The International Journal of Engineering and Science (IJES)
|| Volume || 9 || Issue || 07 || Series I || Pages || PP 20-30 || 2020 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Reliability centered maintenance for distribution system infrastructure in Nigeria

Chinweike Okoli[1], Roland Uhunmwangho[2], Ezugwu Kingsley[1]
[1]*Department of Electrical Engineering,University of Nigeria, Nsukka, Enugu State, Nigeria*
[2]*Department of Electrical/Electronic Engineering, University of Port Harcourt, East/West Road, PMB 5323 Choba, Rivers State, Nigeria*

--**ABSTRACT**--
The study deals with the development of optimal maintenance model for distribution system infrastructure. The main objective is to minimize the total maintenance cost while maximizing the index of reliability of the whole system. In the proposed model, the limits of the indices, such as SAIDI and SAIFI, are considered as constraints of the maintenance programs. The RCM method has used the power interruption statistical data in analyzing the reliability indices of the distribution system. The result of the maintenance strategy has helped in deciding the appropriate maintenance selection to improve the system reliability, and minimize the interruption in the distribution system.
Keywords: Power System Reliability, Reliability-Centered Asset Maintenance (RCAM), Power System Maintenance, Preventive maintenance, Corrective Maintenance
----
Date of Submission: 18-06-2020 Date of Acceptance: 06-07-2020

I. INTRODUCTION

The deregulation of the power systems industry that is an ongoing process in Nigeria, has led to a stronger market orientation and competition among the power companies [1]. There has been a lot of attention on the customer, thus changing the driving factors of the power system market from technical to economic driving factors [2].

There is much pressure on utility companies that operate the distribution systems network to be economical in several market requirements [3].]. On one hand, as customers are being billed for a service, the quality of service offeredis being given increased attention by customers, and the central authorities[4]. On the other hand, electric power distribution companies must make sure that their expenditure is cost-effective [1], [5]. This has not only lead to a more cautious use of corporate funds, viz a viz postponed investments, a reduction in maintenance, fewer employees etc., but also increased use of cost-benefit analysis [6]. There will be trade offs between the customers' demand for quality and the interests of utilities in economic terms [7-8].

Therefore, this situation calls for broader perspective on asset management of the power transmission and distribution systems. This new approach in asset management relates maintenance effort to system availability and total cost, with the aim to reach an optimal maintenance management [9], [10].

One major expenditure for power distribution utility is the cost of maintaining system infrastructure, for example by adopting periodic or condition maintenance, collectively called preventive maintenance (PM) [11]. Normally, preventive maintenance schemes usually consist of planned maintenance activities carried out at regular intervals (scheduled maintenance). Such a maintenance strategy might be very wasteful; it may be expensive (in the long run), and it may not even extend component lifetime as could reasonably be expected [11], [12]. Therefore, since 1990, many utilities changed their maintenance strategies based on rigid programs by more flexible schedules using periodic or even continuous condition monitoring and data analysis [13]. Some of these techniques have been collectively termed Reliability-Centered Maintenance (RCM).

In the past several years now, reliability-centered maintenance has been well developed into electric power systems [14-17]. However, there is an absence of procedures that relate the reliability of a system to its component maintenance [18]. This is because there is insufficient input data; also, the unwillingness in using theoretical tools for taking care of the practical issue of maintenance planning.However, there is a lack of techniques that relate system reliability to component maintenance [18].

This paper models reliability-centered asset maintenance (RCAM) scheme, which provides a quantitative relationship between system reliability and the total maintenance cost. The method is developed from RCM principles attempting to relate more closely the impact of maintenance on the cost and reliability of the system. The method has been applied on a distribution system in Nigeria: a rural system of overhead power lines in the south eastern part of Nigeria, the Enugu-Ezike system. The study was carried out using actual system data and in close co-operation with the operating utility (Enugu Electricity Distribution Company).

II. ASSET MANAGEMENT OF ELECTRIC POWER NETWORKS

Maintenance is crucial for distribution system operators both when acquiring new assets (apparatus) and when trying to utilize already existing assets in the best possible manner [19]. The cost of maintenance and consequences of failures can be significantly higher than the cost of the equipment. Hence, it becomes important to study maintenance and its effects in all stages of the lifetime of the asset [20].

One of the major risks that are associated with utility infrastructure is the probability of failure occurrence and its consequence. Maintenance actions are carried out based on components condition, characteristics, and potential failures' probabilities and consequences [21]. There are many classification of maintenance action that is utilized in power system reliability assessment. These maintenance actions are; condition based maintenance, time based maintenance, reliability centered maintenance, etc. For three decades now, the condition based maintenance and time based maintenance as well as reliability-centered maintenance has been well introduced into electric power systems. The condition-based maintenance and time-based maintenance has rather high expenses for monitoring sensors, fault diagnosis system, and communication. Also in terms of protection and control, engineers are suffering from data overload. However, reliability centered maintenance depends heavily on practical experiences in diagnostic analysis and maintenance measures.

