American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-7, Issue-4, pp-106-112
www.ajer.org
Research Paper Open Access

Preventive Maintenance For Substation With Aging Equipment Using Weibull Distribution

Dikio C. Idoniboyeobu[1], Biobele A. Wokoma[2]& Victor C. Ibanibo[3]
[1,2&3](Department of Electrical Engineering, Rivers State University, Nigeria)
Corresponding author: Dikio C. Idoniboyeobu

ABSTRACT: *Preventive maintenance (PM) for substation with aging equipment was considered in this work. The main objective was to develop PM model to study the impact of PM on cost minimization in a distribution substation. Weibull distribution equation was used to develop the PM cost minimization models which were simulated in MATLAB program to illustrate the impact of PM replacement policy with UST distribution substation as the case study. The total cost minimization was computed with regards to the total failure recorded within the study year. The result shows an inverse relationship i.e. decrease in total cost from 2501.7 to 2500.7and increase in length of the interval from 50000 to 500000. The analysis also revealed that adequate PM replacement policy can minimize the total expected cost which in turn increases the total availability of the electrical infrastructure or equipment. The result suggested that the right scheduling and constant interval replacement policy of PM is important to increase the electrical infrastructure or equipment availability in the substation. It is therefore recommended that regular schedule inspection, testing, and servicing of equipment should be performed in the UST distribution substation.*

KEYWORDS *-Preventive Maintenance; Cost Minimization; Substation Equipment; Replacement Policy; Failure Rate; Reliability Assessment*

Date of Submission: 28-03-2018 Date of acceptance: 12-04-2018

I. INTRODUCTION

Preventive Maintenance (PM) system consists of a routine maintenance action taken in a planned pattern based on the average breakdown rates of the system components or equipment [1]. They are actions taken to improve the condition of equipment for optimal performance and prevent unintended failure or breakdown. The main function of an adequate PM strategy is to regulate the state of an infrastructure or equipment and ensure its reliability and availability [2]. An adequately implemented PM will mitigate operating cost, extend the expected life of the equipment, improves the equipment efficiency and thereby reducing the equipment failure rate. Conversely, inadequately implemented PM or lack of PM will lead to higher operating cost and failure rate of equipment, and shorter life of equipment [3].

Poor PM scheme has been considered one of the major factors responsible for power interruptions in generation, transmission and distribution stations [4] and has led to continues aging and degrading of the electrical infrastructure or equipment in Nigeria. More than two-thirds of all electrical infrastructure or equipment breakdown in Nigeria could have been avoided or shielded by regular PM strategy. Studies prove that the breakdown of an electrical infrastructure or equipment is three times greater for those infrastructure or equipment that are not included in a scheduled or planned PM scheme as compared to those that are included in a routine PM scheme. More so, in a planned preventive maintenance (PPM) scheme maintenance managers can plan equipment outages at a determine time rather than correcting untimely breakdown or failure regularly [5].

Maintenance scheme can be in any form like replacement, rebuilds, cleaning, inspections, calibrations, adjustment and lubrication [6]. When there is a limited resources, actualizing a reliable PM scheme may not be realistically attainable and there are certain level of risk that may occur when the limited resources could not afford the necessary PM scheme. Constant scrutiny and review of the PM program is required in order to keep the risk low and still maintain balance between the limited resources and optimal operation [7].

With UST Distribution Substation as the electrical infrastructure and equipment presented as a case study; protective relays, overhead lines, circuit breakers and power transformers are therefore basically the main components of the distribution substation. Their state of working is very essential to achieving optimal power supply and any failure of this component could lead to outage. For achieving reliability, it is important to maintain these components constantly as appropriately applied maintenance strategy can increase the reliability level of a distribution substation. Having a PM scheme in place will result to extension of equipment life, avoidance of huge financial losses, reduction in production losses and safety hazard, and increase asset values and reliability [8].

