International Journal of Electrical and Electronic Engineering, Volume 2, Number 1, 2010
Printed in Nigeria. All Right Reserved Copyright©2010 Blackwell Educational Book

A GENERALIZED MODEL FOR QUANTITATIVE EVALUATION OF RELIABILITY INDICES OF THE NATIONAL GRID SYSTEM

G. A. Ajenikoko [1], O. A. Fakolujo [2] and T. I. Raji [3]
[1,3] Dept. of Electrical and Electronic Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
[2] Dept. of Electronic and Electrical Engineering, University of Ibadan, Oyo State, Nigeria

ABSTRACT

Reliability indices are considered to be reasonable and logic ways to judge the performance of an electric power system. Reliability indices which are proposed by the IEEE are used to evaluate the performance of selected distribution systems on the national grid. Ten years of outage data (1998 - 2007) from seven selected distribution systems on the national grid were used as case studies in this research work. A generalized model is developed for a quantitative evaluation of relative indices of the national grid system. The development of the model stated with identification of the system reliability indices and estimating the contributions of system indices to the failure rate of the selected distribution system on the national grid. The computed system reliability indices are used as input parameters for the generalized model. Relative CAIDI index is computed by simulation using MATLAB 7.7 which automatically generates the graph of the relative CAIDI against names of feeders. The percentage average relative CAIDIs for Ibadan, Port-Harcourt and Benin distribution systems are 71.86%, 52.79% and 75.79% respectively, thus, average reliability levels. Ilorin, Ikeja, Kaduna and Kano distribution systems have percentage average relative CAIDIs of 11.95%, 39.76%, 40.17% and 41.08% respectively with poor reliability levels. With the aid of curve fitting (cf) tools, two distinct model equations were developed from which a generalized model is formulated for a quantitative evaluation of reliability indices of the national grid. The generalized model is a polynomial function whose order depends majorly on the level of industrialization of the distribution systems and the number of distribution feeders.

Keywords: Relative CAIDI, reliability indices, system average reliability index (SAIDI), system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI).

INTRODUCTION

The function of an electric power system is to satisfy the system load requirement with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability. (Roberts et al 1999, Anderson and Bose 2003, Billinton 2000). Distribution system is 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 working and often a study of the electrical conditions in one phase is sufficient to give a complete analysis. (Wang et al 2000). The electric utility industry is moving towards a deregulated, competitive environment where utilities must have accurate information about system performance to ensure that maintenance costs are spent wisely and that customers expectations are met. (Sacket et al, 2007). To measure system performance, the electric utility industry has developed several performance measures of reliability. There reliability indices include measures of outage duration, frequency of outages, system availability and response time. (Sakis et al, 2006). System reliability is not the same as power quality. System reliability pertains to sustained interruptions and momentary interruptions. Power quality involves voltage fluctuation, abnormal waveforms and harmonic distortions. An interruption of greater than five minutes is generally considered a reliability issue, and interruptions of less than five minutes are a power quality concern. (Singh and Mith 2006). With the advent of performance based rates, utilities are taking a closer look at their reliability data and working to improve their indices. Studies have shown that reliability is greatly affected by lightning, circuit length, circuit density, and system voltage. There is an almost direct correction between lightning and reliability (the more lightning flashes, the lower the reliability), as well as circuit length, with longer circuits have more interruptions. Some data also suggests that utilities with higher system voltages tend to have more outages, but this may be related to the length of the circuit more than the voltage. (Billinton and Peng, 2007).

Model Development

The development of the model started with identifications of system reliability indices and estimating the contributions of the system indices to the failure rate of the selected distribution system on the Nigerian national grid systems. The computed system reliability indices are used s input parameters for the model.

These indices are the system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), and customers average interruption duration index (CAIDI).

$$Relative \quad CAIDI = \frac{mean \quad SAIDI}{mean \quad SAIFI} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$SAIDI = \frac{Customer \quad Interruption \quad Duration \quad Index \quad (CID)}{Total \quad Number \quad of \quad Customers \quad Served \quad (TNCS)} \quad \ldots\ldots\ldots(2)$$

$$SAIFI = \frac{Total \quad Number \quad of \quad Customer \quad Interruption \quad (TNCI)}{Total \quad Number \quad of \quad Customers \quad Served \quad (TNCS)} \quad \ldots\ldots(3)$$

$$CAIDI = \frac{Customer \quad Interruption \quad Duartion \quad (CID)}{Total \quad Number \quad of \quad Customer \quad Interruption \quad (TNCI)} \quad \ldots\ldots\ldots\ldots(4)$$

Seven distribution systems are used as case studies in this research work. For the seven distribution systems, the relative CAIDI is computed by simulation using MATLAB 7.7 which automatically generates the graphs of relative CAIDIs against names of feeders. With the aid of curve fitting (cf) tools, two distinct model equations are formulated for the seven distribution systems for the quantitative evaluation of reliability indices of the national grid. Ibadan, Ikeja, Kaduna, Port-Harcourt and Ilorin distribution systems have the same mathematical model which is given by:

$$RC = P_1x^6 + P_2x^5 + p_3x^4 + P_4x^3 + P_5x^2 + P_6x + P_7 \ldots\ldots\ldots\ldots(5)$$

Where RC = relative CAIDI

X = number of feeders.