It gives the relationship between relationships between component reliability and system maintenance.

III. RELIABILITY CENTERED MAINTENANCE (RCM)

One method for relating reliability and PM is known as reliability-centered maintenance (RCM). RCM is a systematic strategy to maintain a balance between corrective and preventive maintenance. This method chooses the right preventive maintenance activities for the right component at the right time to reach the most cost-efficient solution [22]. According to [23], it originated in the civil aircraft industry in the 1960s with the introduction of the Boeing 747 series, and the need to lower PM costs in attaining a certain level of reliability. RCM was introduced into the electric power industry in the 1980s. Today RCM is used or considered by an increasing number of electrical utilities [24], [25]. According to [5] an RCM analysis basically focuses on preserving system function where critical components for system reliability are prioritized for PM measures. Notwithstanding, RCM is generally not capable of showing the relationship between system reliability and total maintenance cost. This therefore takes us to reliability-centered asset maintenance (RCAM) method, which gives us a quantitative relationship between PM of assets and the total maintenance cost [5]. The overall principle of the RCAM approach is contained in three main stages namely: System reliability analysis, Component reliability modeling, and System reliability and cost/benefit analysis. The first two stages (i.e. system reliability analysis and component reliability modeling) define the system and evaluate critical components affecting system reliability, and the quantitative relationship between reliability and PM measures. The final stage (i.e. System reliability and cost/benefit analysis) however deals with the benefits in costs due to the impact of maintenance on reliability.

There are several costs associated with system failures. These costs include:

i. the cost of restoring a failure
ii. the cost of preventive maintenance
iii. the cost of interruption

The optimal maintenance method and PM strategy is the solution that minimizes the sum of these three costs.

IV. METHODOLOGY

A. Data Analysis

The method of reliability centered asset management requires the available failure statistics from the power distribution networks, as well as about the reliability evaluation of electrical equipment. The infrastructures in which data were collected include:

1. Feeder line 33KV
2. Transformers 3-phase, 33/0.415KV
3. Fuses (D fuses)
4. Isolator switch
5. Outgoing feeder 0.415KV
6. Surge arresters 33KV
7. Gang insulator 33KV
8. Feeder pillar

B. Evaluation of Reliability Indices

The reliability indices will be evaluated in two stages; the component reliability indices, and the customer reliability indices.

i. Component reliability indices

i. Failure rate

The failure rate of each component was evaluated using the number of outages and the total time that the component was to be in operation.

$$\lambda = \frac{number\ of\ outages\ on\ component\ in\ a\ given\ period}{total\ time\ component\ is\ to\ be\ in\ operation}$$

$$\lambda_t = \lambda_1 + \lambda_1 = \sum_{i=1}^{n} \lambda_i = 0.0332$$

Average of $\lambda = 0.0028 f/yr$

ii. Repair time

The repair time of each component was evaluated using the number of outages and the total outage time. The total repair time of the system was calculated by the summation of the individual repair time. It is expressed as;

$$\mu = \frac{number\ of\ outages\ on\ component\ in\ a\ given\ period}{total\ time\ component\ is\ not\ in\ operation}$$

$$\mu_s = \mu_1 + \mu_2 = \sum_{i=1}^{n} \mu_i = 0.7577$$

Average of $\mu = 0.063 hr/f$

iii. Mean time between failure (MTBF)

MTBF refer to as the reliability of reparable components in a distribution system. It describe the total time the component was in operation. It is expressed as;

$$MTBF = \frac{total\ system\ operating\ hour}{number\ of\ failure}$$

$$MTBF = \frac{1}{\lambda} = \frac{1}{0.0028} = 357.14$$

iv. Mean time to repair (MTTR)

This is the average time it takes to restore a particular component to its normal operation. It is the time taken to identify the fault and to repair it. It is expressed as

$$MTTR = \frac{total\ duration\ of\ outages}{frequency\ of\ outages}$$

$$MTTR = \frac{1}{\mu} = \frac{1}{0.063} = 15.87$$

v. Availability

Availability is the measure of the duration for which the component is in operation at any time. It is given by the expression.

$$Avialability\ (A) = \frac{MTBF}{MTBF + MTTR}$$

$$A = \frac{\mu}{\lambda + \mu} = \frac{0.063}{0.063 + 0.0028} = 0.957$$

ii. Customer reliability indices

The reliability indices utilized in this work to evaluate the customer reliability indices include: SAIDI, SAIFI and ASAI.

