Engineering and Technology Journal e-ISSN: 2456-3358

Volume 08 Issue 12 December-2023, Page No.- 3244-3254

DOI: 10.47191/etj/v8i12.18, I.F. – 7.136

Reliability and Availability Improvement Techniques for Nigeria Electric Power Stations

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ABSTRACT: The maintenance of plant in the electric power stations involves an annual expenditure of millions of dollars and it is therefore essential to establish the cost-effectiveness of the present maintenance policies. The major problems in this evaluation are the lack of information and lack of suitable techniques to analyze the information. Most items of electric power plants are complex mechanical units and as such it is extremely difficult to predict their failure although condition monitoring can sometimes be used. This study explores how to use reliability engineering to identify best practice for maintenance work in electric power stations. It identified how to identify failure before their occurrences and how the maintenance management functions can become more conscious of the sole of maintenance management in enhancing has become the prominent management issues for electric utilities.

KEYWORDS: Reliability engineering, maintenance, electric power isolation, application, failure.

1 INTRODUCTION

In recent years plants have started using reliability engineering to enhance maintenance practices and asset management. In this paper a case on reliability engineering for maintenance management in electric power station plants is analyzed. Reliability is used for optimization methods for maintenance management practices in order to improve overall effectiveness of operation and maintenance of the plant to become more cost-effective in maintenance. However for organizations in plants maintenance looking for a break through improvements in maintenance, on top of reliability engineering, other means ie the intelligent decision support system(IDSS) for maintenance, are required as sell. The electric power industry is relatively technology oriented with bulky sophisticated plants and equipment and other valuables assets requiring heavy capital investment. In the past, with a few exceptions, traditional electric power utilities were publicly owned and protected by regulation within governmentally determined territories with few exceptions to productivity [1].Many utilities tried to maximize reliability of equipment and plants with less emphasis on costs and quality of their operation and maintenance (O and M) [2]. But nowadays things have been changing very rapidly, electric utilities are facing fiercely external competition pressure. Deregulation, privatization and competitive markets for electric supply coupled with economical, technological, social, political transitions affected changes in organizational as well as in operation and maintenance of power systems.

Coupling utilities to adopt a new cost-cutting measures and models; in order to adopt to conservative approach to increase reliability and sustainability of plants and equipment. These conflicting needs can be achieved through developing and incorporating reliability engineering in maintenance.

RELIABILITY DEFINITION

Reliability is an engineering discipline for applying scientific know-how to component, assembly plant or process so that it will perform intended function, without failure for the required time duration when installed and operated correctly in a specified environment. Reliability terminates with failure[3]. Other definition of reliability are:

(i) The duration of probability of failure-free performance under stated conditions

(ii) The probability that an item can perform to definition

For non-redundant items, this equivalent to definition (i). For redundant items this is equivalent to definition of mission reliability. Reliability (the absence of failure which defines the probability of the failure free interval). High cost motivates engineering solution to reliability problems for controlling and reducing costs. Reliability has time dependent impact, PM product quality and the cost of unreliability. Enhancing reliability satisfies customers for on-time deliveries through increase equipment availability problems that waste money, the business issue of reliability is prevention and control of failure to reduce costs for improving customer satisfaction.

Failure occurs when a process cannot perform its intended function. Downtime measures equipment process failure. High costs and customer dissatisfaction are measures for product and process failures [4] . At the heart of reliability effort is the need to find affordable level of business reliability. This study will show methods for modeling failure costs to obtain a corrective action plan based on cost on unreliability. Good reliability engineering is not the search for perfection, rather it is the search for pragmatic solution for making reliability improvement[4].

RELIABILITY THEORY

When assessing the performance of a large number of nominally identical units, it is always found that the behaviours of units can vary considerably between individual plants. Thus whilst the mean life has some important issues, it is generally to investigate the variability in much more detail. Data of this type is frequently presented as a histogram showing the proportion of units with specific life line. With very large population of items the group spacing can be made small enough to be equivalent to a continuous density function which can be described concisely by an analytical. The bell-shape of the normal density unction is frequently met in engineering, but many other shapes are possible. To provide flexibility in matching different density shapes and for easier analytical manipulation. It is common in reliability studies to use the Weibull distribution which has a density function F(t)-given in Equation 1.

$$f(t) = \frac{\beta}{\lambda}\left(\frac{t}{\eta}\right)^{\beta-1} \exp\left[-\frac{t}{\eta}\right]^{\beta}$$