P_1, P_2, P_3, P_4, P_5, P_6, P_7 are the coefficients.

The values of these coefficients are obtained from the results of the "simulation" for each of the distribution systems.

The model equation for these distribution systems is a polynomial equation of order 6.

For Kano and Benin distribution systems, the model equation developed is:

$$RC = Q_1y^4 + Q_2y^3 + Q_3y^2 + Q_4y + Q_5 \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where RC = relative CAIDI

y = number of feeders

Q_1, Q_2, Q_3, Q_4, and Q_5 are the coefficients.

The values of these coefficients are obtained from the simulation results of the distribution systems. The model equation for these two distribution systems is a polynomial of order 4.

Now, from

$$RC = P_1x^6 + P_2x^5 + p_3x^4 + P_4x^3 + P_5x^2 + P_6x + P_7 \ldots\ldots\ldots\ldots(5)$$

$$RC = Q_1y^4 + Q_2y^3 + Q_3y^2 + Q_4y + Q_5 \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where RC = relative CAIDI,

P_1, P_2, P_3, P_4, P_5, P_6, P_7 and Q_1, Q_2, Q_3, Q_4, Q_5 are the coefficients of the distribution system.

x and y represent the number of feeders for the distribution systems. Therefore, the generalized model equation is:

$$RC = \sum_{n=0}^{k} A_{k+1-n} B^n \; \underline{\qquad\qquad\qquad} (7)$$

Where RC = relative CAIDI

A = coefficients of the distribution system which are determined from the results of the simulation work. These coefficients can also be determined using Lagrange method, Newton method or Chebyshev method.
B = number of feeders
n = running variable.
K = order of the polynomial

RESULTS AND DISCUSSIONS

Electricity requirement of the seven distribution systems used as case studies in this research paper fall into categories which can be classified as:

(i) small scale level
(ii) medium scale level
(iii) large scale level
(iv) very large scale level

The five cities (Ibadan, Ikeja, Kaduna, Port-Harcourt and Ilorin) that obeyed the same model equation fall into one of these categories, most probably, medium scale. This is bearing in mind, the level of industrial activities in these cities compared with other industrialized cities in the world. Ilorin will be in the small scale level. For the five cities to be described by the medium scale level has a range in terms of power requirement which could be true for other classifications. The five cities are more industrialized than Kano and Benin. The more industrialized a city is, the higher the order of the polynomial. The order of the polynomial goes up for cities where industries in them are fully operational. The relative CAIDIs for the distribution systems are as displayed in tables
1.0 to 7.0, while the simulation results are also displayed in figures 1.0 to 7.0
The percentage average relative CAIDIs for Ibadan, Port-Harcourt and Benin distribution systems are 71.86%, 52.79% and 75.79% respectively, thus they have average reliability levels while Ilorin, Ikeja, Kaduna and Kano distribution systems have percentage average relative CAIDIs of 11.95%, 39.76%, 40.17% and 41.08% respectively making them to have poor reliability levels.

Table 1.0: Relative CAIDI for Ibadan Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	Agodi	0.8676
2	Eruwa	0.7966
3	Eleyele	0.8746
4	Moniya	0.7902
5	Secretariat	0.6801
6	Bashorun	0.5895
7	Premier	0.6416
8	Ijokodo	0.7212
9	Cocoa	0.5910
10	Onireke	0.6335

Table 2.0: Relative CAIDI for Ilorin Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	Gaoma	0.1743
2	Unity	0.1729
3	Oke-Oye	0.1418
4	Tanke	0.0932
5	GRA	0.0760
6	Adewole	0.0688
7	Kulende	0.0801
8	Airport	0.1113
9	Kwara Poly	0.2045
10	Water Works	0.0717

Table 3.0: Relative CAIDI for Ikeja Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	Olowu	0.5333
2	Opebi	0.5336
3	Dopemu	0.4906
4	Awuse	0.4576
5	Medical	0.3825
6	Mafoluku	0.3696
7	Oba Akinjobi	0.3225
8	Gen Hosp	0.3120
9	7-UP	0.2893
10	Atagbole	0.2853

Table 4.0: Relative CAIDI for Portharcourt Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	Air port	0.7540
2	P/H town1	0.7057
3	Refinery 1	0.6372
4	Refinery 2	0.6305
5	P/H town 2	0.5448
6	Shell 1	0.4857
7	Shell 2	0.3994
8	Glass factory	0.3737
9	Michellin	0.3746
10	Shell 3	0.3738

Table 5.0: Relative CAIDI for Kaduna Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	FDR3	0.5490
2	FDR2	0.5612
3	FDR1	0.5077
4	Arewa	0.4768
5	Kujama	0.4146
6	Dawaki	0.3867
7	Tundun wada	0.2772
8	St Gorald	0.2667
9	Junction road	0.2884
10	Constitution Rd	0.2886

