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A MODIFIED LINEAR CONTRIBUTION FACTOR MODEL FOR IMPROVEMENT OF RELIABILITY INDICES OF ELECTRICAL DISTRIBUTION SYSTEMS

G.A. Ajenikoko[1], O.A. Fakolujo[2], andT.I. Raji[3]
[1,3]Department of Elec. and Elec. Eng., Ladoke Akintola University of Tech., Ogbomoso, Osun State, Nigeria
[2]Department of Electrical Engineering,University of Ibadan, Ibadan, oyo State, Nigeria

ABSTRACT

In Nigeria, sastisfactory degree of reliability has not been attained in our power systems in recent times. The average duration of interruptions that customers experience is quite high and the degree varies from place to place. This is evident all around the nation, most especially in urban commercial cities. Previous researchers have focused on assessment of power system reliability indices using different models. In this work, a computationally efficient modified linear contribution factor model (LCFM) is developed. The model can be used for appreciable improvement of all the major system reliability indices of practical distribution systems unlike the conventional LCF model which can only improve some of the system reliability indices of practical distribution systems. Data collection and data analysis were carried out to develop the LCF model used on the three selected distribution systems on the Nigerian National Grid. The results of this work indicate that part of the reliability indices computed for the distribution systems SAIFI is more sensitive to the LCF model than SAIDI and CAIDI but that the sensitivity is low for SAIDI index compared to CAIDI. This is due to the quantization of the annual number of customer interruptions caused by the type and placement of protective devices on the distribution systems of the National Grid. With the use of the modified LCF model, the average percentage improvement in the system reliability indices become 97.72%, 98.55% and 98.63% for Ibadan, Ilorin and Ikeja distribution systems resectively as against an average percentage improvement of 36.08%, 11.36% and 24.36% in the system reliability indices for Ibadan, Ilorin and Ikeja distribution systems resectively with the use of conventional LCF model. The result of this research work confirm the efficiency of the modified LCF model.

Keywords: ***Distribution Systems, Linear Contribution Factor, Reliability Indices, System Average Interruption Duration Index, System Average Interruption Frequency Index, Customer Average Interruption Duration Index.***

INTRODUCTION

The primary role of a power system is to provide reliable and continuous supply of energy to satisfy system load. Power system reliability, in a broad sense, can be defined as the ability of the system to provide an adequate supply of electric power with a satisfactory quality. Power systems have three main components: generation, transmission and distribution systems. The generation systems generate electricity, transmission system delivers the generated electricity to distribution systems for supplying load. The generation systems together with transmission systems are called the composite system or the bulk power system (Meliopoulos *et al,* 2001, Singh and Billinton, 2005).The reliability of a composite power system is comprised of both adequacy and security assessment as shown in Figure 1.0. Adequacy assessment relates to the ability of the system to supply 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. 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 by the loss of generation and transmission lines (George *et al.,* 2004, Lauby and Billinton, 2004). Definition of reliability indices The reliability of a system is quantified by stating certain parameters of its performance. These performance parameters are very important and are known as indices, indicators or measures of reliability. They are the foci or objectives of system reliability indices. Notable reliability indices include: failure rate, mean time between failure, mean time to repair, availability factor, system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI), and customer average interruption duration index (CAIDI). Most of the electrical distribution utilities measure their reliability performance using reliability indices such as SAIDI, SAIFI and CAIDI. (Buzacott, 2003, Meliopoulos et al, 2004 and Neto et al, 2004). The reliability of a system can be improved by reducing the frequency of faults and by reducing the repair time by means of various design and maintenance

strategies.Two sets of reliability indices, customer load point indices and system indices have been established to access the reliability performance of distribution systems. Load point indices measure the expected number of outages and their duration for individual customers. (Khan E. and Billinton R, 2002).