Equation 1

where f(t) is the proportion of failure per unit time

t is the appropriate time units

η is the characteristics life or scale factor in the name unit and

β is the shape factor

Other functions can be determined directly from the density function e.g. the cumulative proportions of failure f(t) is obtained by integration as in Equation 2:

$$F(t) = \int f(t)dt$$

Equation 2

$$F(t) = 1 - \exp\left[-\frac{t}{\eta}\right]^{\beta}$$

Equation 3

It can be seen that regardless of the parameter vales, when t is zero, the function is zero and as t becomes very large relative to the characteristics life the function tends to unity. The cumulative proportion of the units surviving at any time t is simply the complement of F(t) and is therefore the reliability R(t) is given by Equation 4.

$$R(t) = I - F(t) = 1 - \left(1 - \exp\left[-\frac{t}{\eta}\right]^{\beta}\right)$$

Equation 4

On expanding Equation 4 becomes Equation 5.

$$R(t) = \exp\left[-\frac{t}{\eta}\right]^{\beta}$$

Equation 5

Whist the above discussion is related to the proportion of a large number of units, the result can usefully be interpreted in terms of the behavior of a single unit. If no other information is available for the unit, then it can usefully be deduced that it has a certain probability of failing at a different times. The values can be determined directly from histogram or density function provided that a small time increments are used. Other probabilities can be deduced such as that of surviving units time t which is termed the reliability and the probability of failure before time to which unreliability. These values can be determined directly by the functions R(t) and F(t) respectively.

It is frequently important to establish the probability of failing say, the next week given that a unit has already been in operation for a specified time . This changes the analysis slightly since unit obviously could not have failed before the specified time. In terms of large group of units, it is necessary to recalculate the proportion of failures based on those remaining units not failed at a time. A new function termed the hazard rate h(t) is therefore defined which provides the information for hazard function as given in Equation 6.

$$h(t) = f(t)/R(t)$$

Equation 6

And for a Weibull distribution it is given in Equation 7.

$$h(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}$$

Equation 7

It can be noted that there is a significant differences in this function with changes in the shape parameter. For values greater than unity, the function increase implying that as equipment are getting older its tendency to fail increases, which is of what most engineers will expect. If the shape parameter is unity then the age of the equipment is irrelevant in terms of failure and this has various implications in terms of maintenance policies. But finally, when the shape factor is less than unity the likelihood of failure is supposed to decrease with age, which is commonly termed infant mortality.

Most process plants use highly complex engineering equipment which is usually required to repair on failure rather than replace them with new units. When plants are used over a long period it is frequently found that the failure characteristics vary with time. [5]. Therefore being an initial period with a fairly high number of failures followed by a long period with relatively few failures. Unfortunately, however as equipment begin to suffer from wear, corrosion and fatique, the number of failures begins to increase again rapidly. This variation can obviously be described using the three values of Weibull distribution parameters and a combination of these based on equipment age is frequently referred as bathtub-curve. When assessing the parameters of a particular item of equipment, the mean time to failures (MTBF) usually refers to the constant hazard rate region (whether the item is replaced or repaired) whilst the mean life is usually taken to employ the final wear out failure when the unit must be replaced.

Two notable ad surprising finings from the 1960 FAA/Airline industry reliability programme are:

(i) Scheduled overhauls had little effect on the overall reliability of a complex item unless it had a dominant failure mode, and

(ii) There were many items found for which there was no effective form of scheduled maintenance.

As the results of these various aircraft studies unfolded, the traditional views of equipment failure as deputed by the first generation (pre -world war I) and the second generation world war II curves were challenged [6]. Finally a new series of third generation failure causes developed relating to specific types of equipments on aircraft. Various studies have been carried out to relate these curves to other industries [7].

It becomes evident from the third generation failure patterns that views of equipment failure to change, as did what should be done to prevent failure, imposed age limit and time based maintenance schedule often do little or nothing to improve the reliability of complex equipment. Traditional maintenance can actually increase failure rate by introducing infant mortality into otherwise stable systems. [7] to address these issues, maintenance was faced with four challenges.[7] to deal with effectively with type of failure process with appropriate maintenance tactics to:

(i) compose maintenance productivity towards a more proactive approach

(ii) extend sum length between schedule shutdown and

(iii) ensure the active support and cooperation of people from the maintenance, materials, operation and technical functions.

Reliability centered maintenance provides a maintenance oriented framework to meet these challenges, RCM can be defined as a structured, logical process for developing or optimizing maintenance requirements of a physical resources in its operating context to realize its inherent reliability where inherent reliability is a the level of reliability which can be achieved ith maintenance programme. This level of reliability is a function of the equipment design and cannot improve without redesign[7]

RCM is basically a methodology to balance the resources being used with the required inherent reliability base on the following:

(i) A failure is an unsatisfactory condition and maintenance attempts to prevent such condition from arising

(ii) The consequences of failure determine the priority of the maintenance effort

(iii) Equipment redundancy should be eliminated where appropriate

(iv) Condition based maintenance are predictive tactics which are favoured over traditional time based maintenance and

(v) Run to failure is acceptable where warranted

(vi) Improvement justification requires knowing when things fail

(vii) How thing fails.