Table 6.0: Relative CAIDI for Kano Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	Spare	0.2082
2	Rua	0.4365
3	Waterworks	0.3035
4	Spanish	0.4917
5	Banguda	0.6142

Table 7.0: Relative CAIDI for Benin Distribution Systems

S/N	Names of Feeders	Relative CAIDI
1	GRA	0.4915
2	Guiness	0.7320
3	Sapele koko	0.8218
4	Ikpoba Dam	1.0392
5	Etete	0.7050

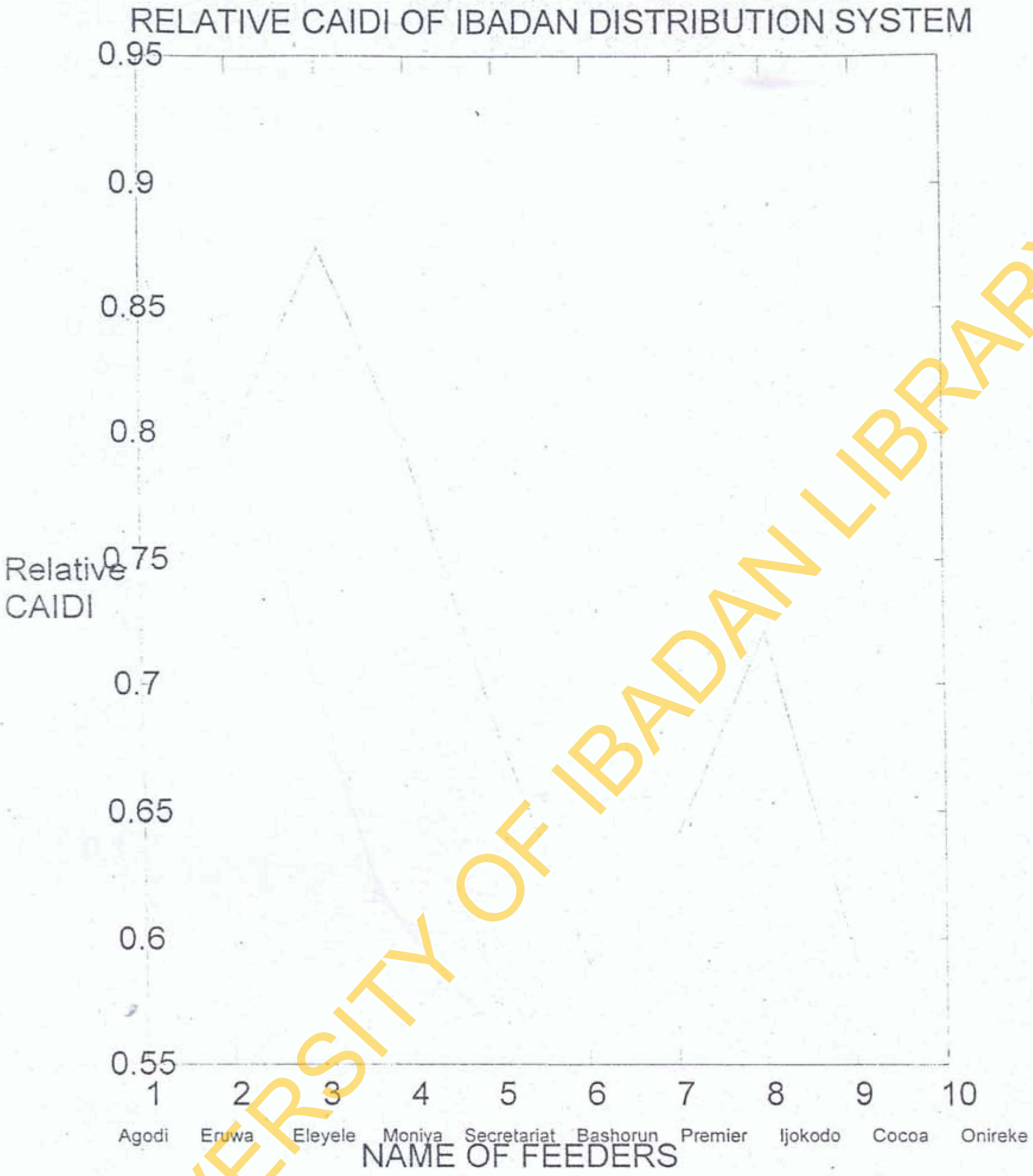

Figure 1.0: **Simulation Graph of relative CAIDI for Ibadan**
Case Study 1: Ibadan Distribution Systems