Maintenance models are aimed at achieving reliability by means of enhancing operation of equipment and reducing maintenance cost. These models are very important in this study because they provide a deeper understanding on the different maintenance methods by determining the most effective inspection, cost and frequency of maintenance. However, it basic purpose is to achieve optimum balance between resources and benefit of maintenance. This paper is aimed at studying the impact of PM cost minimization model on UST distribution substation to determine the most reliable and efficient inspection, cost and frequency of maintenance to electrical components and equipment.

II. RELATED WORKS

Several studies have been performed on preventive maintenance for substation with aging equipment. The paper presented in [9] concluded that availability electrical infrastructure or equipment increased with increased in planned maintenance rate in the substation when the value of maintenance is varied based on the model developed from Markov process.

Papers [10-11] presented studies on implementing a PM planning model on an aging and deteriorating production system (lathe machine). These works focused on the effectiveness of PM model on reliability of the lathe machine using Markov model and the result obtained showed that the machine's availability increases with increase in the PM rate of performance. They also concluded that appropriate planning of PM is important to decrease the machine's failure (corrective) maintenance. Effective preventive maintenance scheduling was presented in [12]; results obtained indicated that machines experience critical failures when maintenance action is carried out inadequately. The research revealed that the failures associated to the machine includes wear and tear and delay to maintenance of the machines resulted to failure. Maintenance optimization for substations with aging equipment was carried out in [13]. Models and algorithms for maintenance schedules/policies, equipment reliability, and cost minimization were developed and studied to improve substation performance while minimizing the operational cost.

The maintenance optimization for power distribution systems were performed in [14-16] with multi-objective approach for electrical equipmentconsidered the cost of customer interruption and maintenance cost and was built on developed equipment reliability indices. Results obtained illustrated that with different application of maintenance to different components; it is possible to minimize total maintenance cost while maximizing reliability for customers.

III. METHODOLOGY

The procedure for developing PM cost function and associated parameters used for the substation is presented. Weibull distribution equation[17] was used to develop the PM cost minimization, which was then simulated using MATLAB. Weibull distribution model is more flexible to use when compared with other models. Relevant data were obtained from the UST Substation located in Port Harcourt, Rivers State, Nigeria.

3.1. Preventive Maintenance Cost Model

Thepreventive maintenance cost mathematical model developed was based on the below assumptions.
Assumptions:

- The electrical infrastructure or equipment are independent in their operation and are subjected to failure.
- The electrical infrastructure or equipment has identical failure distribution.
- The electrical infrastructure or equipment failure rate function is constantly increasing with time.
- Preventive or planned replacements are less costly than failure replacements i.e. the total cost associated to repairing electrical infrastructures or equipment failure is far greater than the cost associated to carry out PM on the electrical infrastructures or equipment before failure.

Let N– represent the group of independent electrical infrastructures or equipment that is subject to failure. The repair cost is consisted of a fixed cost$\mathbf{C_1}$for each repair and a variable cost $\mathbf{C_2}$per electrical infrastructure or equipment.
The repair cost per electrical infrastructure or equipment decreases as the number of electrical infrastructures or equipment requiring repairs increases while the production loss cost $\mathbf{C_3}$due to the electrical infrastructure or equipment breakdown increases.

Let N(t) represent the number of electrical infrastructure or equipment at time t,
Then$(0 \leq N(t) < N)$ (1)

Let $F(t)$ represent number of electrical infrastructures or equipment of identical failure distribution. $N(t)$Distribution will then be given as:

$$[P(N(t)n)] = \binom{N}{n}[1 - F(t)]^n [F(t)]^{N-n} \quad (2)$$

Where,
$P = [(N(t) = n)]$, is the probability that the number of electrical infrastructures or equipment operating at time "t" equals "n". Then, N(t) distribution in binomial will mean;

$$E[N(t)] = N[1 - F(t)] \quad (3)$$

Now, if the faulty electrical infrastructures or equipment is repairable at a fixed costC_1, and variable cost C_2 per electrical infrastructure or equipment. If a faulty electrical infrastructure or equipment is irreparable after failure, then a production loss of C_3 is obtained. Since the production will increase as the scheduled time for repair increases and the repair cost per electrical infrastructure or equipment decreases, then there exist an optimum scheduled time (maintenance time) that minimizes the expected total cost per unit time. Considering a random maintenance scheduling which states that repairs are undertaken whenever the number of operating electrical infrastructure or equipment reaches a certain level, **n**. The time to reach this level is a random variable, **T**, with a cumulative density function (**cdf**) of G(t).

