

```
BEGIN
    %initialization parameters
    Set order of polynomial,N
    Set intervals a = -1 and b = 1
    Set k = 0 to N
    For each k
        theta = (2*N+1-2*k)*pi/(2*N+2)
        xn = (b - a) / 2*cos(theta) + (a+b)/2
        evaluate yy from coordinates x and y
        d (1) = yy/N+1
    End For
    Compute the coefficients T_1 = cos (theta)
    {
    For m = 2 to N+1
            Cosm = cos((m-1)*theta)
            d = y * cosm*2/(N+1)
            T_1 = 2*convolution of cos(theta) and T_1
            c = d * T_1
            update the polynomial coefficient c
    End For
END
```

4 Discussion of Results

The results of the system reliability indices for Ibadan distribution system, Ikeja distribution system and Port-Harcourt distribution system are presented. These results are discussed subsequently in Figure 2 to Figure 15.

Figure 2 shows the combined reliability indices of Ibadan distribution systems. Moniya feeder had the highest CAIDI index with a relatively low SAIDI index owing to the prolonged customers interruption on this feeder compared to all other feeders in the distribution system. Agodi feeder had low system reliability indices compared to all other feeders in the system. This is as a result of customer interruptions which had reduced appreciably.

Figure 3 shows the graph of Relative CAIDI and the number of feeders for Ibadan distribution system. The distribution system has a percentage relative CAIDI of 71.86 %. The model confirmed that Eleyele feeder appeared to be a critical feeder with a relative CAIDI of 0.8747, hence the most reliable of all the feeders. This is because customers' interruptions on these feeders were greatly reduced and clearing of the faults were done properly. Bashorun feeder with a relative CAIDI of 0.5895 appeared to be the least reliable feeder. Customers attached to the remaining eight feeders experienced a prolonged period of interruptions.

Figure 4 shows the combined reliability indices for Ikeja distribution systems. The relatively high values of CAIDI index on Olowu and Opebi distribution feeders suggested that customers on these two feeders were interrupted for a long period of time. General Hospital feeder had a low system reliability indices since customers' interruption on this feeder had reduced.

Figure 5 shows the graph of Relative CAIDI and the number of feeders for Ikeja distribution system. The relative CAIDI varies directly as the number of feeders i.e. the relative CAIDI increases as the number of feeders increases and vice versa with average percentage relative CAIDI for 39.76%, hence having a poor reliability level. Olowu and Opebi feeders had relative CAIDIs of 0.5333 and 0.5336 respectively, hence improved reliability levels, while the remaining eight feeders had relative CAIDIs of less than 0.5, thus poor reliability levels. This is in agreement with the IEEE standard. Opebi feeder recorded the highest relative CAIDI of 0.5336 while Alagbole feeder recorded the least relative CAIDI of 0.2853, hence the least reliable feeder.

The reliability indices for Port-Harcourt distribution system is shown in Figure 6. Customers attached to Airport and Port-Harcourt 1 feeders were interrupted for a long time, thus, making the CAIDI index values of these feeders to be relatively higher than any other feeder in the distribution zone. Airport and Port-Harcourt 1 feeders still maintained relatively higher values of CAIDI owing to the fact that the prolonged customers' interruptions on these two feeders still continued.

Figure 7 shows the graph of Relative CAIDI and the number of feeders for Port-Harcourt distribution systems with percentage relative CAIDIs of 52.79% hence having an improved reliability. Five of the distribution feeders – Airport, Port-Harcourt town 1, Refinery 1, Refinery 2 and Port-Harcourt town 2 feeders had relative CAIDI of 0.7540, 0.7057, 0.6372, 0.6305 and 0.5448 respectively, thus having improved reliability levels. This agrees with the IEEE Standard. The remaining five feeders had poor reliability levels as a result of their relative CAIDIs. Airport feeder appeared to be the most reliable of all the feeders while glass factory feeder appeared to be the least reliable.