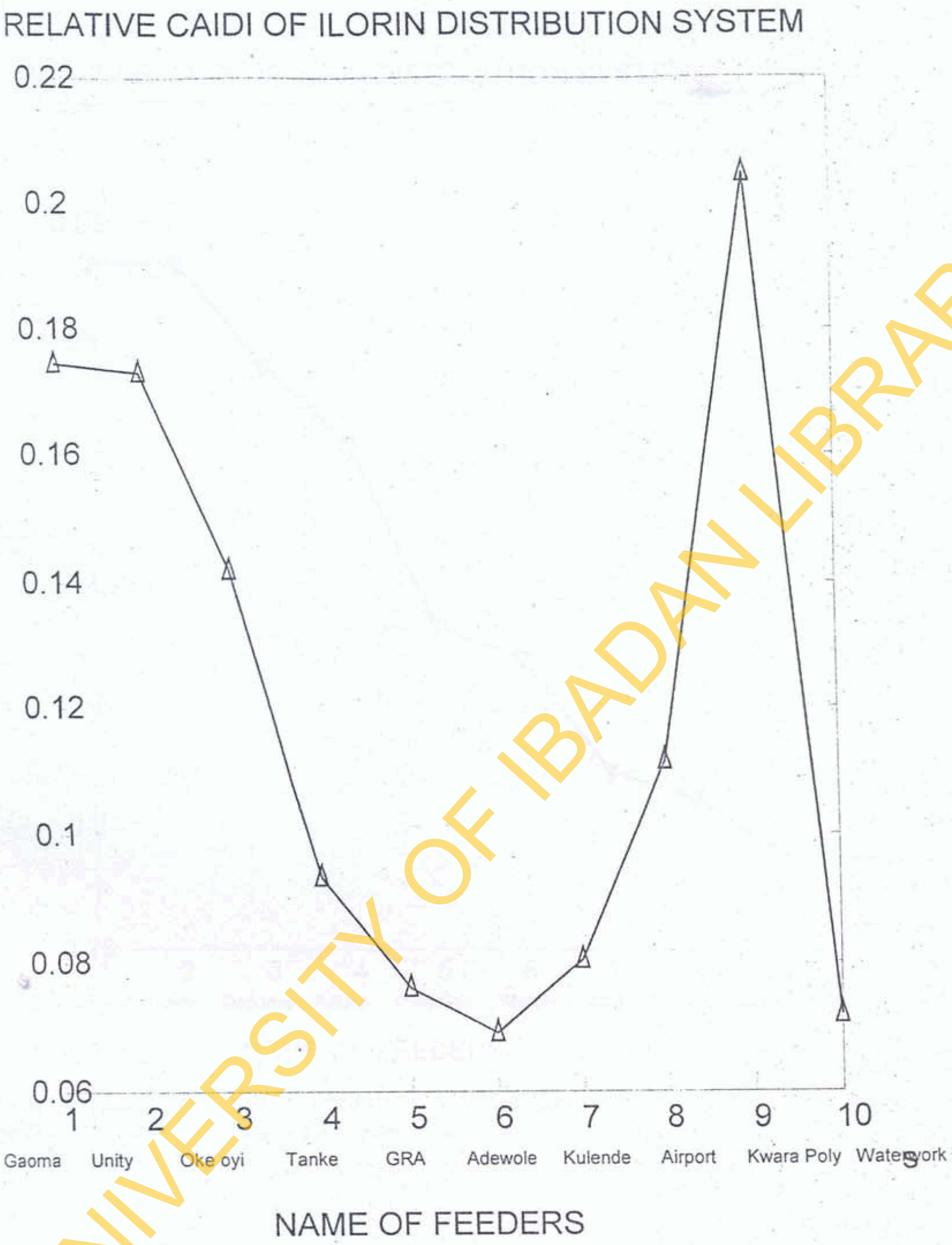

Figure 2.0: **Simulation Graph of relative CAIDI for Ilorin**
Case Study 2: Ilorin Distribution Systems