Let T = the **n**th order statistics of N random variables.

Thus, the expected repair cost per cycle (R_c) is mathematically expressed as:

$$R_c = C_1 + C_2 R_c = C_1 + C_2 N \int_0^{\infty} F(t) dG(t) \quad (4)$$

The expected production loss per cycle P_c will be

$$P_c = C_3 \int_0^{\infty} [N - E(N(t))][1 - G(t)] dt \quad (5)$$

$$P_c = C_3 \int_0^{\infty} \left[N - E\left[(N(t))\right]\right] G(t) dt \quad (6)$$

$$P_c = C_3 N \int_0^{\infty} F(t) G(t) dt \quad (7)$$

For $G(t) = 1 - G(t)$ (8)

The total expected cost per unit time will be:

$$C[G(t)] = \frac{R_c + P_c}{\int_0^{\infty} t dG(t)} \quad (9)$$

$$G(t) = (0 \, if t \leq t_0) \quad (10a)$$

$$(1 \, if t > t_0) \quad (10b)$$

For, t_0 = the scheduled time for group maintenance hence, equation (9) can be re-written as:

$$C(t_0) = \frac{1}{t_0}\left[C_1 + C_2 N F(t_0) + C_3 N \int_0^{\infty} F(t) dt\right] \quad (11)$$

From equation (11), $C_o = \infty$ and $C(\infty) = C_3 N$

Then the cost per unit for the optimum schedule is less than $C_3 N$.

The optimum schedule policy summarized as given below: Assuming that $F(t)$ is continuous, the derivative of f(t) exist, and the failure rate per electrical infrastructure or equipment is λ

If $\frac{-f(t)^{*}c}{f(t)} < \frac{C_3}{C_2} fort > 0,$

Therefore

a) $if \frac{C_3}{\lambda} < \frac{C_1}{N + C_2},$

Then there exists a unique and finite optimum scheduling time to satisfies the equations

$$C_2t_0f(t_0)^* + C_3tof(t_0)^* - C_2F(t_0)^* - C_3\int_0^0 F(t)dt = \frac{C_1}{N} \quad (12)$$

The minimum cost per unit time is gotten as:

$$C(t_0)^* = C_2NF(t_0)^* + C_3NF(t_0)^* \quad (13)$$

b) Otherwise, $t_0{}^* = \infty$

The condition in (a) is realistic, for example, if the failure distribution is assumed to be exponential with a rate ofλ. Then, $\frac{-f(t)^*}{f(t)} < \frac{C_3}{C_2} becomes \left[\frac{C_3}{\lambda} > C_2\right]$ (14)

This translates to the average production loss per electrical infrastructure or equipment. Also, the condition $\frac{C_3}{\lambda} < \frac{C_1}{N+C_2}$simply mean that the average production loss per electrical infrastructure or equipment when group repair of 'N' electrical infrastructure or equipment is then performed. Thus, it is necessary to plan the repair before the breakdown of all electrical infrastructures or equipment.

When N identical electrical infrastructures or equipment exhibit a constant failure rate λ, then the necessary boundary to obtain an optimum policy is given as:$\frac{C_3}{\lambda} < \frac{C_1}{N+C_2}$.

Now, by substituting the probability distribution function (**pdf**) of the exponential distribution into equation (12), we get

$$(X^* + 1)\ell^{1-x} = A \quad (15)$$

Where $X^* = \lambda t_0{}^*$

$$A = \frac{\frac{C_3}{\lambda} - \left(\frac{C_1}{N+C_2}\right)}{\frac{C_3}{\lambda - C_2}} \quad (16)$$

Equation (15) is the expected number of electrical infrastructure or equipment to be repaired.