i. System Average Interruption Duration Index (SAIDI)

SAIDI can be defined as the average interruption duration for customers served during a specified time period. The unit is "minutes or hours". The advantages of this index is that it helps the utility to report for how many minutes customers would have been out of service if all customers were out at one time. It is expressed as;

$$SAIDI = \frac{Total\ outage\ duration\ in\ hours}{Number\ of\ customers\ supplied}$$

$$SAIDI = \frac{552}{589} = 0.9372 hrs/cust$$

SAIDI for the whole year is given as 6.2547hrs/cust

ii. System Average Interruption Frequency Index (SAIFI)

This is defined as the average number of times that a customer is interrupted during a specified time period. The resulting unit is "interruptions per customer. It is evaluated by the ratio of the frequency of interruption and the number of customer supplied. It is expressed as;

$$SAIFI = \frac{Frequency\ of\ outages}{Number\ of\ customers\ supplied}$$

$$SAIFI = \frac{41}{589} = 0.0696 int/cust$$

SAIFI for the whole year is given as 0.5959int/cust

iii. Average Service Availability Index (ASAI)

This is a measure of the average availability of the distribution system that serves customers. ASAI is evaluated in this project work by the ratio of the customer hours service availability and customer hours service demanded. It can also be evaluated by the difference between the total hours and duration of interruption divided by the total hours. It is usually represented in percentages. It is expressed as;

$$ASAI = \frac{customer\ hours\ service\ availability}{customer\ hours\ service\ demanded}$$

Or

$$ASAI = \frac{Total\ hours - Duration\ of\ interruption}{Total\ hours}$$

$$ASAI = \frac{744 - 552}{744} = 0.2581$$

ASAI for the whole year is given as 0.9651

iv. Interruption cost index (I^H)

This index is also known as hazard rate index. The major aim of this index is to relate the interruption cost with the system reliability importance. The index can also be seen as the expected cost if the studied component fails. It can be expressed as;

$$I^H = \frac{\partial C_{int}}{\partial \lambda_i}, \qquad i = 1,2,3 \ldots \ldots$$

But

$$C_{int} = \lambda_t . (K_l P_l + C_l P_l U_t)$$

Where

λ_t = the total failure rate of the component (f/yr)
λ_i = the failure rate of component i (f/yr)
U_t = the total repair time of the component (h/f)
I^H = the hazard rate index of component i (cost/f)
C_{int} = the interruption cost of the system (int/f)
P_l = the electrical power at load point (kw)
K_l = cost constant at load point (cost/kw)
C_l = cost constant at load point (kwh)

In this paper, the cost constant at load point is obtained from the utility and is given as:
C_l = 48.50Naira/kwh
K_l= 5412Naira/kw

To obtain the electrical power at load point in kw, a 300kva transformer in the network was considered. The loading percentage of the transformer is 47 and a power factor of 0.8 was used. But

$$P_{kw} = S_{kva} \times p.f = 300 \times 0.8 = 240kw$$

$$P_l = 47\%\ of\ 240 = 112.8kw$$

C. Modeling of Maintenance Cost

The cost of the maintenance task is the cost associated with each corrective or preventive task, whether time-based or condition-based. The expected corrective maintenance cost is the total cost of maintenance resources needed to repair or replace failed items. Similarly, the expected preventive maintenance cost is the total cost of maintenance resources needed to inspect and/or examine an item before failure takes place and to replace any items rejected. Thus, the total maintenance cost is the sum of the corrective and preventive maintenance costs and the overhead costs (i.e., cost of interruption). This is expressed as:

$TC = CCM + CPM + CI$

Where

TC = total cost of maintenance

CCM = total cost of corrective maintenance (i.e., $\sum C_{cm}$)

CPM = total cost of preventive maintenance (i.e., $\sum C_{pm}$)

CI = total cost of interruption = C_{int}

The optimal maintenance method is the solution that minimizes the sum of these three costs.

In this paper, five level of maintenance have been considered which include:

Level 1: 100% maintenance level which can be viewed as replacement or installation of new component (i.e., 100% CM and 0% PM)

Level 2: 75% maintenance level (i.e., 75% CM and 25% PM)

Level 3: 50% maintenance level (i.e., 50% CM and 50% PM)

Level 4: 25% maintenance level (i.e., 25% CM and 75% PM)

Level 5: 0% maintenance level (i.e., 0% CM and 100% PM)

Table 1 shows the 100% maintenance level cost (i.e. 100% CM and 0% PM) and the failure rate of each component.