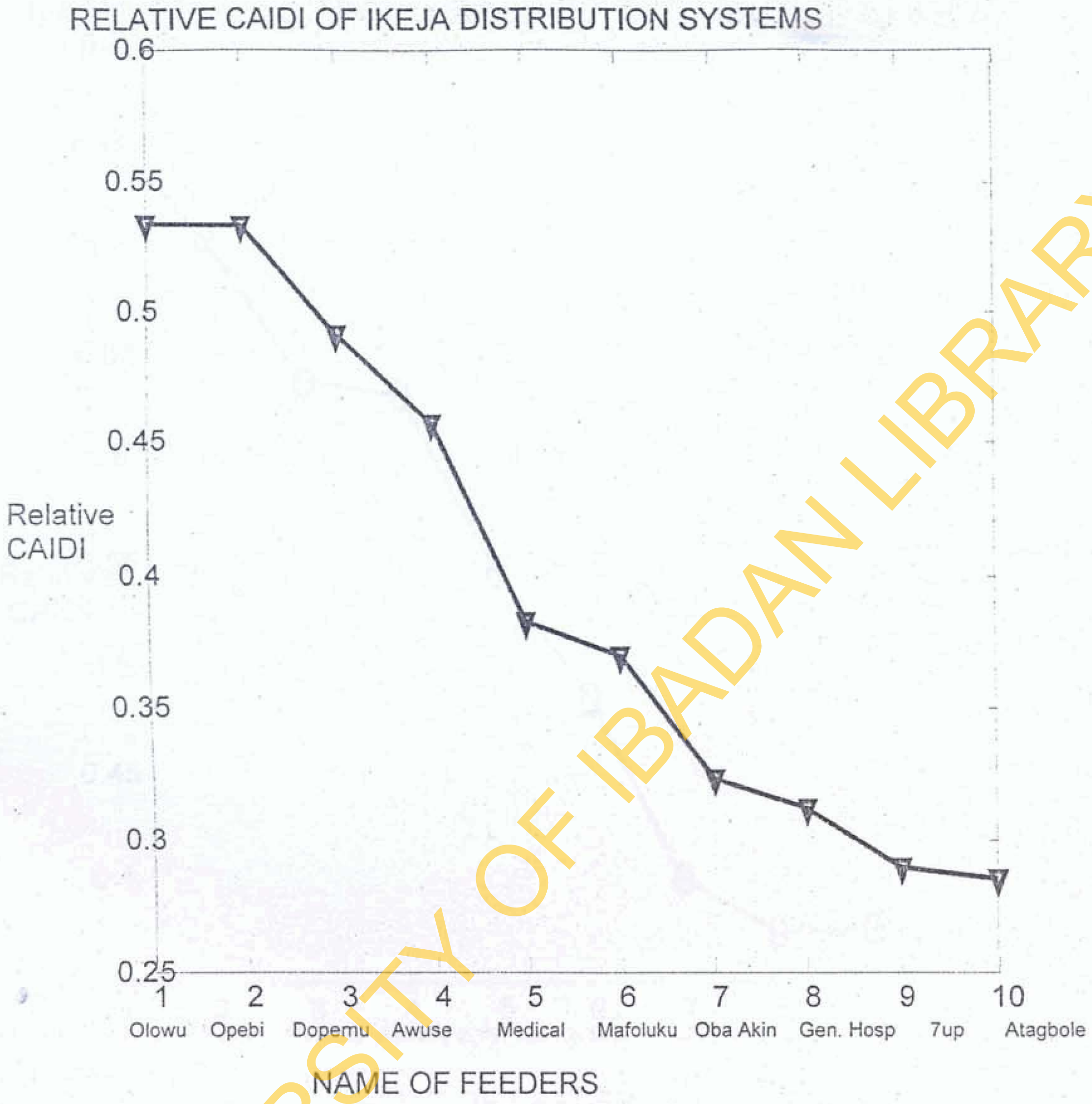

Figure 3.0: **Simulation Graph of relative CAIDI for Ikeja**
Case Study 3: Ikeja Distribution Systems