The expected cost for the optimum policy will be:

$$C(t_0)^* = C_3N + N\lambda\left(C_2 - \frac{C_3}{\lambda}\right)\ell^{-\lambda t_0{}^*} \quad (17)$$

Assuming a total of four (4) electrical infrastructure or equipment under studied; equation (17) becomes;

$$C(t_0)^* = 4\left[C_3 + \lambda\left(C_2 - \frac{C_3}{\lambda}\right)\ell^{-\lambda t_0{}^*}\right] \quad (18)$$

Table 1: UST Injection Substation Infrastructure/Equipment Faults Records for 2016

S/N	Infrastructure or Equipment	Form of Failure / Breakdown	Total Failure/Breakdown Recorded				Total Failure Recorded	Maintenance Actions
			Ojoto	UST	Federal	Wokoma		
1	Overhead Line Conductor	Short circuiting, bridging, foreign bodies, etc.	10	5	9	9	33	Cutting down trees, reconnection of wires, applying conductor separator, etc.
2	Power Transformers	Oil leakage, bushy substation, accumulation of dirt, dust and moisture, oil assessment and aging etc.	5				5	Changing of oil, bushing, silica, gel etc.

3	Circuit Breaker	Mechanical and contact failure, Wear and tear, Carbon deposit, etc.	6	3	5	4	18	Checking for carbon deposits and other contaminants, arc quenching, etc.
4	Protective Relay	Wear and tear, foreign materials such as dust and dirt, physical and mechanical damage	3	2	1	2	8	Replacement of wear & tear, check for foreign materials etc.
5	Overall Failure/Breakdown Received						64	

As shown in the Table 1, the following were obtained;

F = 64, the total number of faults
N = 4, the total number of infrastructure or equipment considered

Faults per electrical infrastructure or equipment $= \frac{F}{N} = \frac{64}{4} = 16\,faults$ (19)
Obtaining the failure rate (λ) for a unit infrastructure or equipment, we have:

Failure rate (λ)= $\frac{faultsperelectricalinfrastructureore \quad quipment}{totaltimeinayear}$ (20)

The total time in a year can be obtained by multiplying the total number of days within the period of January 2016 to December 2016 by the total hours in a day i.e.

$$= 365days \times 24hours = \ 8760hours \quad (21)$$

Therefore, $\lambda = \frac{16}{8760} = 0.001826\,fault/hr$ (22)

Taking production loss C_3as 50,000 naira and variable cost C_2 as 25,000 naira respectively

Applying into equation (18);

$$C(t_0)^* = 4\left[C_3 + \lambda\left(C_2 - \frac{C_3}{\lambda}\right)\ell^{-\lambda t_0{}^*}\right] \quad (23)$$

$$C(t_0)^* = 4\left[50{,}000 + 0.001826\left(25{,}000 - \frac{50{,}000}{0.001826}\right)\ell^{-0.001826\ t_0}\right] \quad (24)$$

$$C(t_0)^* = 182.6\ell^{-\ 0.001826\,t_0} \quad (25)$$

Assuming the optimal preventive replacement interval for the electrical infrastructures
$t_0 = 0:20:365$;

Equation (23) was modelledand developed into systems application software in MATLAB version 7.5, R2007b.

IV. RESULTS AND DISCUSSIONS

The graph presented in Figure 1 is a plot of total cost against number of days. It shows the total cost of the group maintenance decreasing as the number of days in the year 2016 is increasing. For a scheduled time to perform group maintenance ranging from 0 to 365 days, the optimum total cost of performing group maintenance is approximately 96 naira based on the assumed values for the production loss, variable and fixed cost.

There is an inverse relationship between the total cost of performing group maintenance and the number of days in the year. Thus, it requires a high cost at the beginning of the year to perform group maintenance than towards the end of the year. The total cost of performing group maintenance continues to decrease through the year until it gets to about 96 naira at the 365 days.