The general relative CAIDI model for Ibadan, Ikeja and Port-Harcourt distribution systems is given by equation (19) with polynomial order of 6.

$$RC = P_6x^6 + P_5x^5 + P_4x^4 + P_3x^3 + P_2x^2 + P_1x + P_0 \quad (19)$$

$$R^2 = 0.9815$$

where:

RC = Relative CAIDI,

x = Number of feeders,

$P_0, P_1, P_2, P_3, P_4, P_5, P_6$ are the coefficients. They depict the behaviour of the system.

R^2 = Coefficient of Determination.

The values of the coefficient of determination, R^2 show the extent of the reliability of the model to predict the relationship between the relative CAIDI and the number of feeders.

In addition Tables 2, 3 and 4 depict the comparisons of the coefficients of the model equations using different methods for Ibadan, Ikeja and Port-Harcourt distribution systems respectively. Observation shows that the results obtained for the coefficients were the same irrespective of the methods used. The result compared favorably well with the model results.

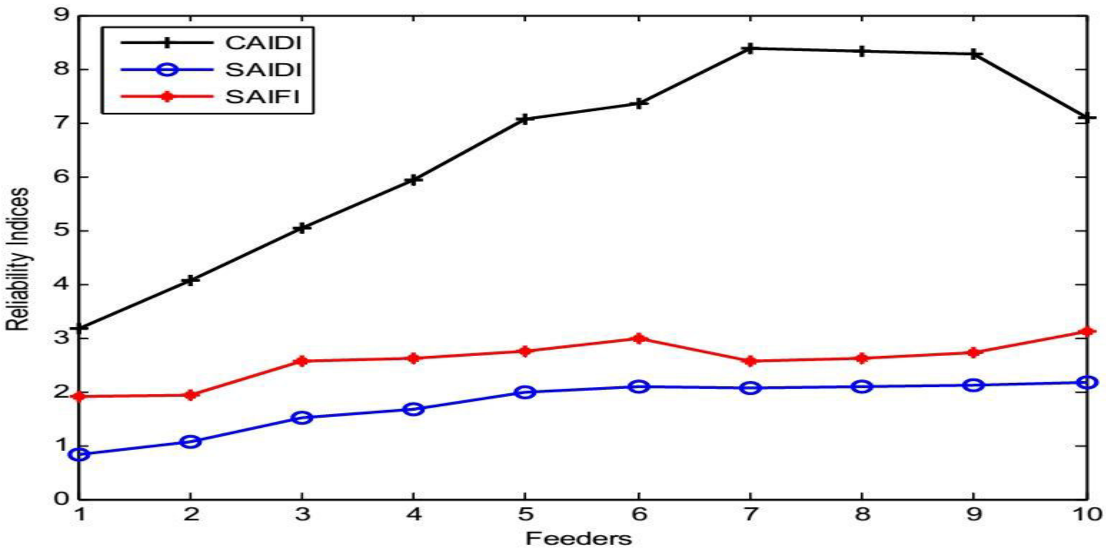

Figure 2: Combined Reliability Indices for Ibadan Distribution Systems

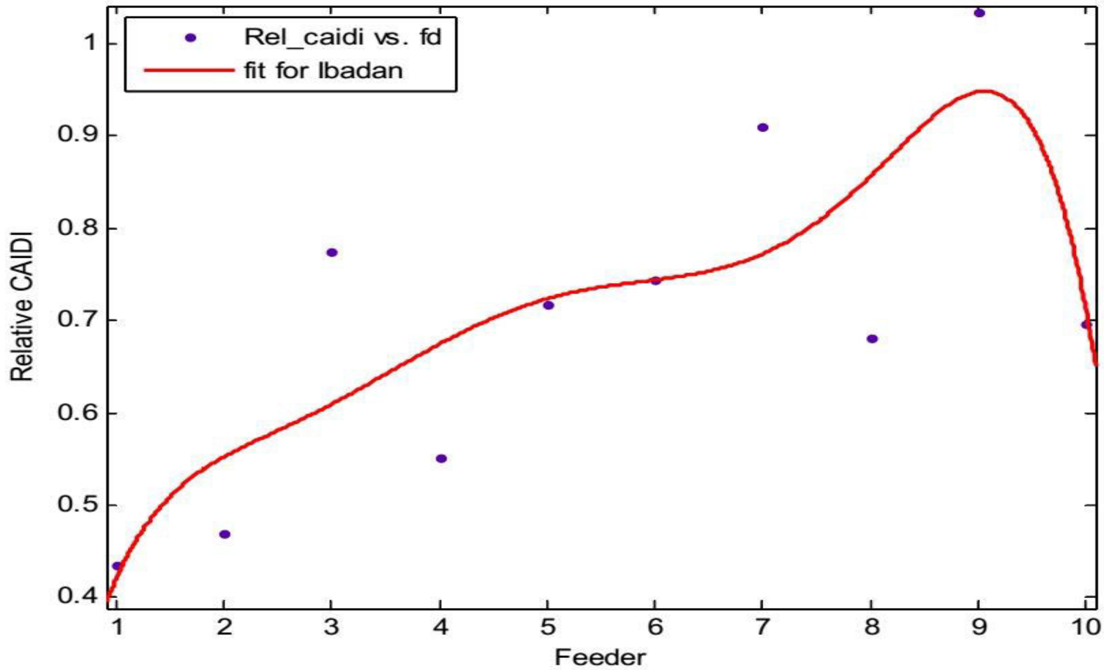

Figure 3: Relative CAIDI for Ibadan distribution systems.