Relative CAIDI of Portharcourt Distribution Systems

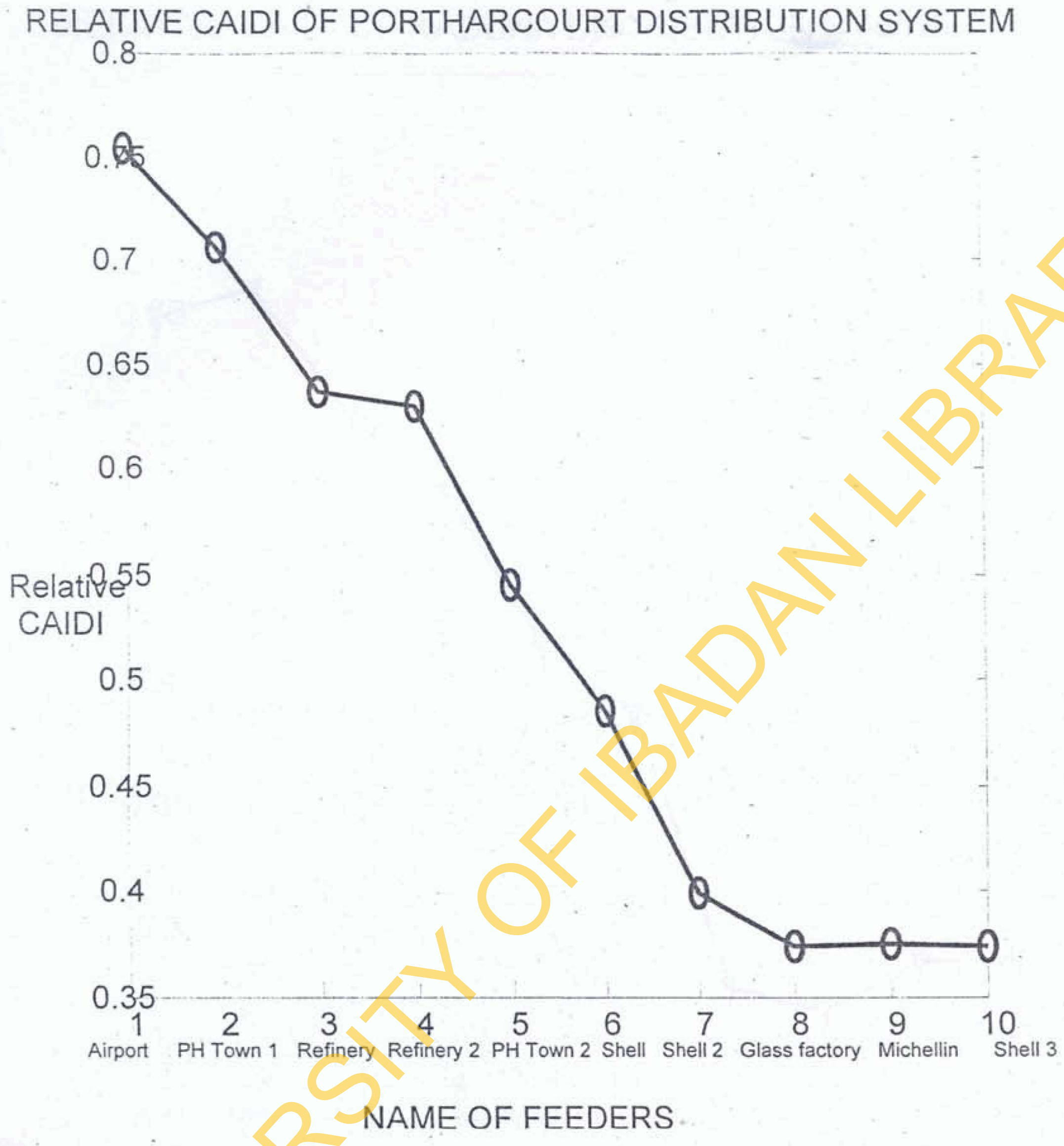

Figure 4.0: **Simulation Graph of relative CAIDI for Portharcourt**
Case Study 4: Portharcourt Distribution Systems

