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

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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 was 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 Mitra 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).

Review of Related Work

A time sequential Monte-Carlo simulation technique for evaluating probability density functions of distribution system reliability indices is presented by Wang et al (2000). An event based index histogram shows the probability of parameters related to specific failure events. An annual index histogram presents the probabilities of indices created by aggregating the event-based parameters over a year. The results show that the time varying cost model (TVCM) has relatively slight impacts on the probability distribution of the load point and system indices.

Kovalev and Lebedeva (2000) developed a model for evaluating the reliability of electric power systems for long-term operational planning. The problem of determining the reliability of an electric power system of arbitrary configuration is considered and a mathematical formulation of the problem, ways and methods of obtaining its solution are given. Reference information on a program developed to solve the problem and recommended areas in which this program can be used are also presented.

Elena and Vitaly (2001) investigated a new reliability index for the multi-state system (MSS) reliability. It is a dynamic reliability index. The mathematical tool of logic differential calculus of multi-valued logic (MVL) function is used for calculation of the reliability indices. These indices investigate the outcome of a modification of a serviceability level of a separate system component for system reliability. These indices can be determined during the design stage of a system and can then be used for optimization of MSS reliability.

A linear contribution factor model of distribution reliability indices and its application in Mante-Carlo simulation and sensitivity analysis is reported by Fangxing et al (2003). This linear model can be applied to risk analysis and sensitivity analysis. Traditional approaches for both analysis require many repetitions of reliability index assessment. The model failed to appreciably improve the reliability indices of most system indices in an electrical distribution system of the national grid.

Neto et al (2006) described a methodology to evaluate the impact of distributed generation on the reliability indices of the distribution network considering the network constraint. This impact is assessed considering that distributed generation can be connected to an isolated feeder or to a feeder with tie-lines. The network constraints model used is based on a simplified version of the power summation load flow method and compensation techniques. The results with the proposed methodologies, to model the isolated and interconnected operations of distributed generation, demonstrate that distributed generation has a significant impact on the reliability indices of distribution networks. The proposed methodologies have been validated in a large distribution test system. The results show the importance of considering the impact of distributed generation on the reliability indices of distribution networks.

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 as 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).

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

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

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

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

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 equations (5) and (6), the generalized model equation is obtained as:

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

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

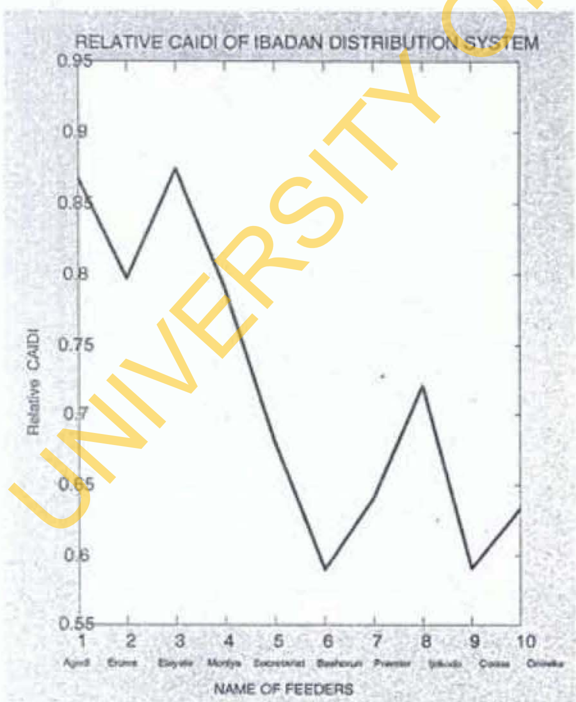

Figure 1.0: **Simulation Graph of relative CAIDI for Ibadan**
Case Study 1: Ibadan Distribution Systems