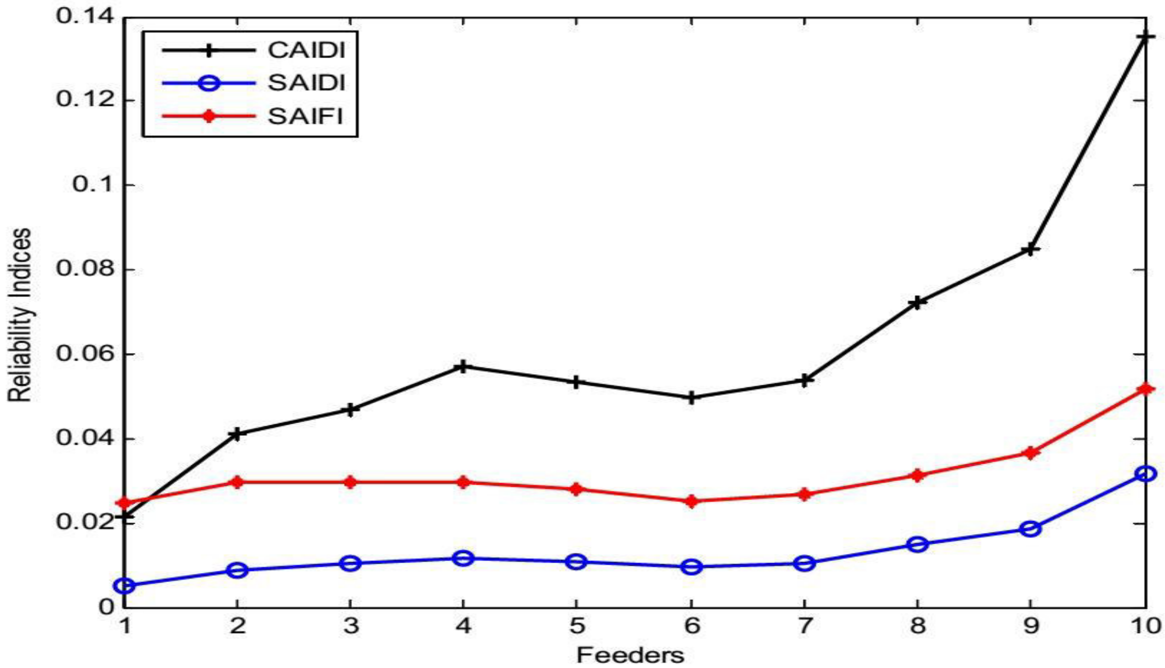

Figure 4: Combined reliability indices for Ikeja Distribution System

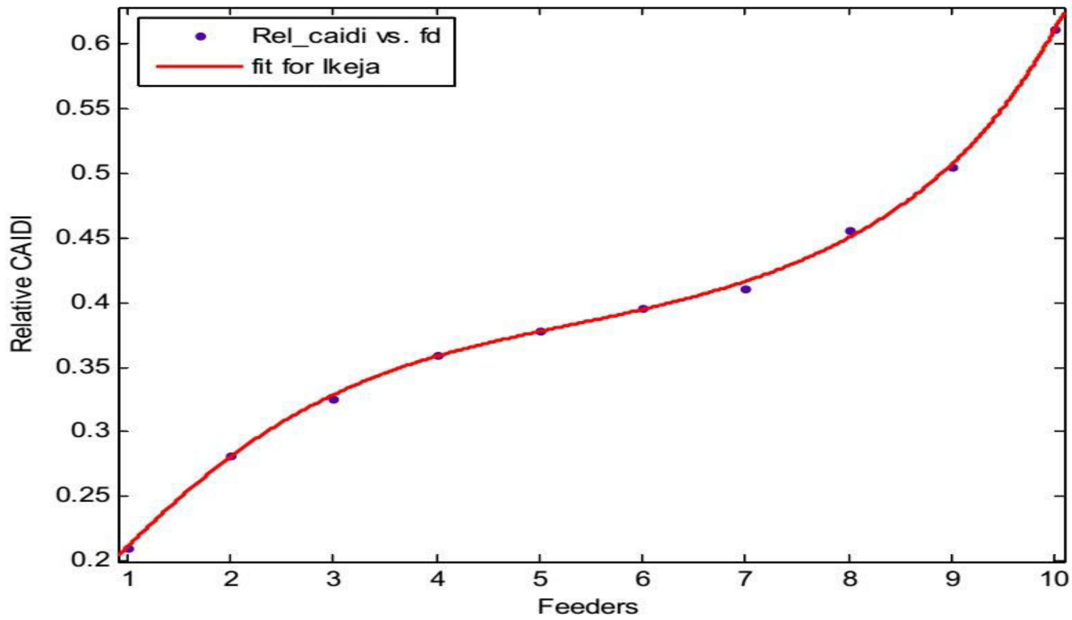