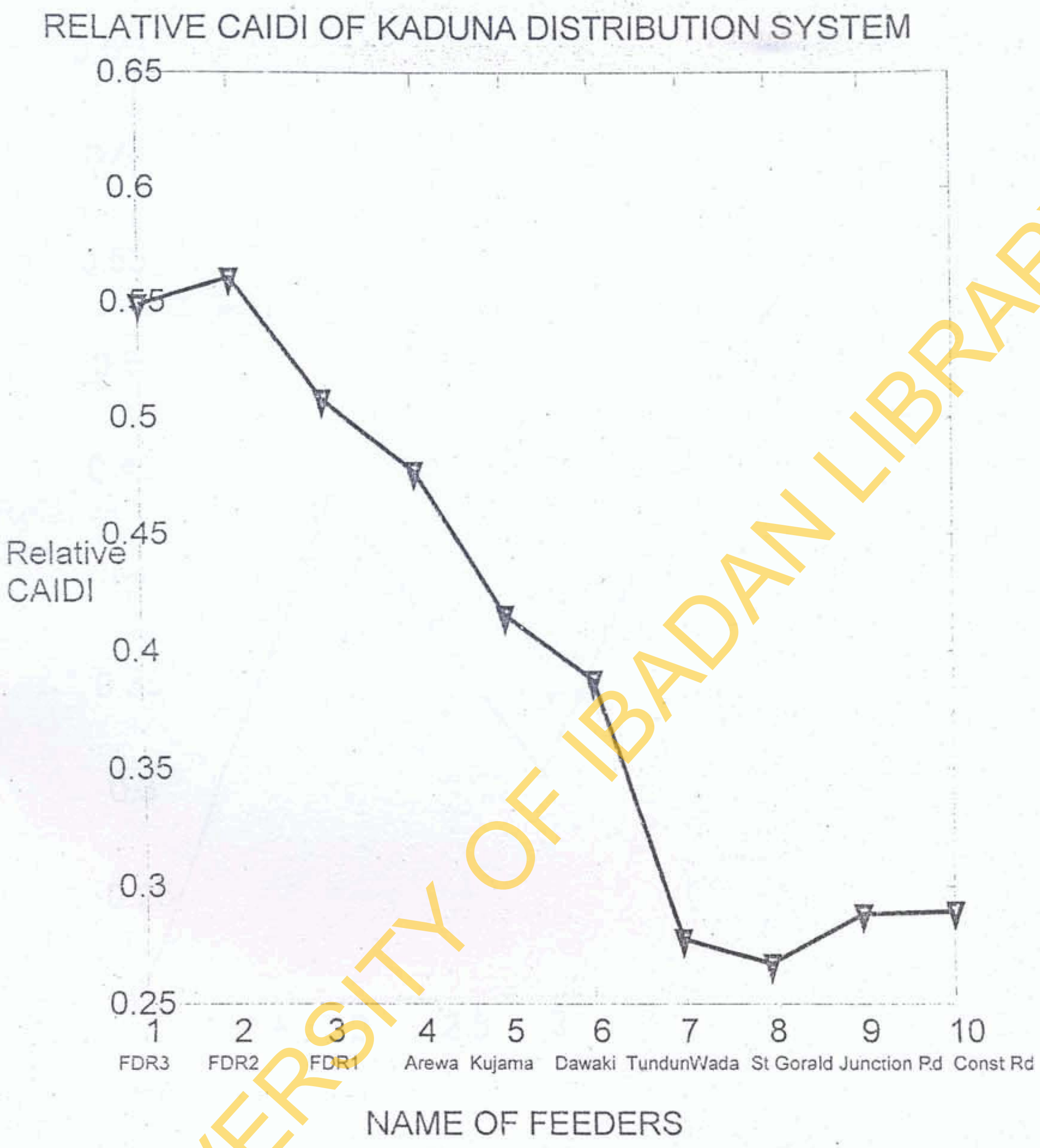

Figure 5.0: **Simulation Graph of relative CAIDI for Kaduna**

Case Study 5: Kaduna Distribution Systems

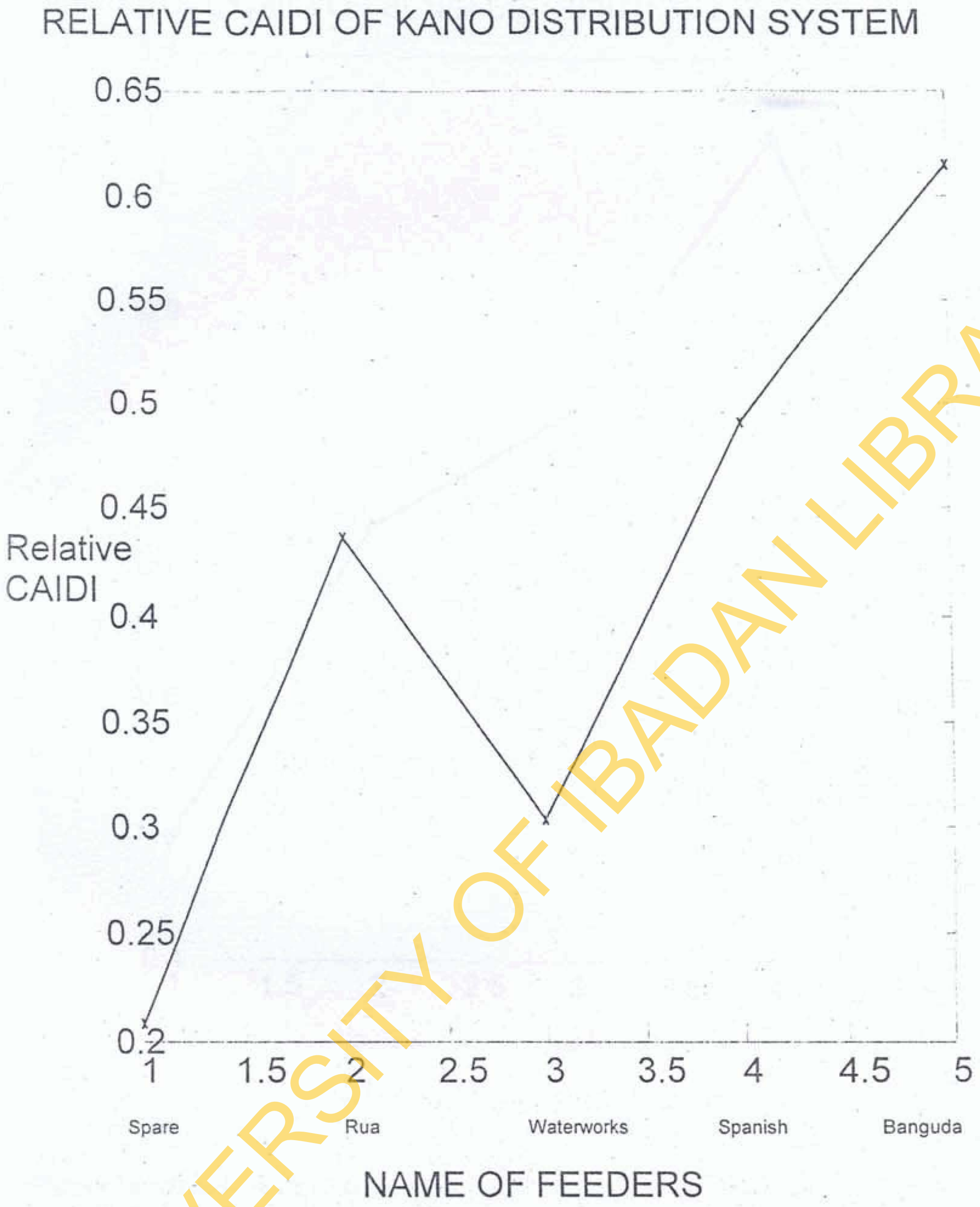

Figure 6.0: **Simulation Graph of relative CAIDI for Kano**
Case Study 6: Kano Distribution Systems

