International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 6, June, 2012

Critical Review of Reliability Centred Maintenance (RCM) for Asset Management in Electric Power Distribution System

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ABSTRACT

The purpose of maintenance is to extend equipment lifetime or at least the mean time to the next failure. Maintenance too incurs expenditures that result in very costly consequences when not performed or performed too little, and it may not even be economical to perform it too frequently. Therefore the two costs must be balanced.

In the past, this balance had been estimated by extrapolating the experience obtained from existing systems and using the rule - of – thumb methods. Nowadays, the tempo of advanced and softiscated research in that direction has rendered such rule – of – thumb methods obsolete. The literature works describing the reliability centred maintenance methods for managing distribution assets have grown until the papers can now be numbered in thousands. This paper presents critical review of the various existing methods that have been developed by different reseachers and proposes a probabilistic model that will provide a quantitative connection between reliability and maintenance, a link missing in all the heuristic approaches.

Keywords: *Reliability Centred Maintenance, Probabilistic Model, Asset Management, Electic Power, Distribution System.*

1. INTRODUCTION

Today's electric power distribution systems operate in a competitive market. For a utility to remain viable it should therefore be able to provide electricity to customers with a high degree of reliability and be cost-effective in delivery. The cost of maintaining system assets, especially through preventive maintenance (PM) incurs huge expenditures. Electric power utilities have always employed (PM) programs to keep their equipment in good working condition for as long as it is economic. At present, when system's continuous availability is heavily constrained and the construction/purchase of new and better equipment may not be feasible, the role of maintenance becomes particularly significant. Thus, an efficient maintenance program has become an important part of what is often called asset management.

The need for Power Utilities Organisations in this era of restructured power systems is to supply improved and reliable electric services to their customers. A large percentage of individual customer interruptions originate within the actual distribution failures and faults. The type of protective equipment used can have a direct bearing on the frequency and duration of outages experienced by the customer. Distribution system failures are a major contribution to the service continuity levels experienced by customer.

A considerable amount of literature is now available regarding the development of quantitative reliability centred maintenance for asset management in electric power systems. The approaches presented in the literature range from simple direct statistical interpretation to relatively sophisticated probabilistic methods using Markov methods.

The purpose of this paper is to review the various approaches that have been used in managing asset in electric power systems, identify how different Utilities define reliability, examine the dynamic of maintenance in elecric power Utilities and then propose a method for making an informed and intelligent decision on asset maintenance management. This is followed by conclusion.

2. RELIABILIY AS DEFINED BY UTILITIES

Three different definitions of electrical reliability from three different utility companies as found from several literatures are summarised below:

a. "The degree to which an electrical system can deliver power to customers at contract specifications, or acceptable regulatory standards. Reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply. It is usually considered for two primary elements: adequacy of supply and security of supply" [1].

b. "The ability of a generation system and of a transmission and distribution system to deliver uninterrupted electricity to customers on demand, and to withstand sudden disturbances such as short circuits or loss of major system components. Reliability maybe evaluated by the frequency, duration, and magnitude of any adverse effects on consumer service" [2].

c. "RELIABILITY is the assurance of a continuous supply of electricity for customers at the proper voltage and frequency" [3].

A close examination of the definitions given in a, b and c above shows that each Power Utility considers reliability differently. This means, Utilities itself as at now, do not agree on a single definition of Reliability [3].

The widely accepted and adopted standard in most developed Countries of the world is when Reliability is expressed in 9s. In other words, if something is reliable 99% of the time, the reliability level is said to be two 9s. Three 9s of reliability would indicate a reliability level of 99.9%. The electrical system is expected to operate 24 hours per day, 7 days per week or 8766 hours per year.

The table 2.1 below illustrates how many hours, minutes, or seconds per year the electrical system will be unavailable for each level of reliability.

Table 2.1Reliability Level

9s of Reliability	Outage durations per year
2	876.6 hours
3	87.66 hours
4	8.766 hours
5	5.25 minutes
6	30 seconds
7	3 seconds

Electrical reliability is more than just power outages. Because electricity is used to power some very sensitive, mission critical technology, the quality of the electrical power is just as important as its availability.

3. MAINTENANCE DYNAMICS

Over the past twenty years, maintenance has changed more than any other management discipline. The changes are due to a huge increase in the number and variety of physical assets (plant, equipment and buildings) which must be maintained throughout the world, much more complex designs, new maintenance techniques and changing views on maintenance organization and responsibilities [4] and [5].

Maintenance is also responding to changing expectations. These include a rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the relationship between maintenance and product reliability, and increasing pressure to achieve high plant availability and to contain costs.

The changes are testing attitudes and skills in all branches of industry to the limit. Maintenance people are adopting completely new ways of thinking and acting, as engineers and as managers.