(viii) Conversion of failure into money statement

Reliability engineering principles help define when and how things fail, provide facts for life costs comparisons to help decide the lowest long-term cost of ownership driven by single estimate, net present value (NPV), which is used for converting hardware issues and alternative into money issues. The engineering department should be responsible for providing facts about lie cycle costs over project lie and they must provide more than a single alternative. Knowledge about, time to failure and failure modes are found by reliability engineering principles. The dead of most equipment must be analyzed from small data samples using a very practical reliability techniques of Weibull [8], for each failure modes that occur. Mostly, reliability tools used for predicting failures and funding cost effective alternative include:

Mean time between failure (MBTF) indices, availability, maintainability, capability, TPM and reliability practices, critical time, significantly affecting safety, cost, Weibull, normal and log-normal, probability plots, part distribution for vital free problems, failure-tree analysis, life cycle costs(LCC) models and Monte Carlo simulation etc.

Reliability

Reliability deals with reducing the frequency of failures over a time-interval. Reliability is a measure of the probability for ‘failure –free operation’ during a given interval ie it is a measure for a failure-free operation. It is often expressed as give:

$$R(t) = \exp[-\frac{t}{MBTF}] = \exp(-\lambda t)$$

Equation 8

Where λ is constant failure rate

MBTF is the mean time between failure

Or expressed in Weibull terms as:

$$R(t) = \exp(-\frac{t}{\eta})^{\beta}$$

Equation 9

where MBTF = $\frac{OH}{NF}$

OH is the operating hours per year

NF is the number of failures per year

MBTF is a yard stick for reliability. It measures the tine between system failure and is easier to understand their probability numbers for a given omission time, high reliability requires long MTBF, long failure –free interruptions resulting in increased productive capacity while requiring fewer spare parts and less manpower for maintenance activities which leads to lower costs. Improving reliability often occurs by reducing errors from people or improving processes/ procedures and these changes can usually be made at small costs. Reliability improvement being expectations for improving availability, decreasing downtime and smaller maintenance costs; improved secondary failure costs and results in better chance for making profits [9]. The equipment is free from failure or for longer operated for long period of time. High reliability (low chances for failures) and high maintainability (practicable maintained times) tends toward highly effective systems

Reliability+ unreliability=1

Equation 10

Unreliability (UR) -1-R(t)

Equation 11

Or for a parallel system

$$R(t) = 1 - (UR)_1 (UR_2)$$

Equation 12

Availability deals with the duration of uptime operations and is a measure of how often a system is alive and well. It is expressed as:

$$A = \frac{Uptime}{Uptime + Downtime}$$

Equation 13

Uptime refers to capability to perform the task without failure and downtime refers to not being able to perform the task. As availability grows, the capacity for making money increases because the equipment is in service for longer percentage of time. When the availability is known, the estimates of uptime for a given interval can be done e.g an operation is desired to operate around the clock (a total of one year is 8760 hours) and it has an availability of 98%. The process uptime is .98x8760=8584.8 hours/year and the downtime of 0.02x8760-17502 hours/year, as availability+ unavailability =1, a system must be available (ready for service) and reliable (absence of failure for designated time interval) to produce effective results. Maintainability deals with duration of maintenance outages or how it takes to complete (ease and speed) of maintenance actions compared to a datum. The datum includes maintenance (all actions necessary for retaining an item in or restoring an item to a specified good condition) performed by personnel's having specified skill level, using procedures and resources at each prescribed level of maintenance. Maintainability characteristics are usually determined by equipment designs which then set maintenance procedures, and determine the length of the repair times.

Key maintainability index is the mean time to repair (MTP) it is a limit for maximum repair. Quantitatively, it refers to the ease with which hardware or software is repaired or restored to a functioning state. It has probability and measured based on the total downtime for maintenance including all time for diagnose, trouble shooting, tear-down time for maintenance, active repair time, verification testing that repair is adequate, delays for logistics movements and administrative maintenance delays. It is often expressed as:

$$M(t) = 1 - \exp(-\frac{t}{MTTR} = I - \exp(t - \mu t)$$

Equation 14

Where μ is the constant for maintenance rate, MTTR is the mean time to repair and it is the average of repair time which is easier to visualize than probability values. This implies the ease to use repair time criterion is often expressed in experimental repair time rather than more accurate cumbersome lognormal distribution.