METHODOLOGY OF DATA COLLECTION AND ANALYSIS

In this research paper, ten years of outage information from Ibadan distribution systems, Ilorin distribution systems, and Ikeja distribution systems were collected and analysed. Making use of the proposed method of data collection scheme, a highly compressed version of such comprehensive database that retained only the essential information is used in this analysis. A relevant observation that emerged from data collection exercise is that all outages appear to be full, implying that partial outages were either not encouraged or not recorded by the system operator.

DEVELOPMENT OF A MODIFIED LINEAR CONTRIBUTION FACTOR MODEL (LCFM) FOR IMPROVEMENT OF RELIABILITY INDICES

Steps in the analysis of outage data for LCFM development

The following steps are employed in the development of a modified linear contribution factor model to improve the reliability indices of practical distribution systems:

1. Identification of the system reliability indices for the distribution system under study.
2. Computation of the failure rate for the selected feeders in the distribution systems.
3. Computation of the system reliability indices.

$$SAIDI = \frac{\text{customer interruption duration}}{\text{Total number of customers served}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{Total number of customers served}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

$$CAIDI = \frac{\text{customer interruption duration}}{\text{Total number of customer interruption}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

4. Computations of the contributions to each of the system reliability indices from the selected feeders.

$$SAIDI = \Sigma (SAIDI^C) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$$SAIFI = \Sigma (SAIFI^C) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

$$CAIDI = \Sigma (CAIDI^C) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where $SAIDI^C$ = contributions to SAIDI from the feeders
Where $SAIFI^C$ = contributions to SAIFI from the feeders
Where $CAIDI^C$ = contributions to CAIDI from the feeders

5. Perform sensitivity analysis for the system reliability.
6. Compute the percentage improvement in the reliability indices of the distribution systems under study using the modified linear contribution factor model (LCFM).

$$\text{Percentage improvement} = \frac{(A_\alpha - A_\alpha) \times 100\%}{A_\alpha} \quad \ldots\ldots\ldots\ldots 7$$

Where A_α = mean value of reliability indices without the LCF model.
A_α = reliability index with the LCF model

RESULTS AND DISCUSSION

The percentage improvements in the reliability indices for Ibadan distribution system, Ilorin distribution system and Ikeja distribution system using the conventional and modified LCFM model are as displayed in tables 1 – 6 while the graphical representations are also displayed in figures 1-6. The graphical representation of percentage improvement of Ibadan, Ilorin and Ikeja distribution systems with the conventional LCF model and the modified LCF model are also displayed in figure 7. It is evident that part of the reliability indices computed for the distribution system SAIFI is more sensitive to the LCF model than SAIDI and CAIDI but however the sensitivity is low for SAIDI index compared to CAIDI. This is as a result of the quantization of the annual number of customer interruptions caused by the type and placement of protective devices on the distribution system.

Table 1: Percentage Improvement in the Reliability Indices for Ibadan Distribution Systems Using Conventional LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Agodi	14.2985	16.4802	62.7971
2	1998-2007	Eruwa	14.6529	18.3942	58.8286
3	1998-2007	Eleyele	14.9286	17.0689	63.1989
4	1998-2007	Moniya	18.0245	22.8101	79.9487
5	1998-2007	Secretariat	18.4892	27.1877	68.4609
6	1998-2007	Bashorun	16.5933	28.1467	58.7199
7	1998-2007	Premier	19.1695	29.8796	64.4078
8	1998-2007	Ijokodo	20.5650	28.5164	73.0723
9	1998-2007	Cocoa	19.3524	32.7462	59.4429
10	1998-2007	Onireke	20.3408	32.1071	63.7727