Figure 5**:** Relative CAIDI for Ikeja distribution systems

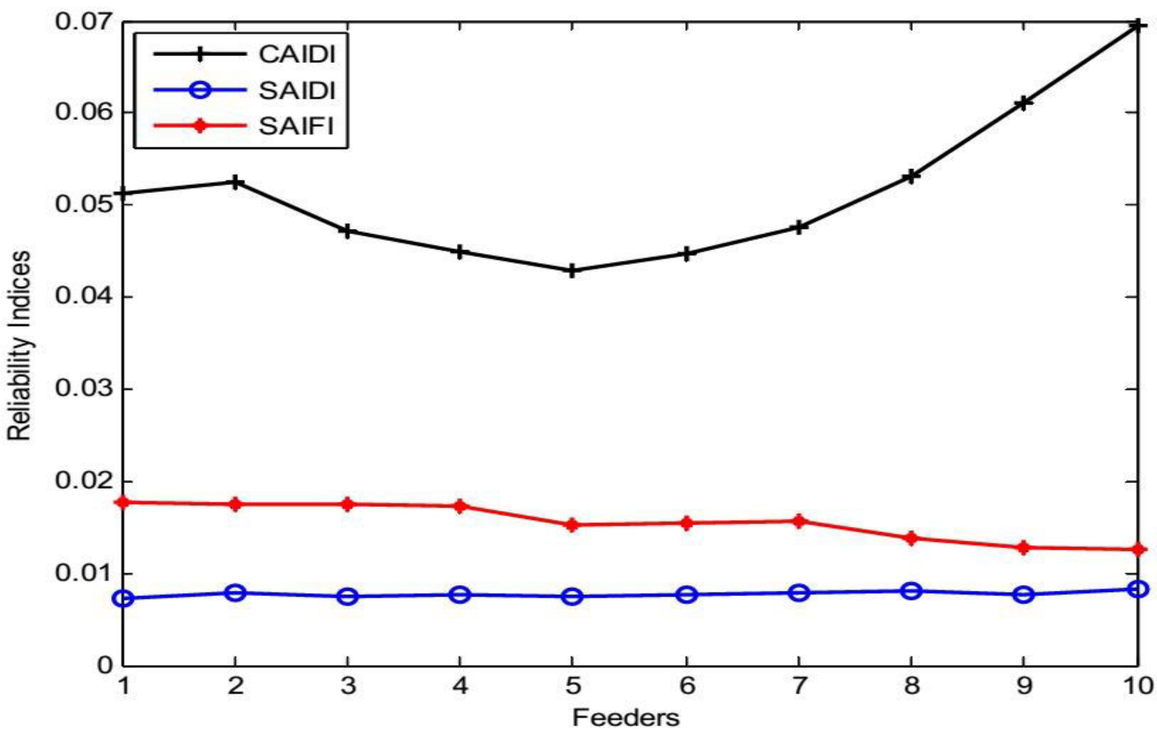

Figure 6: Combined reliability indices