Capability

This measures capability to perform the intended function on a system basis. Capability is synonymous with productivity which is the product of efficiency x utilization. Efficiency measures the productive work output versus input. Utilization is the ratio of time spent on productive efforts to the time consumed e.g supposes efficiency is 80% and utilization is 81.9%, then capability is 0.8x0.819=65.52%. Capability measures how well production activity is performed to the datum

Capability(Productivity)=efficiency Utilization

Equation 15

System Effectiveness

System effectiveness quantifies important elements and associated costs to find areas for improvements to increase overall effectiveness and reduce losses. The Equation helpful for understanding back-off-information[10].

Help tool for easing LCC calculations involving probabilities is the effectiveness equation which gives a Figure of merit for judging the chances of producing the intended results. This issue is finding a system effectiveness value which give the best long term of cost of ownership with trade -off consideration.

System effectiveness=Effectiveness/LCC

Equation 16

Cost is a measure of resources usage. It never includes all possible elements but just includes the most important elements. Effectiveness is a measure of value received (effectiveness rarely includes all value elements as many as build be possibly included).

Effectiveness=availabilityxreliabilityxmaintainabilityxcapability

Each elements of the effectiveness has value between 0 and 1. The measure adds availability to LCC.

Failure modes effect and fault tree analyses

Failure modes and effects analysis (FMEA) is an analysis used for evaluating reliability by examining

Expected failure modes to find the effect of failure on equipment or system. FMEA searches for potential failure and how failure will affect the overall systems. FMEA is helpful for finding small failure. Simple FMEA studies can be enhanced by use of criticality analysis search failure modes effect and criticality analysis (FMECA). It starts with more detail on the chances of failure for costly pattern . FMEA can be performed following a process as:

(i) Perform preparatory work
(ii) Collect data
(iii) Summaries and encode
(iv) Calculate losses
(v) Determine the significant few
(vi) Validate result using gap analysis (sum of the results+ or -10%)
(vii) Fault tree analysis (FTA) is a deductive ideality analysis tool for evaluating reliability driven by top view of what will fail and search for root causes of top event. FTA provides both reliability assessment and fault probability perspectives. FMEA and FTA can be used quantitatively and qualitatively.

Basic Concept

The cumulative distributive function F(t) , the probability is a random variable is not greater that 't'

$$F(t)=\int_{-\alpha}^{t} f(dt)dt$$

Equation 17

where f(t) is the probability density function of random variable, time to failure and F(t) term unreliability function when talking about failure.

The reliability function R(t) or the probability of the device not failing prior to time t, is given by

$$R(t)=1-F(t)=\int_{-\alpha}^{t} f(dt)t$$

Equation 18

Differentiating Equation 18, it becomes

$$\frac{-dR(t)}{dt}=f(t)$$

Equation 19

The probability of failure in a given interval between t_1 to t_2 is expressed by the reliability function:

$$\int_{t_1}^{\alpha} f(t)dt-\int_{t_2}^{\alpha} f(t)dt=R(t_2)-R(t_1)$$

Equation 20

The rate at which failure occurs in the interval t_1 and t_2 is called the failure rate λ. That is the anticipated number of times an item will fail within a specified period. It is the ratio of the probability that failure occurs in the interval divided by the interval length.

$$h(t)=\frac{R(t_i)-R(t_{2)}}{t_1-t_2(R(t_2)}$$

Equation 21

Alternatively

$$\lambda(t)\frac{R(t)-R(t_1-t_{2)}}{R(t)}$$

Equation 22

where $t=t_1$ and $t_2=t+\Delta t$

The hazard rate h(t) or instantaneous failure rate is defined as the limit of the failure rate, as the interval length approaches zero or

$$h(t)=\lim[\frac{R(t)-R(t+\Delta t)}{\Delta R(t)}=\frac{-1}{R(t)}[\frac{dR(t)}{dt}=\frac{1}{R(t)}[\frac{dR(t)}{dt}]$$

Equation 23 a

$$F(t)=\frac{-dR(t)}{dt}$$

Equation 23 b

Substituting Equation 23b into 23 a, we have

$$h(t)\frac{f(t)}{R(t)}$$

Equation 24a

From the fundamental relationship in reliability analysis of the density function of the time to failure f(t), and the reliability function R(t) , the hazard function for any time 't' can be found. Equation 24 is a general expression derived for the hazard failure rate. This can also be done for the reliability function.

$$h(t)=\frac{1}{R(t)}[\frac{dR(t)}{dt}$$

Equation 24b

$$\frac{dR(t)}{R(t)}=h(t)dt$$

Equation 25a

Integrating both sides

$$\int_{o}^{t}\frac{dt(t)}{R(t)}=\int_{0}^{t} h(t)dt$$

Equation 25b

$$LnR(t) - Ln(0) = \int_{o}^{t} -h(t)dt$$

Equation 25c

But R(0) =0

$$R(t) = \exp[-\int_{0}^{t} h(t)dt$$

Equation 26

This is the general function. If h(t) can be considered a constant failure rate λ