Table 1: Failure rate and the CCM for each component

Component name	Failure rate (f/yr)	CCM (₦)
Feeder line (1km)	0.0197	380,000
Transformer	0.0028	2,100,000
Fuse (D fuse)	0.0118	55,000
Isolator switch	0.000458	185,000
Outgoing feeder	0.00504	350,000
Surge arrester	0.000108	48,000
Gang insulator	0.000233	230,000
Feeder pillar	0	40,000
Total	0.0401393	3,388,000

Now, considering different maintenance levels, and applying the 6:1 preventive maintenance ratio rule, Table 2 shows the new values of the failure rates.

Table 2: **Failure rate of each component for different levels of maintenance**

Component name	Failure rate for75% CM & 25%PM	Failure rate for50% CM & 50%PM	Failure rate for25% CM & 75%PM	Failure rate for 0% CM 100%PM	Failure rate for100%CM & 0% PM
Feeder line (1km)	0.0156	0.01149	0.00739	0.00328	0.0197
Transformer	0.00222	0.00164	0.00105	0.00047	0.0028
Fuse (D fuse)	0.00934	0.00689	0.00443	0.00197	0.0118
Isolator switch	0.00036	0.00027	0.00017	0.00008	0.00045
Outgoing feeder	0.00399	0.00294	0.00189	0.00084	0.00504
Surge arrester	0.00009	0.00006	0.00004	0.00002	0.00010
Gang insulator	0.00018	0.00014	0.00008	0.00004	0.00023
Feeder pillar	0.0	0.0	0.0	0.0	0.0
Total	0.03169	0.02343	0.01505	0.0067	0.04012

So, the cost of interruption (C_{int}) for different maintenance level is computed as:

$$C_{int}\ for\ Level\ 1 = 0.04012[(5820 \times 112.8) + (48.50 \times 112.8 \times 0.82263)] = 26519.18\text{cost/yr}$$

$$C_{int}\ for\ Level\ 2 = 0.03169[(5820 \times 112.8) + (48.50 \times 112.8 \times 0.82263)] = 20946.98\text{cost/yr}$$

$$C_{int}\ for\ Level\ 3 = 0.02343[(5820 \times 112.8) + (48.50 \times 112.8 \times 0.82263)] = 15487.15\ \text{cost/yr}$$

$$C_{int}\ for\ Level\ 4 = 0.01505[(5820 \times 112.8) + (48.50 \times 112.8 \times 0.82263)] = 9948.0\text{cost/yr}$$

$$C_{int}\ for\ Level\ 5 = 0.0067[(5820 \times 112.8) + (48.50 \times 112.8 \times 0.82263)] = 4428.68\text{cost/yr}$$

V. FORMULATION OF THE MATHEMATICAL MODEL THAT MINIMIZES THE SUM OF THESE THREE COSTS (CCM, CPM, AND CI).

The main aim of this project work lies on the bases that the total cost of applying a maintenance measure should be less than not taking any action. If little or no PM is done, then more system failure is likely to occur resulting in more repair actions being required. Therefore, the important issue is to compare the cost associated with different maintenance levels with the objective of minimizing the total cost of maintenance. In order to compare the reliability indices gotten before i.e. SAIDI, SAIFI and ASAI with the cost of PM and CM, a mathematical model has been chosen. This is to help and choose the best maintenance cost between the CM and PM. In order to achieve that, a scaling factor "s" has been introduced. The aim is to vary this factor and by so doing vary the value of the various cost and reliability value. The scaling factor has been chosen between the range of 0 and 1 with an interval of 0.05. The major reason of considering the reliability index values obtained and the maintenance cost is to account for the reliability of the system after maintenance. The scaling factor will be varied until the system reliability meets the requirement.

VI. THE MATHEMATICAL MODEL

The mathematical model used in this study is therefore given as:

$(1- s)$ SAIDI

S $\times$ SAIFI

CCM = $s[\lambda_t \sum_{i=1}^{n} C_{cm}^{i}]$

CPM = $\frac{(1-s)[\lambda_t \sum_{i=1}^{n} C_{cm}^{i}}{2} + CPM_{prev}$

CI = $s[C_{int} \times E_{lp}]$

TC = $\sum_{i=1}^{n} A$

Where

A = CCM + CPM + CI

s = scaling factor

TC = Total cost of maintenance

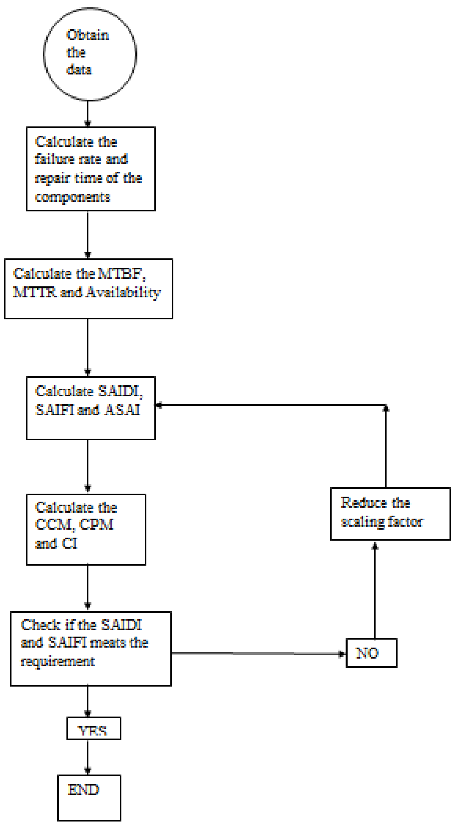


Figure 1: The flow chat of the study

Figure 1 shows the flow chat of the maintenance model. The IEEE standard 1366-1998 is set as a constraint in obtaining standard system reliability indices for SAIDI and SAIFI.

VII. DISCUSSION OF RESULTS

The results will be presented in two stages:

A. System Reliability Level

B. Maintenance Strategy Level

A. System Reliability Level

The component and customer reliability indices for Enugu-Ezike rural distribution infrastructure are presented in tables 3 and 4.

From the tables 3 and 4, the availability of the infrastructure is seen to have a value of 0.9535 and 0.9651 respectively. This shows that availability of the system calculated through any of the two means is valid and can be accepted for interpretation of result. Also, the value shows that the infrastructure is available for an approximate average of 95% to 96% in a year. Comparing this value (96%) to the IEEE ASAI standard of 99.99989 for distribution system availability, it is worthy to note that, the area has poor performance and need to be improved upon by using maintenance strategies. This will help to increase the system reliability.

.

Table 3: Basic indices on each component availability

component	λ (f/yr)	U (hr/f)	MTBF	MTTR	AVAILABILITY (%)
Feeder line	0.0197	0.0598	50.76	16.722	0.752
Transformer	0.0028	0.063	357.14	15.87	0.957
Fuses	0.0118	0.397	84.75	2.519	0.971
Isolator switch	0.000458	0.0456	2183.4	21.93	0.990
Outgoing feeder	0.00504	0.236	198.4	4.237	0.979
Surge Arrester	0.000108	0.0033	9259.26	300.30	0.9686
Gang insulator	0.000233	0.0179	4286.33	55.866	0.987
Feeder pillar	0	0	0	0	0
Total	0.0401393	0.82263	24.91	1.216	0.9535

Table 4: computed customer reliability indices

Month	Freq. of int.	Duration of int.	Total hours	No. of customers	SAIDI (hrs/cust)	SAIFI (int/cust.)	ASAI (p.u)
January	41	552	744	589	0.9372	0.0696	0.2581
February	39	211	696	589	0.3582	0.0662	0.6968
March	18	100	744	589	0.1698	0.0306	0.8656
April	27	162	720	589	0.2750	0.0458	0.7750
May	26	345	744	589	0.5857	0.0441	0.5363
June	24	271	720	589	0.4601	0.0407	0.6236
July	12	37	744	589	0.0628	0.0204	0.9503
August	19	179	744	589	0.3039	0.0323	0.7594
September	19	490	720	589	0.8319	0.0323	0.3194
October	55	452	744	589	0.7674	0.0934	0.3925
November	58	519	720	589	0.8812	0.0985	0.2792
December	13	366	744	589	0.6214	0.0221	0.5081
Total	351	3684	8784	589	6.2547	0.5959	0.9651

Again from table 4, the value of SAIDI for each customer served is 6.2547 hours for the whole year. The value is more than 4 times the IEEE standard 1366-1998 which gives a value of 1.5hours. The area also has SAIFI 0f 0.5959 interruption per customer for the year which is also below the standard according to the IEEE standard 1366-1998 which gives a value of 1.10 interruption per customer.

In the simulation of this stage, the scaling factor s is set as 0 to 1 at a step of 0.05, and the reliability indices were varied as a result. This helps in getting a value of SAIDI and SAIFI very close to the standard. The various costs of CCM, CI and CPM for five different maintenance levels were obtained. So there are totally 20 groups of results. The results of the simulation are presented in figures 2 to 5.