Table 2: Percentage Improvement in the Reliability Indices for Ibadan Distribution Systems Using Modified LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Agodi	98.8572	98.8572	98.8572
2	1998-2007	Eruwa	98.7913	98.7913	98.7913
3	1998-2007	Eleyele	98.4529	98.4529	98.4529
4	1998-2007	Moniya	98.1372	98.1372	98.1372
5	1998-2007	Secretariat	97.6083	97.6083	97.6083
6	1998-2007	Bashorun	96.9365	96.9365	96.9365
7	1998-2007	Premier	97.6059	97.6059	97.6059
8	1998-2007	Ijokodo	96.8546	96.8546	96.8546
9	1998-2007	Cocoa	96.8061	96.8061	96.8061
10	1998-2007	Onireke	97.1693	97.1693	97.1693

Table 3: Percentage Improvement in the Reliability Indices for Ilorin Distribution Systems Using Conventional LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Gaoma	3.3272	19.0898	17.2874
2	1998-2007	Unity	3.2554	18.8324	16.6919
3	1998-2007	Oke-Oye	2.7706	19.5334	14.0821
4	1998-2007	Tanke	1.9140	20.5361	9.5509
5	1998-2007	GRA	1.6216	21.3269	7.7423
6	1998-2007	Adewole	1.4135	20.5552	6.8644
7	1998-2007	Kulende	1.7651	22.0256	8.6015
8	1998-2007	Airport	2.5654	23.0539	12.1143
9	1998-2007	Kwara Poly	4.9272	24.0898	20.4342
10	1998-2007	Water Works	1.7864	24.9286	6.9569

Table 4: Percentage Improvement in the Reliability Indices for Ilorin Distribution Systems Using Modified LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Gaoma	97.0192	97.0192	97.0192
2	1998-2007	Unity	98.9886	98.9886	98.9886
3	1998-2007	Oke-Oye	98.4908	98.4908	98.4908
4	1998-2007	Tanke	98.1878	98.1878	98.1878
5	1998-2007	GRA	98.2737	98.2737	98.2737
6	1998-2007	Adewole	97.3427	97.3427	97.3427
7	1998-2007	Kulende	98.3820	98.3820	98.3820
8	1998-2007	Airport	98.9516	98.9516	98.9516
9	1998-2007	Kwara Poly	99.9457	99.9457	99.9457
10	1998-2007	Water Works	99.8925	99.8925	99.8925

Table 5: Percentage Improvement in the Reliability Indices for Ikeja Distribution Systems Using Conventional LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Olowu	10.3091	19.3736	53.0010
2	1998-2007	Opebi	9.9203	18.6295	53.1763
3	1998-2007	Dopemu	9.5105	19.3830	48.5535
4	1998-2007	Awuse	9.4139	20.5015	45.5384
5	1998-2007	Medical	13.9448	21.3221	74.6414
6	1998-2007	Mafoluku	7.6066	20.5819	36.0738
7	1998-2007	Oba Akinjobi	7.0873	21.9744	32.0086
8	1998-2007	Gen Hosp	7.1455	22.9012	30.7002
9	1998-2007	7-UP	6.8087	23.5388	28.0634
10	1998-2007	Atagbole	6.9242	24.0939	27.9629

Table 6: Percentage Improvement in the Reliability Indices for Ikeja Distribution Systems Using Modified LCF Model

s/n	Year	Name of Feeders	% Improvement		
			SAIDI	SAIFI	CAIDI
1	1998-2007	Olowu	98.9400	98.9400	98.9400
2	1998-2007	Opebi	98.4100	98.4100	98.4100
3	1998-2007	Dopemu	98.5500	98.5500	98.5500
4	1998-2007	Awuse	98.6400	98.6400	98.6400
5	1998-2007	Medical	98.7300	98.7300	98.7300
6	1998-2007	Mafoluku	98.4500	98.4500	98.4500
7	1998-2007	Oba Akinjobi	98.8800	98.8800	98.8800
8	1998-2007	Gen Hosp	99.0300	99.0300	99.0300
9	1998-2007	7-UP	98.2700	98.2700	98.2700
10	1998-2007	Atagbole	97.8800	97.8800	97.8800