In the face of this avalanche of change, managers everywhere are looking for a new approach to maintenance. They seek a strategic framework which synthesizes the new developments into a coherent pattern, so that they can evaluate them sensibly and apply them. A philosophy which provides such a frame-work is called **Reliability-centered – Maintenance (**RCM**)**.

3.1 Maintenance and RCM

There are two elements involved in the management of any physical asset. It must be maintained and from time to time it may also need to be modified. Maintenance is therefore according to reference 6 ensures that physical assets continue to do what their users want them to do. What the users want will depend on exactly where and how the asset is being used (the operating context). This informed our formal definition of RCM as a process used to determine the maintenance requirements of any physical asset in its operating context.

In the light of the earlier definition of maintenance, a concise definition of RCM could be "a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context.

The cost of maintaining system assets, especially through preventive maintenance (PM), incurs huge expenditures. Electric power utilities have always employed (PM) programs to keep their equipment in good working condition for as long as it is economic. At present, when system extensions are heavily constrained and the construction/purchase of new and better equipment may not be feasible, the role of maintenance becomes particularly significant. Thus, an efficient maintenance program has become an important part of what is often called asset management [7].

The purpose of maintenance is to extend equipment lifetime, or at least the mean time to the next break- down whose repair may require significant expenditure [8]. Clearly, too little maintenance may have very costly consequences. On the other hand, maintenance, too, has a price-tag, and it may not be economical to perform it too frequently. In a cost-effective scheme, the two expenditures (the cost incured for doing no maintenance and that for performing maintenance too often) must be balanced.

In the past, attempts to approximate this balance have often been based on trial and error methods [9, 10]. In this paper, an analytical tool will be proposed, which helps to identify the best maintenance policies.

This paper addresses the importance of maintenance on the reliability of electrical distribution systems. This focuses on preserving system function, identifying critical failure modes, prioritizing important components and selecting possible and effective maintenance activities, a cost – effective preventive maintenance plan which defines reliability centred maintenance. The diagnosis of the following self-imposed questions will elucidate the rationale behind this present effort:

- **Does distribution part of electricity systems constitute the greatest risk to the interruption of power?**

Electric power system is not 100% reliable. The ability to use electric energy when needed is the fundamental function of any modern utility company.

The existence of sophisticated machines and production lines had increased the need for electricity supply that is highly reliable.

Distribution aspect of electricity system had been identified as constituting the greatest risk to realizing uninterrupted power supply [11]. Studies show that a typical distribution system accounts for 40% of cost to deliver power and 80% of customer reliability problems [12]. This means that distribution systems are critical for financial success and customer satisfaction. And yet distribution systems have not received the desired attention. This was obvious from the difference in the number of publications.

The main reasons advanced as to why distribution systems had not been given the required attention include the following:

a. They are less capital – intensive

b. Their failures cause more localized effects when compared with generation and transmission systems and

c. Focus on transmission system is moving toward distribution, as business focus changes from consumers to customers.

- **Has introduction of liberalised market led to a shift from technical to economical driving factors?**

The introduction of deregulated market has introduced major changes in electrical power systems. These changes had led to the movement of the driving factors from technical to economical. As a result, new investors are coming into the power sector. This global level change in the running of power sector has brought about new opportunities and new complications. In an increasingly competitive market environment where companies emphasize cost control, operation and maintenance (O&M) budgets are under constant pressure to economize. In order to ensure that changing utility environment does not adversely affect the reliability of customer power supply, several state regulatory authorities have started to specify minimum reliability standards to be maintained by the distribution companies [13].

- **How effective is preventive maintenance expenditure?**

Electricity power utilities own and operate system generation, transmission and distribution of electricity. These utilities play active role in the deregulated market. The implication of this is that they also face market requirements. This means that customers will only pay for energy delivered. The monitoring authority, which in the case of Nigeria is Government, will impose sanctions/regulations. Investors or Owners of utilities expect the managers to deliver electricity to customers at minimum cost. This means that utilities must satisfy reliability requirements at minimum cost. To achieve this, manager of these utilities must consider maintenance cost for system assets as an important expenditure area. Preventive maintenance measure is an activity undertaken regularly at pre – selected intervals while the device is satisfactorily operating to reduce or eliminate the accumulated deterioration [14]. It should also be noted that repair is the activity to bring the device to a non – failed state after it has experienced a failure. When the cost incurred by a device failure (such as cost of downtime, repair expenses, revenue lost etc.) is larger than the cost of preventive maintenance, it is worthwhile to carry out preventive maintenance.

Preventive Maintenance measures can affect reliability in two ways:

a. It helps in improving the condition of the asset and

b. It aids in prolonging the life time of an asset.

On the other hand, reliability is also affected in two ways:

a. It reduces the frequency of power outages by preventing the actual cause of failure.

b. It also reduces the duration of power supply interruptions.