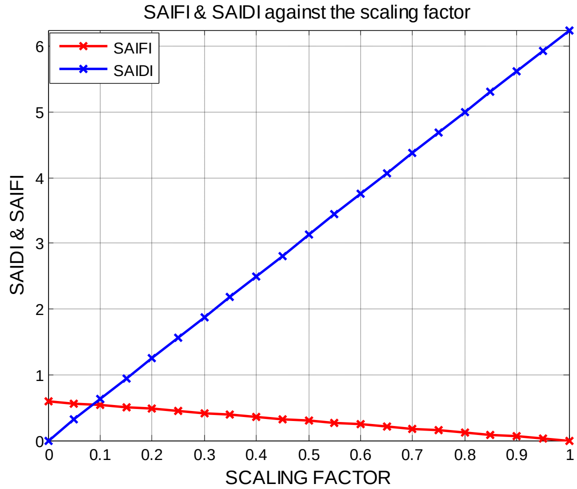


Figure 2. A graph of SAIFI AND SAIDI against the scaling factor

It is clear from the figure 2 that the SAIDI is increasing rapidly during the whole period, while the SAIFI is decreasing slowly during the whole period.

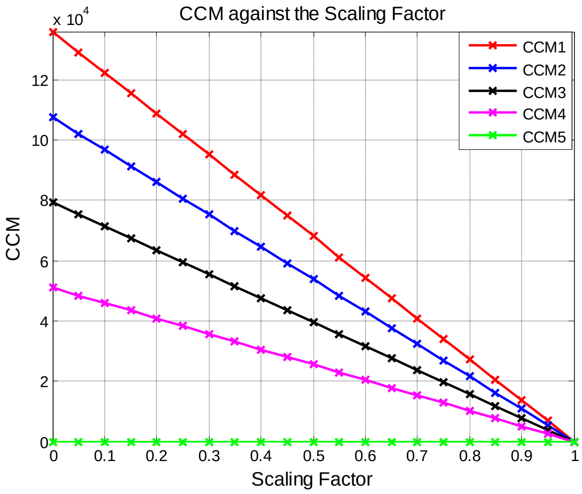


Figure 3. A graph of CCM against scaling factor

From figure 3, CCM1 represents 100% CCM, CCM2 is 75% CCM, CCM3 is 50% CCM, CCM4 is 25% CCM, and CCM5 is 0% CCM.

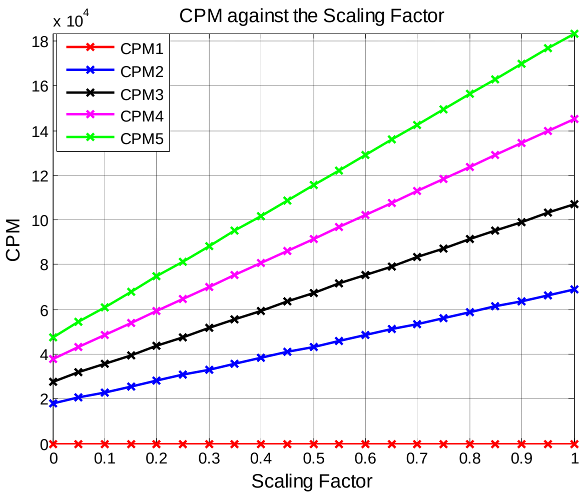


Figure 4. A graph of CPM against scaling factor

From figure 4, CPM1 represents 0% CPM, CPM2 is 25% CPM, CPM3 is 50% CPM, CPM4 is 75% CPM, and CPM5 is 100% CPM.

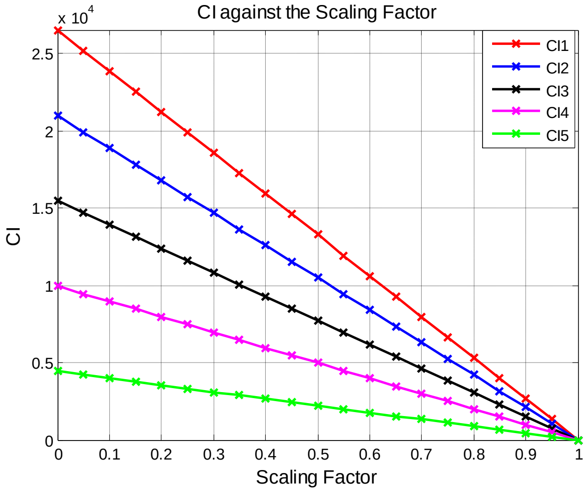
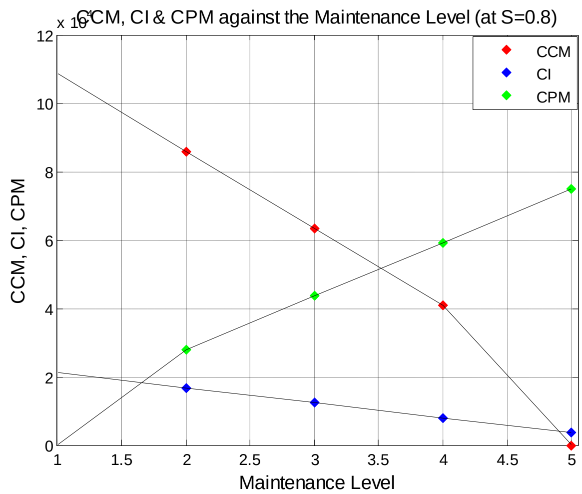


Figure 5. A graph of CI against scaling factor

B. Maintenance Strategy Level

In considering the reliability of the system, a value of the scaling factor is kept constant where the SAIDI and SAIFI are very close to the standard. By analyzing the results from the first stage simulation, we can find a good value of the scaling factor. In this paper, a scaling factor of 0.80 corresponding to the SAIDI of 1.2509 and SAIFI of 0.4767 is close to the standard, and therefore is used to analyze the different cost of maintenance at different maintenance level.