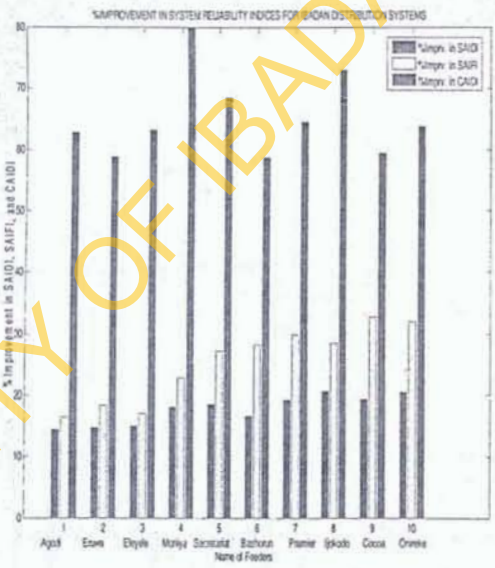

Figure 1: Bar chart For Percentage Improvement in Reliability Indices for Ibadan Distribution Systems with the Conventional LCF Model

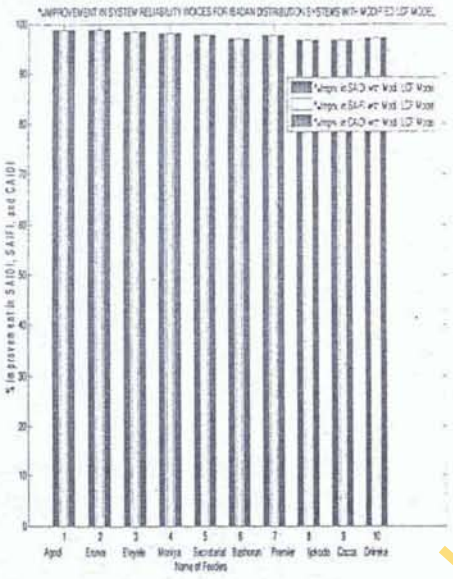

Figure 2: Bar chart For Percentage Improvement in Reliability Indices for Ibadan Distribution Systems with the Modified LCF Model

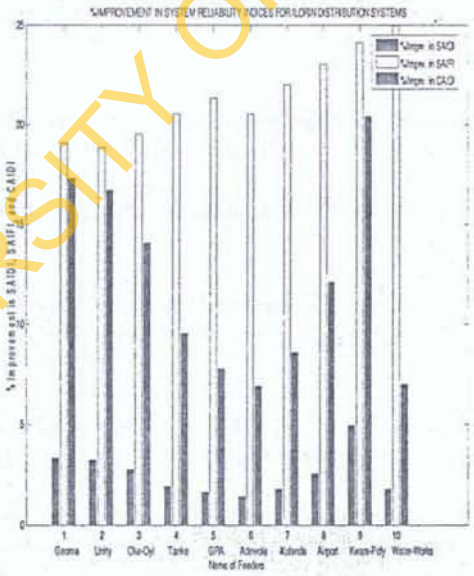

Figure 3: Bar chart For Percentage Improvement in Reliability Indices for Ilorin Distribution Systems with the Conventional LCF Model

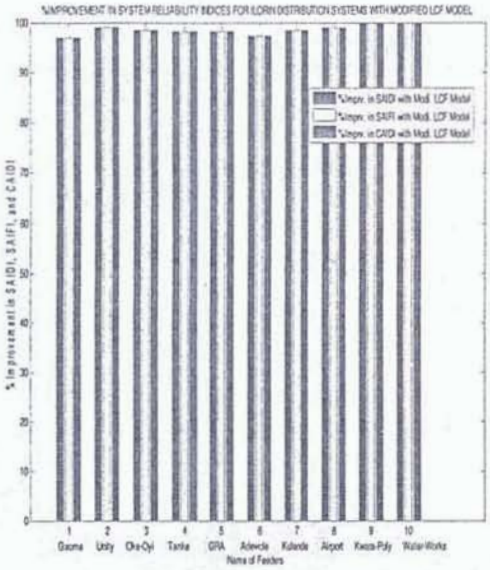

Figure 4: Bar chart For Percentage Improvement in Reliability Indices for Ilorin Distribution Systems with the Conventional LCF Model