, then Equation 26 becomes

$$R(t) = e^{-ht}$$

Equation 27

The reliability function can be related to the probability distribution PDF. The PDF is always equal to 1. Given the concept, subtracting the cumulative function (CDF) also known as unreliability, gives the reliability.

$$F(t) = Q(t) = I - R(t)$$

Equation 28

where Q(t)=unreliability

$$Q(t) + R(t) = 1 - R(t)$$

Equation 29

$$R(t) = 1 - \int_{t}^{\alpha} \int (t)dt$$

Equation 30

$$R(t) = \int_{t}^{\alpha} f(t)dt$$

Equation 31

$$\lambda(t) = \frac{f(t)}{1 - \int_{\alpha}^{t} f(t)dt}$$

Equation 32

$$\lambda(t) = \frac{f(t)}{R(t)}$$

Equation 33

MODELS

Applicable models for reliability analysis include the use of reliability failure prediction mode, effect and criticality analysis (FMECA) and reliability block diagram. Other analytical models globally recognized and used to analyze components, systems and project include [11] **Abernethy, 2000**

(i) Mil-217 provides production to MIL-HDBK 217F

(ii) Bellcose/telecosdia, provide on bellicose, TR-332 issue 6 standard

(iii) FMECA, provide mode effect and criticality analysis to MIC-STD-1629A

(iv) RBD provide reliability block diagram analysis

(v) Fault two provides deductive 'top down' failure analysis utilizing a graphical model of Boolean logic gates

(vi) China 299B provides standards for electronic prediction

All these analytical models developed into several software in the market which : item software, Waismit, Weibull and visual software. However all these software's are based on development of certain statistical distributions namely exponential, gamma, lognormal, normal, binomial, Weibull, passion and Markov analysis of these distributions. The Weibull distribution, a probability modeling distribution is more general in characteristic life distribution. It answers question of what has happened and what is expected to happen after careful examination of data. It is therefore most suited for reliability work by adjusting the distribution parameters; a wide range of life distribution which characterizes engineering practice can be modeled.

One version of the failure density function is mathematically expressed as:

$$f(t) = \frac{\beta}{\eta}(\frac{t-\gamma}{\eta})^{\beta-1} = \exp[-(\frac{t-\gamma}{\eta})]^{\beta-1}$$

Equation 34

Where f(t) ≥ 0, ≥ 0, γ, β, η ....

β is the shape factor, η is the scale parameter of characteristics life, γ is the location factor(minimum life)

Frequently, the location parameter is set at zero (failure is assumed to start at t=0) , it results into a two parameter distribution where the failure density function becomes:

$$f(t) = \frac{\beta}{\eta}(\frac{t)}{\eta})^{\beta-1} = \exp[-(\frac{t}{\eta})]^{\beta-1}$$

Equation 35

Important aspect of Weibull model is how values of the shape parameters, the scale parameters, affect the distribution characteristics such as the shape of the probability density functions curve, the reliability and the failure rate.

The shape parameter can have marked effect on the distribution. If the shape factor is one, the PDF of a three parameter Weibull reduced to a two parameter exponential distribution. Another characteristics of the shape factor is its effects on the failure rate. When the shape factor is less than one, the failure rate decreases with time (infant mortality or the early life failure) the distribution takes the form of a gamma distribution.

$\beta > 1$, the failure rate increases with time (wear out failure)

$\beta > 2$, the distribution twins to the form of a log normal distribution

$\beta > 3$,the distribution turns to the form of a log normal distribution

Because of these reasons, the Weibull model is used to keep identity when distribution from life data backed up the goodness of fit test matrix, the PDF can be used to derive commonly used reliability matrices, such as reliability function, failure rates, mean time between failures, etc.

The reliability function in Weibull distribution is given as:

$$R(t) = e^{-(\frac{t}{\eta})^{\beta}}$$

Equation 36

The failure rate $\lambda(t)$ is given by:

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta} e - (\frac{t-\gamma}{\eta})^{\beta-1}$$

Equation 37

The mean life (MTBF) is given by:

$$\bar{t} = \gamma + \eta\Gamma(\frac{1}{\beta} + 1)$$

Equation 38

Where is the gamma function defined by:

$$\Gamma(n) = \int_0^{\alpha} e^{-x} x^{n-1} dx$$

Equation 39

The median life, β_{50} given by:

$$t = \gamma + \eta(\ln 2)^{\frac{1}{\beta}}$$

Equation 40

The parameterized distribution for a data set will be used to estimate the important life characteristics of equipment reliability mean time between failure and failure rate.