for Port-Harcourt Distribution Systems.

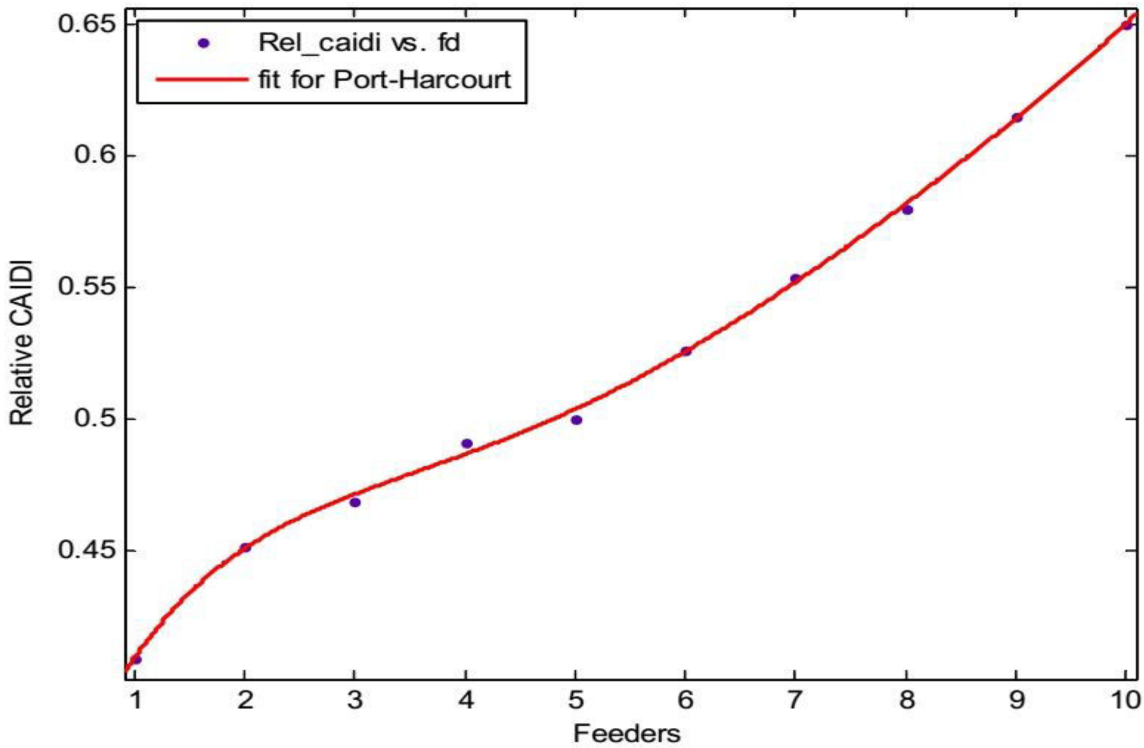

Figure 7: Relative CAIDI for Port-Harcourt distribution system.