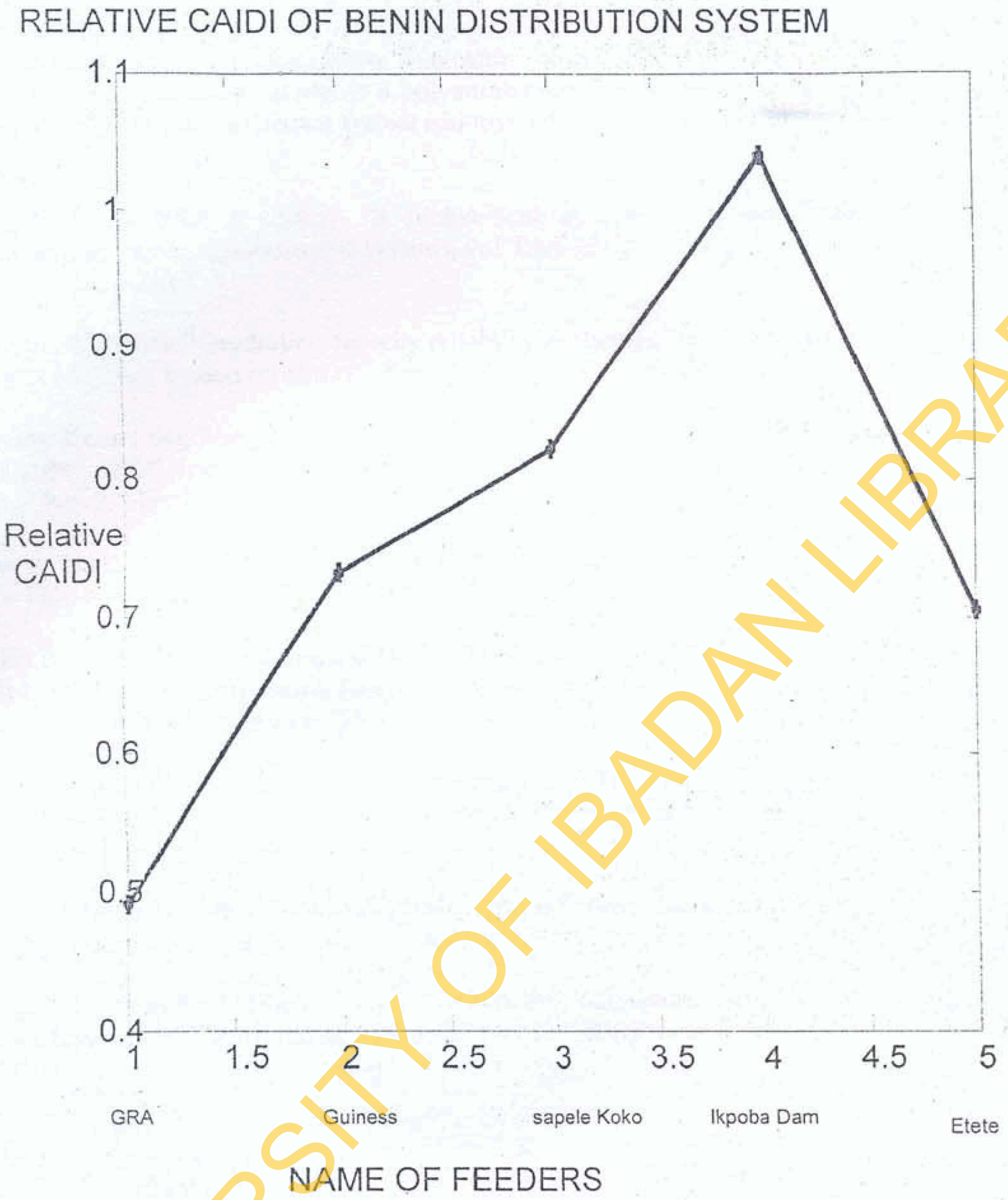

Figure 7.0: Simulation graph of relative CAIDI for Benin distribution system
Case Study 7: Benin Distribution Systems

CONCLUSION

A generalized model for quantitative evaluation of reliability indices for the national grid has been developed. The generalized model is a polynomial function whose order depends majorly on the level of industrialization of the distribution system and invariably, on the number of distribution feeders.

REFERENCES

Anderson P and Bose A (2003): "A probabilistic approach to power system stability analysis".IEEE transactions on power apparatus and systems, vol. PAS-102, pp 2430-2439.

Billington R (2008): "Generating capacity reliability evaluation". IEEE Tutorial Course: Probability Analysis of power system reliability". Tent. 71M 30 – PWR. Pp 23-31.

Billinton R and Peng Wang (2007): "Teaching distribution system reliability evaluation using Monte Carlo Simulation". IEEE Transactions on power systems, vol. 14, No. 2, May 2007.

Roberts, N.H., Andrew C and Brown Y (1999): "Mathematical methods in reliability engineering". Mc Graw Hill, New York, p. 69-83.

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 systems". IEEE Transactions on power systems, vol. 7, No. 1, Feb. 2007, pp 258-263

Sakis Meliopoulos A.P, Carol Cheng S and Feng X (2006): "Performance evaluation of staticsecurity analysis methods". IEEE Transactions on power systems, vol. 9, No. 3, pp 1441-1449.

Singh C.J, Mitra J (2006): "Composite system reliability evaluation using static space pruning".IEEE Transactions on ower systems, vol. 12, No.1, pp 471-479.

Wang P, Billinton R and Goel L (2000): "Probability distribution evaluation of distribution system reliability indices using a time sequential simulation technique". IEEE Transactions on power systems, vol. 11, No. 6, pp 65-71.