The supersmith ^{TM} software package from Fulton finding Ca leading software providers in reliability is a stand-alone programme which is early tom use. It performs all techniques mentioned above. Recently published benchmark in quality engineering indicate supersmith as the only trust worthy source for best practice solutions for performing life data analysis .

Crow- Amasa Reliability Growth Model

Reliability analysis for complex repairable system could be stochastically be represented as a Weibull process, allowing for statistical procedures to be used in the application of this model in reliability growth**[12]**. The statistical extension become known as CROW/AMASA non homogenous Poisson process (NHNP) model. This model was first used by United States army material system analysis activities (AMAAS). It is frequently used on systems when usage is measured as a continuous scale. The CROW/AMSAA model consists of looking at reliability growth within a particular phase. Assuming that a particular phase of the programme begins at t=0 and let $0 < s_1 < s_2 ... < s_n$ be the times that improvements or observations taken. The failure intensity , the times (s_{i-1}) When changes are made in the septum therefore the member of period has the Poisson distribution with mean $h_i ; (s_{i-2} - s_1)$

$$P[N_i = R = [\frac{h_i}{\eta}(s_i - s_{i-1})e^{-h_i}(s_i - s_{i-1})]$$

Equation 41

The constant failure intensity , h_i assumes that the times between successive failures for this interval follow the exponential distribution.

$f(x) = 1 - e^{-hx}$, x>0

Equation 42

Let (NT) denote the cumulative number of failures in improvement period, T, of <T<S $_i$, then (t) is the number of failure in the first interval plus the number of failure in the second interval S_i and T . Having the failure rate λ_i for the second interval , the mean of N(T) , which is $\theta(T)$ is simply:

$$\theta(T) = \lambda_1 S_i + \lambda_2 (T - S_i)$$

Equation 42

If the failure intensity is homogenous Poisson process with mean λT and of the failure intensity is non-homogenous ie the failure intensity is not the same in the interval $S_{i-2,} S_{i-1}$, N(T) follows a non-homogenous Poisson process. Therefore, the mean value function is:

$$\theta(T) = \int_0^t \rho(y) dy$$

Equation 43a

Where $\rho(y) = \lambda$

Equation 43b

$$Y = (S_{i-1} - S_i)$$

Equation 43c

Then for any T,

$$\Pr[N(T) - n = \frac{[\theta(T)]e^{-\theta(T)}}{n!}$$ n=0,1,2…

Equation 44

An integer-value process [N(T), T>0] is called process with an intensity function P(T), P(T) is infinitely small then P(T) ΔT is approximately the probability of system failure in the interval ΔT

The CROW/AMSAA model assumes the P(T) may be approximated by the Weibull failure function.

$$\rho(T) = \frac{\beta}{\eta\beta} T^{\beta-1}$$

Equation 45

Therefore, if λ is $\frac{i}{\eta^{\beta}}$, the intensity function $\rho(T)$ the instantaneous failure intensity λT is defined by as:

$\lambda_i(T) = \lambda\beta T^{\beta-1}$, with T>0, $\lambda > 0$ and $\beta < 0$

From Equation (45) the average number of failures by time T becomes:

$$\theta(T0 = \int_0^T \lambda_i(T)dT = \int_0^T \lambda\beta T^{\beta-1} = \lambda T^{\beta}$$

Equation 46

The cumulative failure intensity λc is:

$$\lambda c = \lambda T^{\beta-1}$$

Equation 47

Therefore, the cumulative MTBF is:

$$MTBF = \frac{1}{\lambda}T^{\beta-1}$$

Equation 48.

The estimation of parameters using maximum likelihood is:

$$f\frac{T}{T_{2-1}} = (\frac{\beta}{\Pi})\Pi^{\beta-1}e^{-1}(T^{\beta} - T_2^{\ \beta})$$

Equation 49

The likelihood function is:

$$L = \lambda^n \beta^{\eta} e^{\lambda T\beta \prod_{i-1}^{n} T^{\beta-1}}$$

Equation 50

where T termination time given by:

$T = [\frac{T_n}{T} > T_n$ if the process is failure terminated.