The following deductions can be made:

I. As the days in the year increases, the group maintenance cost decreases.
II. The right scheduling and constant interval replacement policy of PM is important to increase the electrical infrastructure or equipment availability in the substation.
III. Increased in failure rate of the electrical infrastructure or equipment increases the probability of the electrical infrastructure or equipment's breakdown and reduces the availability of the electrical infrastructure or equipment in the substation which indicates that PM is needed or should be carried out in the distribution substation.

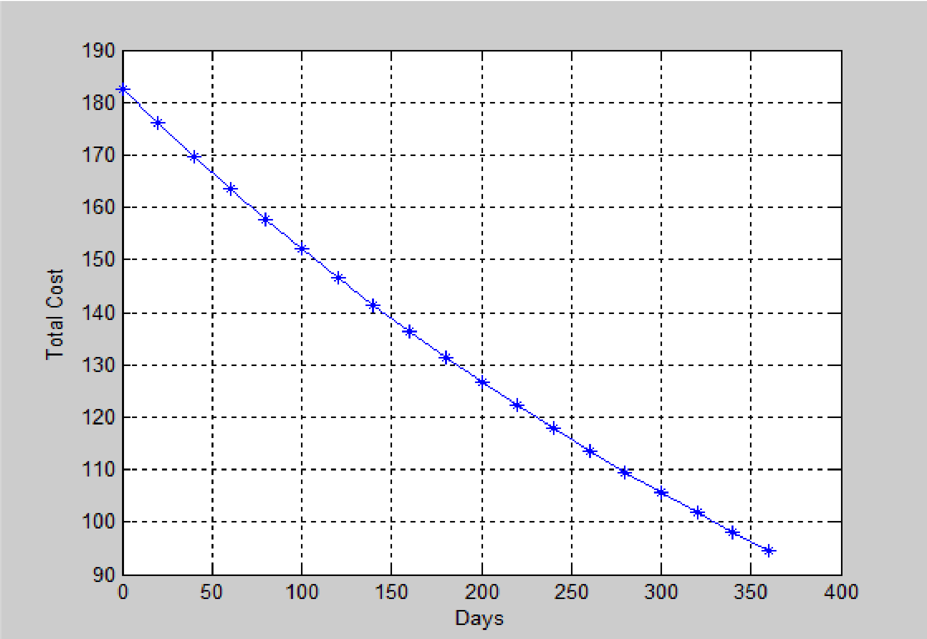

Figure 1: Graph of Expected Cost against Number of Days

V. CONCLUSION

Aging of electrical infrastructure or equipment is an essential fact when considering the reliability and availability of a power system. The adoption of an adequate PM policy with the consideration of aging effect can improve the reliability of the electrical infrastructure or equipment and reduce the high failure rate of equipment in the substation. The reduction in failure rate of infrastructure or equipment will mitigate the huge financial loss experienced in the substation.

An optimal PM model for UST substation infrastructure or equipment was developed using Weibull distribution mathematical model and the model has been represented graphically using MATLAB program. Thispaper as shown that adequate PM replacement policy can minimize the total expected cost which in turn increases total availability of the infrastructure or equipment.

The methods and models developed can by adopted by maintenance managers in making maintenance decision to effectively balance resources and maintenance benefit, likewise minimize excessive depreciation and deterioration of system components or equipment resulting from long years of neglect. With reference to the case study presented herein, achieving infrastructure or equipment reliability would mean maintenance managers be proactive rather than reactive towards combating failure or breakdown of infrastructure or equipment. An adequate PM strategy and regular monitoring of progress by collecting and analysing data should be adopted in UST substation to achieve infrastructure or equipment reliability, long life span, avoidance of huge financial losses, reduction in production losses and safety hazard, and increase equipment values.