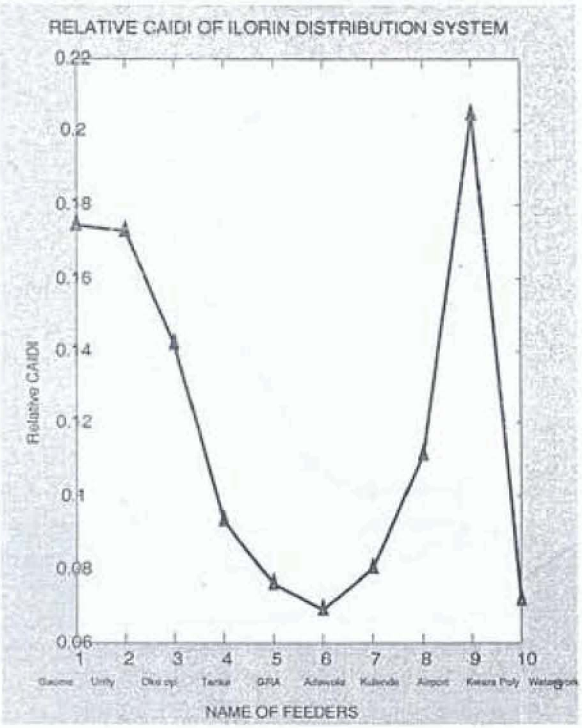

Figure 2.0: **Simulation Graph of relative CAIDI for Ilorin**

Case Study 2: Ilorin Distribution Systems

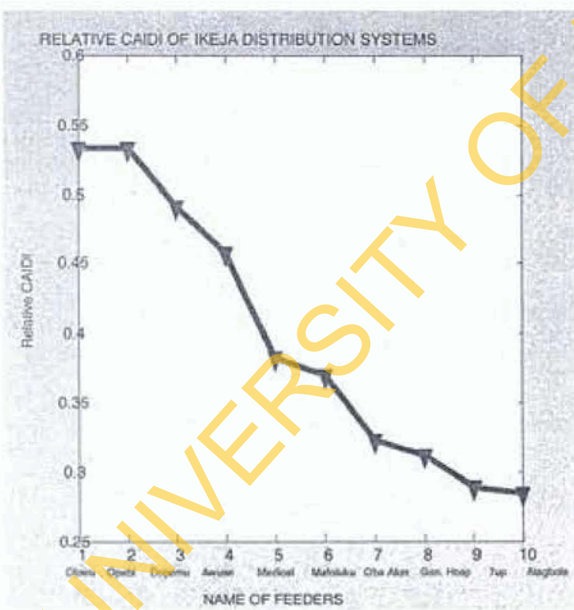

Figure 3.0: **Simulation Graph of relative CAIDI for Ikeja**

Case Study 3: Ikeja Distribution Systems

Relative CAIDI of Port Harcourt Distribution Systems

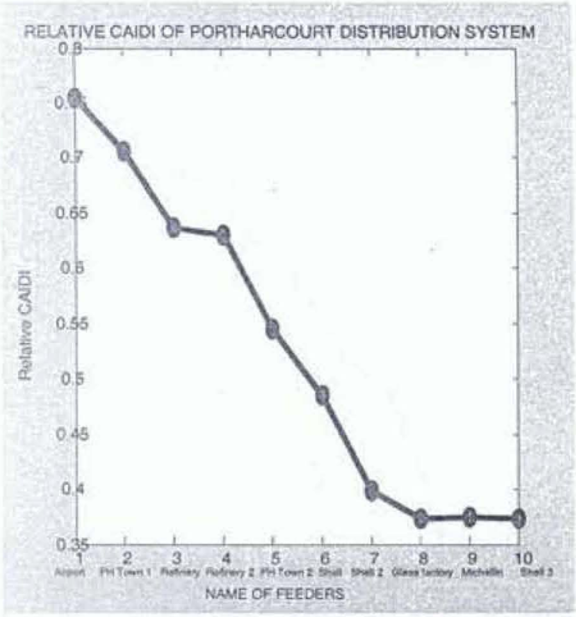

Figure 4.0: **Simulation Graph of relative CAIDI for Portharcourt**
Case Study 4: Portharcourt Distribution Systems