In cost effective expenditure, preventive maintenance applies where reliability benefits outweigh the cost of implementing the preventive maintenance measures. This type of maintenance is costly, inefficient and may not even extend component lifetime. Many modern utilities have now replaced their routine maintenance that is based on rigid schedules with a more flexible program using periodic or even continuous condition monitoring (predictive maintenance). The predictive maintenance routines include group of programs such as Failure Modes and Effects Analysis, Evaluation of Needs and Priorities and Flow Charts for Decision Making.

Some of these approaches have been code named Reliability Centred Maintenance (RCM) [15].

4. THE PROPOSED MAINTENANCE DECISION MODEL

In RCM approach, different maintenance policies can be compared and the most cost – effective for sustaining equipment reliability will be selected. Reliability Centred Maintenance program is not completely new. This program has been installed by some electric utilities as a useful management tool [16]. The problem discovered from the literature with those in existence is that they cannot predict the effect of a given maintenance policy on reliability indicators (such as failure rate, outage time etc) and the approach adopted is still heuristic. The application is still based on experience and judgement at every turn. It takes a long time before enough data are collected for making such judgements [17]. To solve the identified problems above, a probabilistic representation of deterioration process is modeled. A mathematical formulation of the expected transition time from any deterioration state to the failure state (expected remaining life) has been proposed.

Two equivalent models are used to simplify the maintenance model being proposed [18]. The models have three discrete stages representing the deterioration processes. We assume that decision is taken at the end of every inspection. Decisions for maintenance and inspection rate of each stage are considered to be an equivalent repair rate.

Let y_1 = mean time in state 1(year),
y_2 = mean time in state 2(year)
y_3 = mean time in state 3(year)
μ_{21} = Repair rate from state 2 to state 1(/year),
μ_{32} = Repair rate from state 3 to state 2 (/year),
μ_{31} = Repair rate from state 3 to state 1 (/year).

4.1 Perfect Maintenance Model

It is assumed that in the initial state, the system is in good working condition that needs no maintenance. Moreover, it is assumed that maintenance will always improve the device to the previous state; this means that the repair rate of state 2 will improve the device to state 1 and repair rate of state 3 will improve the device to state 2. This type of model is shown in figure 4.1.

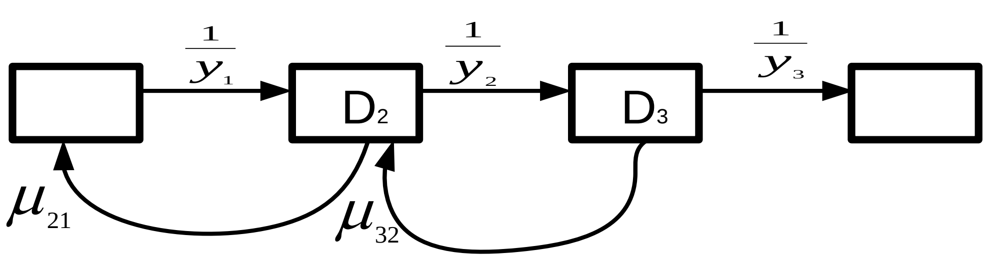

Figure 4.1 Perfect Maintenance Model

4.2 Imperfect Maintenance Model

This model type is slightly different from the model in figure 4.1[19]. Transition rate from state 1 to 3 is introduced (λ_{13}) to describe an imperfect inspection of state 1. This Model accounts for the probability that inspection of state 1 might cause the system to transit to state 3. This Model is therefore the equivalent Model for the maintenance Model proposed since it accounts for a transition of state 1 to state 3 in figure 4.2. This equivalent Model will be used in predicting the remaining life of the system under consideration using the Matlab program to be developed.[20] The imperfect model is shown in figure 4.3 below.