REFERENCES

[1]. C. Sheu, & L. Krajewski, "A Decision Model for Corrective Maintenance Management." International Journal Production Resources, 3(2), pp. 1365-1382, 1994.
[2]. M. G. Sobamowo, S. O. Ismail, S. J. Ojolo, & A. A. Adebayo, "Optimal Preventive Maintenance Models for Steam Turbines: A Case Study of Egbin Thermal Station, Lagos, Nigeria." International Journal of Mechanical Computational and Manufacturing Research, 1 (1), pp. 6-11, 2012.

[3]. O. Ewulum, “A New Maintenance Strategy for Power Holding Company Nigeria to Contest the Current Power Demand Problem.” Master’s Thesis, North-West University, South Africa, 2018.
[4]. F. N. Okafor & F. A. Somolu, “Engineering Challenges Associated with Real-time Operation of a Deregulated Electricity Supply Industry in Nigeria.” Conference Proceedings of Nigeria Society of Engineers, pp. 305-313, 2003.
[5]. M. C. Eti, O. T. Ogaji, & S. D. Probert, “Impact of Corporate Culture on Plant Maintenance in the Nigerian Electric Power Industry.” Applied Energy, 83(4), pp. 299-310, 2004.
[6]. S. N. Oyedepo, & R. O. Fagbenle, “A Study of Implementation of Preventive Maintenance Programme in Nigeria Power Industry: Egbin Thermal Power Plant, Case Study.” Scientific Research, 3(3), pp. 207-220, 2011.
[7]. H. Ge, “Maintenance Optimization for Substations with Aging Equipment.” Doctoral dissertation, The University of Nebraska-Lincoln, 2010.
[8]. Y. Bicen, “Monitoring of Critical Substation Equipment.” 3rd International Istanbul Smart Grid Congress and Fair (ICSG), 2015 (pp. 1-4), IEEE, 2015.
[9]. D. C. Idoniboyeobu, & W. M. Olanrewaju, “Modeling maintenance process for aging electric power stations in Nigeria.” International Journal of Scientific and Engineering Research, 5(8), pp. 530-536, 2014.
[10]. R. Chouhan, M. K. Gaur, & R. Tripathi, “Implementing a Preventive Maintenance Planning Model on an Ageing and Deteriorating Production System.” International Journal of Technology Innovations and Research, 4(1), pp. 1-24, 2013.
[11]. S. V. Dhople, Y. C. Chen, & A. D. Domínguez-García, “A Set-Theoretic Method for Parametric Uncertainty Analysis in Markov Reliability and Reward Models.” IEEE Transactions on Reliability, 62(3), pp. 658-669, 2013.
[12]. A. Hasnida, N. J. Livendran, I. B. Ernnie, A. H. Nurul, & K. Shahrul, “Effective Preventive Maintenance Scheduling: A Case Study.” International Conference on Industrial Engineering and Operations Management, pp. 1249-1257, 2012.
[13]. S. K. Abeygunawardane, “Probabilistic Models for Reliability Assessment of Ageing Equipment and Maintenance Optimization.” (Doctoral dissertation), 2012.
[14]. K. S. Park, & Y. K. Yoo, “Comparison of Group Replacement Policies under Minimal Repair.” International Journal of System Science, 35(3), pp. 179 –184, 2004.
[15]. L. Chen, T. F. Henning, A. Raith, & A. Y. Shamseldin, “Multi-objective Optimization for Maintenance Decision Making in Infrastructure Asset Management.” Journal of Management in Engineering, 31(6), pp. 4-15, 2015.
[16]. S. Kahrobaee, “Reliability Modeling and Evaluation of Distributed Energy Resources and Smart Power Distribution Systems.” Doctoral dissertation, The University of Nebraska-Lincoln, 2014.
[17]. O. Ristić, B. D. Iričanin, & V. Mijailović, “Dynamic Modeling and Simulation of Power Transformer Maintenance Costs.” Serbian Journal of Electrical Engineering, 13(2), pp. 285-299, 2016.

Dikio C. Idoniboyeobu."Preventive Maintenance For Substation With Aging Equipment Using Weibull Distribution”American Journal of Engineering Research (AJER), vol. 7, no. 4, 2018, pp.106-112.