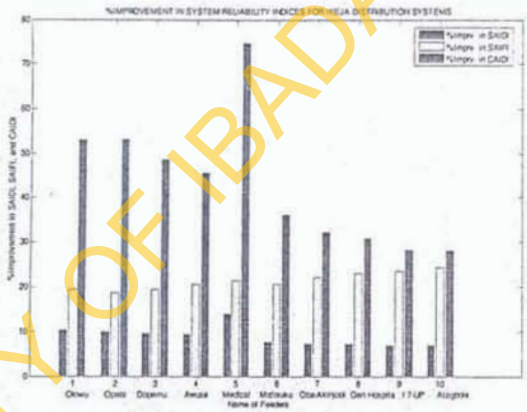

Figure 5: Bar chart For Percentage Improvement in Reliability Indices for Ikeja Distribution Systems with the Conventional LCF Model

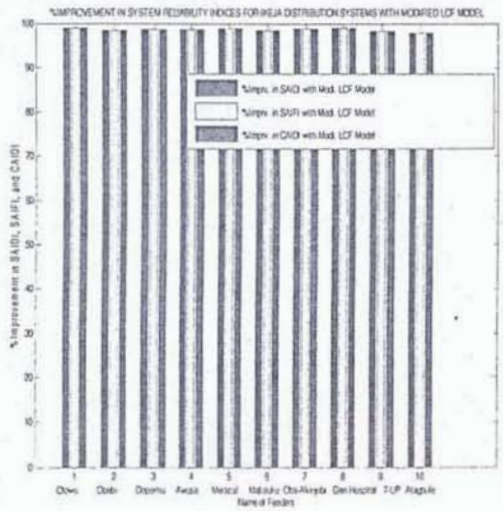

Figure 6: Bar chart For Percentage Improvement in Reliability Indices for Ikeja Distribution Systems with the Conventional LCF Model

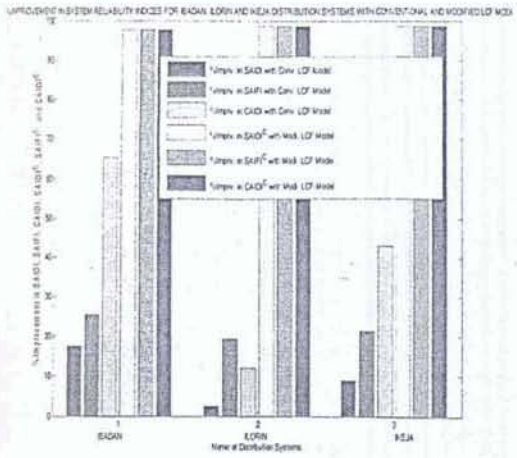

Figure 7: Graph of percentage improvement in reliability indices of Ibadan, Ilorin, and Ikeja distribution systems with the conventional LCF model and the modified LCF model.

CONCLUSION

A modified computationally efficient linear contribution factor model (LCFM) technique for practical distribution systems has been presented in this work. The results of the modified LCF model indicates an average percentage improvement of 97.72%, 98.55%, and 98.63% in the system reliability indices for Ibadan, Ilorin and Ikeja distribution systems respectively as against an average percentage improvement of 36.08%, 11.36%, and 24.36% in the system reliability indices for Ibadan, Ilorin and Ikeja distribution systems when the conventional LCF model was initially employed. This has confirmed the efficiency of the modified linear contribution factor model for improvement of reliability indices of practical distribution systems. A new measure of reliability called "threshold CAIDI" is proposed in this paper. This "threshold CAIDI" helps to identify the feeders that need improvement on the distribution systems of the Nigerian National Grid.

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