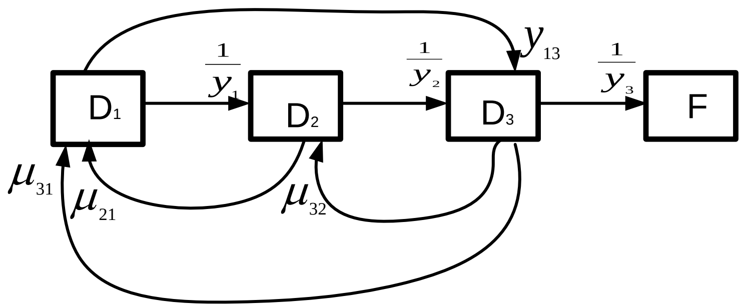

Figure 4.2 Imperfect Maintenance Model

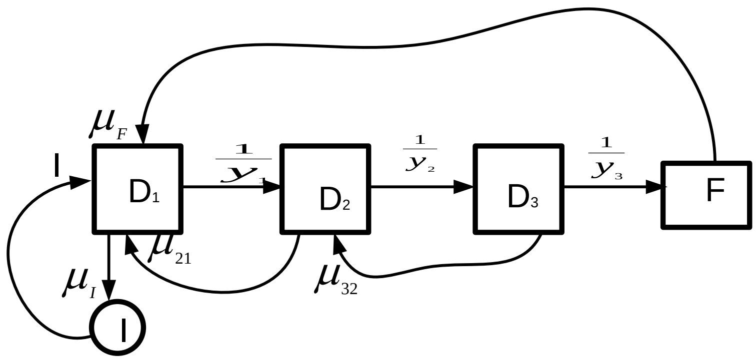

Figure 4.3 Inspection Model

4.3 Inspection Tests

Various inspection tests are considered in developing the proposed model. For example, for a Transformer system; the following tests could be considered in developing the maintenance model.

- Dielectric strength verification,
- Resistivity ,acidity and moisture content analysis
- Routine oil sampling test,
- Dissolved gas analysis and
- Furfural analysis

The condition of the transformer can be obtained by comparing the measured values with the working stardard.

4.4 Investigation

Information elicited from the inspection tests can be used to determine the condition of the system followed by the necessary maintenance action and the rate of the next inspection.

4.5 Maintenance Action

There are three different types of maintenance action that could likely result from inspection activities:

- **Do nothing**

The transformer is in satifactory or good condition and no maintenance is required. The probability that the system is set back to same stage is relatively high.

- **Basic Maintenance**

In this state, the system shows sign of deterioration that requires minor maintenance [21]. This maintenance action performed on the system increases the probability of going back to the previous stage (as good as new one).

- **Replacement**

In this state, investigation revealed that the system requires major maintenance that may demand component or entire system relacement. This action is assumed to bring the system back to its original stage i.e. its initial stage.

5. CONCLUSION

The paper had reviewed critically the various approaches that have been used in managing asset in electric power systems. Three different definitions of electrical reliability as it affects different Utilities companies were also examined. This understanding will assist electric power Utilities operators to make an informed decision on how system assets can be better managed to ensure system reliability. Maintenance dynamics for the last twenty years and its response to changing expectations were also reviewed in this paper. The growing awareness of how an equipment failure affects safety and the environment and the relationship between maintenance and product reliability were also considered. Several research problems raised in the literature works were critically analysed and reasons advanced for adopting a particular method. The applicability of each method is discussed when the asset in question is fully operational.

A model that will link maintenance and reliability in describing the impact on reliability of gradually deteriorating equipment with periodic inspections that can lead to various possible maintenance strategies has been proposed. This will aid in carrying out informed decision on asset management.

BIOGRAPHIES

Anthony Uwakhonye ADOGHE received his B.Eng (Hons), M.Eng and Ph.D in Electrical Engineering from University of Benin and Covenant University in 1985, 2005 and 2010 respectively. He has over 18 years of Industry and Consulting experience in Maintenance, Planning, Electric Power System analysis and Reliability. He is currently a lecturer in the Department of Electrical and Information Engineering, Covenant University, Ogun State, Nigeria. Adoghe is a graduate member of the Institute of Electrical and Electronics Engineers of USA (IEEE), corporate member, Nigerian Society of Engineer (NSE) and a Registered Engineer with the Council for the Regulation of Engineering in Nigeria (COREN). He has authored or coauthored several technical papers. His primary research interest is in modeling, evaluation and application of reliability centred maintenance techniques to maintenance of power system problems.

Claudius Ojo Aremu AWOSOPE received his B.Sc. (1st Hons), M.Sc. Tech. and Ph.D in Electrical Engineering from University of Lagos, University of Manchester Institute of Science and Technology and University of Lagos in 1972,1974 and 1982 respectively. He has taught Electrical Engineering courses at both undergraduate and post graduate levels in a number of Universities in both Nigeria and United Kingdom for more than three decades. Awosope is a Fellow of the Nigerian Society of Engineers (FNSE), Corporate Member of the Institute of Electrical and Electronics Engineers (MIEEE) and registered Engineer with the Council for the Regulation of Engineering in Nigeria (COREN).
He has attended a number of conferences both within and outside the country and has made outstanding contributions to engineering profession. He has authored a number of academic and technical papers in both local and international conference proceedings, journals, Books and periodicals. In addition, Claudius Ojo Aremu Awosope has also won a number of awards and serves as External Examiner and Assessor to a number of Universities within and outside the Country.
He has been a professor at the Department of Electrical and Electronics Engineering, Faculty of Engineering, University of Lagos, Nigeria since 1992. He specializes in the areas of power system reliability, power quality and design Optimization.

Samuel Adebayo Daramola obtained Bachelor of Engineering from University of Ado-Ekiti, Nigeria, Master of Engineering from University of Portharcourt, Nigeria and PhD from Covenant University, Ota, Nigeria. His research interests include Image processing and Cryptography.

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