Figures 6. CCM, CI, and CPM against maintenance level (at S = 0.8)

Figure 6 shows the optimal maintenance strategy, when the objective function is to minimize the sum of these three costs. The system reliability indices SAIFI and SAIDI are 0.4767 and 1.2509 respectively. Most of the maintenance is set at level 2,3, and 4, only few components are in level 5, and there is no level 1 applied. Besides, from the figure 6, it can be seen that the optimal maintenance actions are mostly on level 3 and 4, with the optimum being level 3.5 (i.e 63% PM)

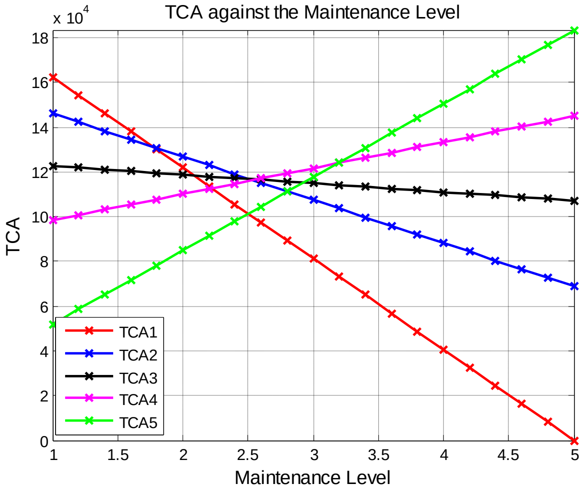


Figure 7. A chart of Total cost of maintenance for different maintenance level

It is obvious from the figure 7 that the total cost of maintaining the system ranges from 100000 to 120000, with 110000 as the optimal maintenance cost. The application of this model has greatly affected the total cost of maintenance by reducing the CCM and CI to the beeriest minimum. From the analysis, it is obvious that adapting the correct method of PM (here 63%) will greatly reduce the total cost of maintaining the system (from 165000 to 100000), and also help to improve reliability of the system.

VIII. CONCLUSION

One of the most important ways to improve the reliability of distribution system is performing maintenance strategies. RCM has been successfully implemented in numerous industries, including many aspects of electric power generation and distribution. In this paper, the concepts, technical steps, and a typical implementation process for a distribution system RCM program were described and implemented. The PM program resulted from the proposed RCM guarantees the cost effectiveness, and reduces the amount of corrective maintenance (CM) and outage costs of both the utility and their customers. The results also show that the reliability indices (SAIFI, SAIDI) have been significantly improved.

ACKNOWLEDGEMENTS

The authors would like to thank all the staff members of Enugu Electricity Distribution Company, Nsukka District who have helped for collection of outage data and for completion of this work.

REFERENCES

[1]. A.U. Adoghe, I.A. Odigwe and S.O. Igbinovia “Power Sector Reforms in Nigeria – Effects on Electric Power Supply Reliability and Stability in Nigeria”, International Journal of Electrical and power Engineering, Medwell Journals, Vol. 3, No 1, pp. 36-42, 2009.

[2]. B.Yssaad, M.Khiat, A.Chaker, ‘’ Reliability centered maintenance optimization for power distribution systems,’’ International Journal of Electrical Power & Energy Systems, Volume 55, February 2014, Pages 108-115

[3]. L. Bertling, R. Eriksson, andR.N Allan. ‘’Relation between preventive maintenance and reliability for a cost-effective distribution system,’’ IEEE Porto Power Tech Conference 2001

[4]. Zhang andE. Gockenbach. “Reliability Centered Asset Management for Power Distribution Systems” Conference Record of the 2008 IEEE International Symposium on Electrical Insulation, June 2008, pp.120-123

[5]. L. Bertling, R. Allan, R. Eriksson, “A reliability – centered asset maintenance Method for Assessing the Impact of maintenance in the power distribution system”. IEEE Transactions on Power Systems , Feb. 2005 Vol.20 (1), pp.75-82

[6]. L. Bertling, "On evaluation of RCM for maintenance management of electric power systems," IEEE Power Engineering Society General Meeting, 2005, San Francisco, CA, 2005, pp. 2638-2640 Vol. 3, doi: 10.1109/PES.2005.1489717

[7]. Zhang, E. Gockenbach, ‘Reliability Centered Asset Management for medium voltage deteriorating electrical equipment based on germany failure statistics’ IEEE transactions on power system, May 2009, vol 24, No2.