Table 2: Comparisons of the coefficients using different methods for Ibadan distribution system

Coefficients	Model Results	Lagrange polynomial	Newton polynomial	Chebyshev polynomial
P_6	0.0003	0.00029	0.00028	0.00029
P_5	-0.0084	-0.00839	-0.00838	-0.0084
P_4	0.1092	0.1091	0.1093	0.1091
P_3	-0.688	-0.688	-0.6889	-0.688
P_2	2.163	2.163	2.163	2.162
P_1	-3.1433	-3.1435	-3.1432	-3.1434
P_0	2.4361	2.4363	2.4361	2.4365

Table 3: Comparisons of the coefficients using different methods for Ikeja distribution system

Coefficients	Model Results	Lagrange polynomial	Newton polynomial	Chebyshev polynomial
P_6	$7x10^{-6}$	$7x10^{-6}$	$7.1x10^{-6}$	$7.2x10^{-6}$
P_5	-0.0002	-0.00021	-0.00022	-0.00021
P_4	0.0019	0.00191	0.00192	0.00187
P_3	-0.0062	-0.0061	-0.0060	-0.0061
P_2	-0.0121	-0.0122	-0.0122	-0.0121
P_1	0.0545	0.0546	0.0545	0.0545
P_0	0.4956	0.4956	0.4956	0.4957

Table 4: Comparisons of the coefficients using different methods for Port-Harcourt distribution system

Coefficients	Model Results	Lagrange polynomial	Newton polynomial	Chebyshev polynomial
P_6	$-3x10^{-5}$	$-3x10^{-5}$	$-3x10^{-5}$	$-3x10^{-5}$
P_5	0.0009	0.00091	0.00090	0.000941
P_4	-0.0104	-0.0105	-0.0105	-0.0103
P_3	0.0533	0.0533	0.0534	0.0536
P_2	-0.1305	-0.1306	-0.1307	-0.1305
P_1	0.0911	0.0911	0.0910	0.0912
P_0	0.7507	0.7506	0.7507	0.7504

5 Conclusions

This study has developed a relative CAIDI model for reliability assessment of electrical power distribution system of Ibadan, Ikeja and Port-Harcourt distribution systems. The developed model started with identification of system reliability indices-System Average Interruptions Duration Index (SAIDI), System Average Interruptions Frequency Index (SAIFI) and Customer Average Interruptions Duration Index (CAIDI). These reliability indices were used as input parameters for the relative CAIDI model. The model is a polynomial of order 6 whose order depends on the level of power requirements of the distribution network.Three different methods – Newton, Lagrange Polynomial and Chebyshev polynomial methods were used to validate the values of the coefficients of the models. The results compared favourably well with the results from the models.

6 References

[1] Ajenikoko G.A and Fakolujo O.A. (2012). Reliability indices in the context of the network operator and customer-a review.International Journal of Engineering Innovation, 4(3), 135-138.
[2] Ajenikoko G.A and Fakolujo O.A. (2013). Analysis of faults associated with bare conductors on Ibadan and Ilorin distribution systems", International Journal of Research and Advancement in Engineering Science, 3(1), 114-123.
[3] Ajenikoko G.A and Olaluwoye O.O. (2014). A generalized model for electrical power distribution feeders' contributions to system reliability indices. International Journal of Engineering Research, 3(11), 640-644.
[4] Ajenikoko G.A, Fakolujo O.A and Oyedoja K.O. (2011). A quantitative evaluation of reliability indices for Nigerian national grid: Osogbo transmission system, a case study.African Journal of Engineering Research and Development, 4(1), 150-157.
[5] Ajenikoko G.A, Fakolujo O.A and Raji T.I. (2010). Reliability and quality assurance of electronic component.Journal of Engineering, Science and Technology, 5(2), 51-55.
[6] Aljohani T.M and Beshir M.J. (2017). MATLAB code to assess the reliability of the smart power distribution system using Monte Carlo simulation. Journal of Power and Energy Engineering, 5(3), 30-44.
[7] Allen W.J and Bruce W.F. (2003). Power generation, operation and control. John Wiley and Sons, Inc., 5(2), 204 – 219.
[8] Balijepalli N. (2002). Advances in distribution system reliability assessment. Retrospective Theses and Dissertations, Iowa State University, 35(7), 1-128.
[9] Barlow R. and Proschan F. (2001). Statistical theory of reliability and life testing probability models. IEEE Transactions on Power Systems, 19(7), 1126-1321.
[10] Buzacott, J.A. (2004). Network approaches to finding the reliability of repairable systems. IEEE Transactions on Reliability, 18(6), 169 –174.
[11] Das B and Deka B. (2013). Impact of distributed generation on reliability of distribution system. IOSR Journal of Electrical and Electronics Engineering, 8(1), 42-50.
[12] Elena N. Z and Vitaly G. L. (2001). Design of dynamic reliability indices. IEEE Transactions on power systems, 18(5), 39-51.
[13] Enrico C and Gianfranco C. (2004). Evaluation of the probability density functions of distribution system reliability indices with a characteristic function-based approach. IEEE Transaction on power systems, 19(2), 31-57.
[14] Fanxing C.A,Melo T.P and Juny Y.F. (2003). Reliability modelling of distribution system."International Journal
[15] Feng, Z. (2006), "Electric distribution system risk assessment using actual utility reliability data", Master's Thesis, University of Saskatche wan, 4(7), 14-17.