Taking the natural log on both sides:

$$v = \eta \ln\lambda + \eta \ln\beta - \lambda T^{\beta} + (\beta-1)\sum_{i-1}^{n} \ln T_i$$

Equation 51

And differentiating with λ, yields:

$$\frac{\partial v}{\partial \lambda} = \frac{\eta}{\lambda} - T * \beta$$

Equation 52

Setting it equal to zero and solving for λ

$$\bar{\lambda} = \frac{\eta}{T\beta}$$

Equation 53

Differentiating Equation 53 with respect to β:

$$\frac{\partial v}{\partial \beta} = \frac{\eta}{\beta} - \lambda T * \beta \ln T + \sum_{i=1}^{n} \ln T_i$$

Equation 54

Se Equal to zero and solve for β

$$\bar{\beta} = \frac{\eta}{n\ln T - \sum_{i=1}^{n} \ln T_2}$$

Equation 55

Probability plotting for normal distribution plating involves plotting the failure times and associated and unreliability estimates on especially constructed probability paper. The form of this graph paper is based on linearization of the CDF of the specific distribution. For the normal distribution, the cumulative density function can be written as:

$$\Gamma(T) = \phi(\frac{T-U)}{\sigma T}$$

Equation 56

Or

$$\phi - 1[F(T)]$$

Equation 57

Now let

$$a = \frac{\mu}{\sigma}$$

Equation 58

$$b = \frac{1}{\sigma}$$

Equation 59

This results in linear Equation:

$$Y = a + bT$$

Equation 60

The normal probability paper resisting linearized function. Since the normal distribution is systematic, the area from μ to $+\infty$ consequently the value of it is said to be the point where R(t) =Q(t)=50%. This means that the estimate of μ can be read from the point where the plotted line crosses the 50^{th} unreliability line. To determine the value of σ from the probability plot it is first to understand the are under the PDF curve that lies between the standard deviation in either direction from the mean (or two standard deviation totals , represents 68.3% of the area under the curve).

Consequently, the interval between Q(t)=84.15% and Q(t)= 15.85% represents two standard deviation. Sins the interval of 68.3% is 84.15%-15.85%=68.3% and is centered on mean at 50%. As a result , the standard estimator can be estimated from:

$$\sigma = (Q(t)84.15\% - Q(t)15.85\%)/2$$

Equation 61

That is the value $\bar{\sigma}$ is attained by substituting the time value, where the plotted line crosses the 84.15% unreliability line from the time value where the plotted crosses the 15.85% unreliability line and dividing the result by two. The process is illustrated in the following example. Seven units are put on a life test and run until failure. The failures times are 85,90,95,100,105,110 and 115 hours. Assuming a normal distribution, estimate the parameter using probability plotting paper.

Q(t)=50th =100 hours

Q(t)=15.85%=88 hours

The estimate of μ determined from the value at the 50% unreliability level, which in this case is 100 hours. The value of the estimator $\overline{\sigma}$ is determined by Equation 61[13

$\overline{\sigma} = (112-88)/2 = 12$ hours

Alternatively $\overline{\sigma}$ could be determined by measuring the distance from Q(t) =15.85% to Q(t) 50% or

Q(t) 84.15% , as either of these two distances is equal is equal to the value of one standard deviation.

Weibull distribution

The Weibull distribution id one of the most commonly used distributions in reliability Engineering of many shapes it attains for various values of β (slope).It can therefore model a great variety of data and life characteristics. The two Weibull PDF is given by[13].

$$f(t) = \frac{\beta}{}(\frac{t)}{\eta}^{\beta-1} = \exp[-(\frac{t}{\eta})]^{\beta-1}$$

Equation 62

$f(T) \geq 0, T \geq 0, \beta > 0, \eta > 0$

η is the scale parameter, β the shape parameter.

Weibull Statistics Properties Summary

The mean or MTBF

The mean $\overline{T}$ od the two –parameter Weibull PDF is given:

$$\overline{T} = \pi\Gamma(\frac{1}{\beta}+1)$$

Equation 63

where $\Gamma(\frac{1}{\beta}+1)$ is the gamma function evaluated at value of $(\frac{1}{\beta}+1)$ .e

The Median

The mean $\overline{T}$ of the two –parameter Weibull is given by:

$$\overline{T} = \eta(1-\frac{1}{\beta})^{\frac{1}{\beta}}$$

Equation 64

The standard deviation σ^T of the two Weibull parameter is :

$$\sigma^T = \eta\sqrt{\Gamma}(\frac{2}{\beta}+1) - \Gamma(\frac{1}{\beta}+)^2$$

Equation 65

The CDF and reliability function of the two parameter distribution is given by:

$$\Gamma F(F) = 1 - e^{-(\frac{T}{n}})$$

Equation 66.

The Weibull function is given by :

$$R(T,t) = \frac{R(T+t)}{R(T)} = \frac{e^{-\frac{T+t}{n}}}{e^{-(n)\beta}}$$

Equation 67

$$R(T,t) = [e^{-(}\frac{T+t)}{n} - (\frac{T}{n})\ ]$$

Equation 68

Equation 68 gives the reliability for a new mission having already accumulated T hours of operation up to the start of this new mission and the unit and checked out to assure they will start the next mission and he units are checked out to assure that they will start the next, successfully(it is called conditional because the reliability of the new mission can be calculated based on the fact that the unit has already accumulated T hours of operation successfully.