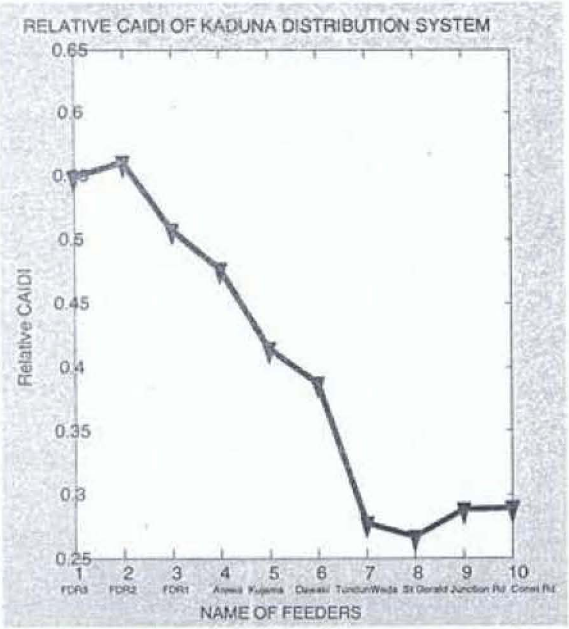

Figure 5.0: **Simulation Graph of relative CAIDI for Kaduna**
Case Study 5: Kaduna Distribution Systems

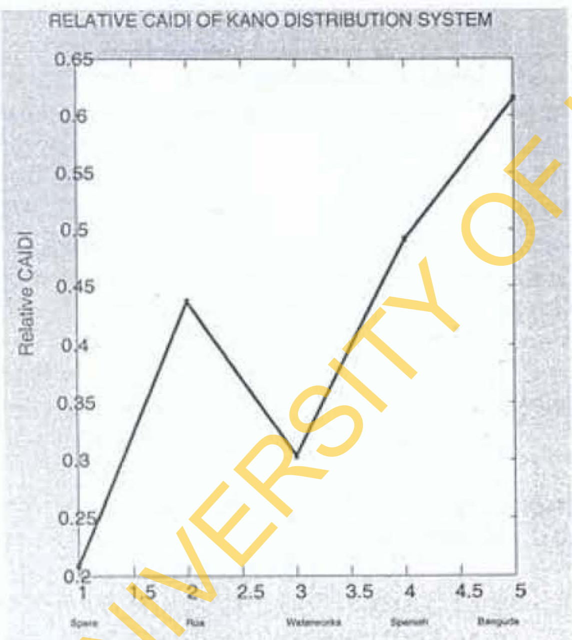

Figure 6.0: **Simulation Graph of relative CAIDI for Kano**
Case Study 6: Kano Distribution Systems

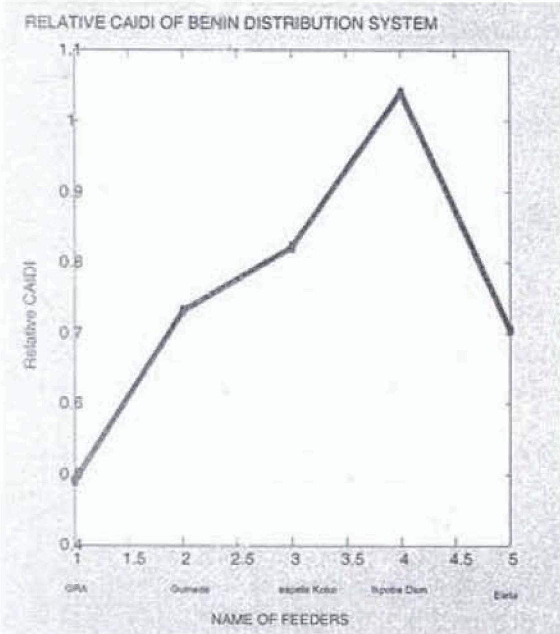

Figure 7.0: Simulation graph of relative CAIDI for Benin distribution system
Case Study 7: Benin Distribution Systems

CONCLUSION

A new measure of reliability index called "Relative CAIDI" has also been formulated to determine the reliability levels of the distribution systems. Thus, Ibadan, Port-Harcourt and Benin distribution systems have percentage Relative CAIDIs of 71.86%, 52.79% and 75.79% respectively, hence 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, thereby having poor reliability levels.

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.

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