[16] George, K, Meliopoulos A.P. and George C. J. (2004). Comparison of linearized stochastic power flow and Monte Carlo simulation. presented at the 36th Annual North American Power Symposium (NAPS), Moscow, Idaho. 3(4), 601-615.
[17] Khan E and Billinton R. (2002). A hybrid model for quantifying different operating states of composite power systems. IEEE Transactions on Power Systems, 7(1),93-98.
[18] Kovalev G. F and Lebedeva L. M. (2000). A model for evaluating the reliability of electric power system for long-term operational planning. IEEE Transactions on Power Systems, 7(3), 118-134.
[19] Kundur P. (2004). Power system stability and control. EPRI Power System Engineering Series, MC-Graw Hill. 6(5), 39-58.
[20] Lauby M and Billinton R. (2004): "A probabilistic method for transmission planning" In Proceedings of the 1998 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Oakland, California. 7(6), 112-138.
[21] Neto A. C, Da Silva M. G. and Rodrigues A. B. (2006). Impact of distributed generations on reliability evaluation of radial distribution systems under network constraints. 9th International conference on probabilistic methods applied to power systems, KTH, Stockholm, Sweden, 4(5), 716-735.
[22] Okorie P.U and Abdu A.I. (2015). Reliability evaluation of power distribution network system in Kano metropolis of Nigeria. International Journal of Electrical and Electronic Science, 2(1), 1-5.
[23] Pieruschka E. (2002). Principles of reliability. Prentice Hall, Englewood & Lifts, 3(4), 36-52.
[24] Power Holding Company of Nigeria (2012). Power system interruption,4(7), 13-18.
[25] Sacket R. K, Bansal R. C and Singh C. O. (2007). Reliability evaluation of power system considering voltage stability and continuation power flow on power system. IEEE Transactions on Power Systems, 7(1), 258 – 263.
[26] Sakis M.A.P, Fang Y, George J.C and Binh D.Q. (2004). Effects of protection systems hidden failures on bulk power system reliability. IEEE Transactions on Power Systems, 6(1), 312-334 .
[27] Sindi H and El-Saadany E. (2016). Unified reliability index development for utility performance assessment developing a novel normalization-based index and comparing it with a fuzzy inference unified index. Intell Journal of Industrial System, 2(3), 149–161.
[28] Sun W.K and Meliopoulos A.P. (2002). Contingency selection via quadratized power flow sensitivity analysis. In Proceedings of the IEEE 2000 Power Engineering Society Summer Meeting, 3(8), 1494-1499.
[29] Xiu-Ren L, Zhen R, Wen-Ying H and Bi-Yun C. (2005). Fussy reliability analysis of distribution systems accounting parameters uncertainty. In proceedings of the fourth international conference on machine learning cybernetics. 5(6), 90-109.
[30] Xu L, Chow M and Taylor S. (2001). Analysis of tree caused faults in power distribution systems. IEEE Transactions on power systems, 23(6), 321-33.