Reliable Life

For the two parameter Weibull distribution, the reliability life T_R of a unit specified by reliability starting the mission at age zero is given by:

$$T_R = \eta - (-\ln[R(T_R)])$$

Equation 69

This is the life for which the unit will function successfully with a reliability $R(T_R)$ if $R(T_R) = 0.50$

Then $T_R - T$, the median life by which half of the units will survive.

The Failure Rate Function

The two parameter Weibull failure rate function $\lambda(T)$ is given by:

$$\lambda(T) = \frac{f(T)}{R(T)} = \frac{\beta}{\eta}(\frac{T}{\eta})^{\beta-1}$$

Equation 70

Probability plotting for the Weibull distribution, one method of calculating the parameters of Weibull distribution is by using probability plotting to better illustrate this procedure, consider the following from [14] KECECIOGLU, 2004). Assuming that six identical units are reliability tested at the same application stress levels. All of these units fail during the test after operating number of hours , $T_2 = 93,34,16,120,53,75$. Evaluate the values of the parameters for a two parameter Weibull distribution and determine the reliability of the units at a time of 15 hours.

Solution

The first step is performing the parameter of the Weibull PDF representing the data using probability plotting as outlined:

(i)First rank the time to failure in ascending order as shown in Table 1.

Table 1: Failure Data

Time to Failure (hours)	Failure order number out of s size of 6
16	1
34	2
53	3
75	4
93	5
120	6

(ii)Obtain their rank plotting positions. Median rank positions are use instead of other ranking methods because , median ranking are at specific confidence level 50%, median ranks can be tabulated in many relaibilitityboks . They can also be estimated by the following Equations.

$$MR\% \approx \frac{j-0.3}{N+0.4}$$

Equation 71

where j is the failure order number and N is the total sample size. The exact median rank are found in Weibull++ by solving:

$$\sum_{k=1}^{N}(N,K)(MR)^k(1-MR)^{N-K} = 0.5 = 50\%$$

For MR, where N is the sample size of i the order number.The failure ranking and percentage is presented in Table 2.

Table 2:Failure Data and percentage ranking

Time to Failure (hours)	Failure order number out of s size of 6
16	10.91
34	26.44
53	42.14
75	57.86
93	73.56
120	89.19

(iii) The results can be plotted on a Weibull Reliabiltiy paper.

CONCLUSION

The improvement in the maintenance practice of Nigerian Electric Power Industry can be realized by the application of Reliability Engineering principles. This starts by proper documentation of the failure data of the equipment in the plant. It is not news that many data are collected and kept by different units of the power plant, but lack organization of the data to a form that can be useful for the operation of the plant. For the Industry to be alive and competitive in energy supply, it must adopt new maintenance practice that is proactive and not reactive. Weibull method of reliability Engineering as presented above becomes a life wire to save the organization and make it relevant in the energy supply chain.

REFERENCES

1. SAE M-1102(1999). Reliability and Maintainability Guidelines for Manufacturing Machinery and equipment-2nd ed., Society of Automotive Engineers, Warrendale,
2. Fabrycky, W. J. and Blancharh, B.S (1991). Life cycle cost and Economic Analysis Prentice Hall, Eaglewood, Cliffs. New Jersey, NJ.Pp. 125
3. Barringer, H. P. (2000b). Reliability Engineering Principles, Barringer and Associates,
4. Barringer, H.P(2001) Reliability Engineering Principles, Barringer and Associates ,inc,Humble,Tx
5. Barringer, H.P.(1996) , Proceedings, Annual Reliability and Maintainability
6. Moubray, J. (1997) *Reliability Centered Maintenance*. New York: Industrial Press. Inc.
7. Moubray, J. (2002) *An Introduction to Predictive Maintenance*. New York: Industrial Press.
8. Abernethy, R.B. (2000) , The new Weibull Handbool, 4th e. Dr. R.B Abernethy, North
9. Barringer, H.P. (1999) Practical Reliability for Refineries and Chemical Plants, P.E.
10. Barringer, H.P. (1995) , Download free Monte-Carlo Software; http://www.barringer
11. Abernathy, R. B. (1998). The New Weibull Handbook , 3rd ed. 53b Oyster Road, North Palm Beach, FL33408-4328
12. Barringer, H. P. (2000d). Weibull Database, http://www.barringer1.com/raptor. Htm
13. Reliasoft the e-magazine for reliability professional issue 14, 2002 pp1-6