[8]. R. E. Brown and M. Marshall, “Budget constrained planning to optimize power system reliability, ”IEEE Trans. Power Syst., vol. 15, pp.887–892, May 2000

[9]. Y.U. Zhang, ”Implementation of reliability centered asset management method on power systems” KTH institute of technology, school of electrical engineering, Stockholm, Sweden 2017.

[10]. Yssaad andA. Abene. Rational Reliability Centered Maintenance Optimization for power distribution systems. Int. Journal of Elect. Power and Energy Syst. 2015; 73, 350–60.

[11]. U. Anthony, “Reliability centered maintenance (RCM) for asset management in electric power distribution system” thesis and student research from covanent university Ota, Ogun state, Nigeria. October 2010

[12]. IEEE/PES Task Force on Impact of Maintenance Strategy on Reliability of the Reliability, Risk and Probability Applications Subcommittee, “The present status of maintenance strategies and the impact of maintenance on reliability,” IEEE Transactions on Power Systems, November 2001, vol. 16, Issue 4, pp. 638-646.

[13]. S. Gupta, A. Pahwa, Y. Zhou, S. Das and R. E. Brown, An Adaptive Fuzzy Model for Failure Rates of Overhead Distribution Feeders. Electric Power Components and Systems 2016. 1175-1190.

[14]. L. Bertling, G. Andersson, and R.N Allan, "Demonstrating the Benefit of Reliability Centred Maintenance (RCM) on the Reliability in Distribution Systems" Proceedings of the 6th PMAPS Conference, Funchal, Madeira, September 2000

[15]. W. Reder and D. Flaten, "Reliability centered maintenance for distribution underground systems," in Proc. IEEE Power Eng. Soc. SummerMeeting, 2000, vol. 1, pp. 551–556.

[16]. Sarchiz, D. Bika, and O. Georgescu, "Mathematical model of reliability centered, maintenance (RCM). Power transm. and dist. Networks applic.," in Proc. IEEE Bucharest Power Tech, Jun. 28–Jul. 2, 2009,pp. 1–4.

[17]. W. Goodfellow, "Applying reliability centered maintenance (RCM)to overhead electric utility distribution systems," inProc. IEEE PowerEng. Soc. Summer Meeting, 2000, vol. 1, pp. 566–569.

[18]. P. Dehghanian, M. Fotuhi-Firuzabad, S. B. Shouraki, R. Kazemi, "Critical Component Identification in Reliability Centered Asset Management of Power Distribution Systems Through Fuzzy AHP" IEEE Systems Journal, Dec. 2012 Vol.6 (4), pp.593-602

[19]. L. Bertling,G. Andersson, andR.N Allan. "Reliability Centered Maintenance Applied to Electrical Distribution Systems", Royal Institute of Technology (KTH), Stockholm, Sweden, pp. 261-261, 2002

[20]. P. Hilber, and L. Bertling(2004). Monetary importance of component reliability in electrical networks for maintenance optimization. Proc. Probability Methods Applied to Power Systems 2004

[21]. P.Hilber., "Component reliability importance indices for maintenance optimization of electrical networks", Royal Institute of Technology (KTH), Stockholm, Sweden, 2005

[22]. J. Moon, Y. Yoon, S. Lee, J. Kim, H. Lee and G. Park, "Reliability-centered maintenance model to managing power distribution system equipment," 2006 IEEE Power Engineering Society General Meeting, Montreal, Que., 2006, pp. 6 pp.-, doi: 10.1109/PES.2006.1709186.

[23]. S. Kumar, G. Chattopadhyay, and U. Kumar, "Reliability improvement through alternative designs-A case study,"Reliability Engineering & System Safety, vol. 92, no. 7, pp. 983–991, 2007.

[24]. W. Li and J. Korczynski, "A reliability-based approach to transmission maintenance planning and its application in BC hydro system,"IEEETrans. Power Del., vol. 19, no. 1, pp. 303–308, Jan. 2004.

[25]. Adoghe, C. Awosope, and S. Daramola. "Critical Review of Reliability Centred Maintenance (RCM) for Asset Management in Electric Power Distribution System," Int. J. Eng. Technol.2012, 2, 1020–1026.

Chinweike Okoli, et. al. "Reliability centered maintenance for distribution system infrastructure in Nigeria." *The International Journal of Engineering and Science (IJES)*, 9(7), (2020): pp. 20-30.