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AN INVESTIGATION INTO THE DISTRIBUTION OF TIME BETWEEN FAILURES ON DISTRIBUTION SYSTEM FEEDER LINES IN SOUTHWESTERN NIGERIA

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ABSTRACT

The Time between Failures distribution observed on four selected feeder lines in the distribution system of Southwestern Nigeria was investigated in this study. Starting with data gathered on the selected feeder lines, the graphical representation of the time between failure distributions on each of them was presented. Least square plot, Bartlet test and Maximum Likelihood estimator technique were used to establish that the distributions were exponential. The distribution parameter, failure rate denoted by, λ , obtained from the least square plot of the feeder lines are 0.0054 f/h, 0.0071f/h, 0.0177f/h and 0.026f/h. The reliability distribution function obtained for each of the feeder lines can be used to estimate the probability of no failure within any given time.

Keywords: distribution system, feeder lines, time between failures, probability distribution function, exponential distribution function.

1. INTRODUCTION

The failure of components, structures and systems are common phenomena worldwide in spite of the astounding technological developments that the world has witnessed within the past two centuries. That a system must one day fail has become a reality no matter how apparently neat and 'perfect' the design may be and no matter how thorough the construction may be. The failure frequency and consequent losses can however be minimized. The need to minimize failure frequency and cost has been the impetus towards the study of failures in systems, components and structures.

The traditional approach to the minimization of failure involves building a wide margin of safety into design. In practice, a safety factor as much as 4 to 10 times the expected stress level is allowed for in the design. In power systems generation planning a reserve greater than a whole generation unit is introduced [1]. This is a deterministic approach and it leads to over design and excessive cost. A more important flaw of the deterministic approach perhaps is the fact that unanticipated load and stress level are not provided for.

The trend is therefore changing from this traditional deterministic approach. Failures and failure causes are seen as phenomena, which cannot be determined with absolute certainty or complete knowledge. They are seen as random or probabilistic. This is particularly true where uncontrollable environmental factors are contributory to failures. In an electrical power system for instance, with many component parts installed outdoor, climatic factors such as rainfall, wind speed, and temperature (which to a large extend are random) are contributory to failures and to changes in load demand.
Because these factors are random, the failures which they cause are also random. The probabilistic approach therefore considers failures as random distributions which exhibit probabilities of occurrence and models the failure using statistical probability distributions [2]. An accurate specification of the probability distribution of the times to failure completely characterizes a failure event and gives a clearer and deeper insight into the failure process.

1.1 Probability distributions used in failure analysis and the associated failure functions

Statistical probability distributions have played much role over the years in modeling uncertainty and in particular, in the modeling of uncertainties in failure, in failure processes and in failure times. In the 1930s and 1940s, Weibull analyzed fatigue life in materials using the popular Weibull distribution. Other distributions which have found applications in failure analysis include: exponential distribution, normal distribution and lognormal distribution.

Four failure functions which are associated with each of the above distributions and with their failure are: the Probability Density Function (PDF), the Cumulative Failure Function (CFF), the Reliability Function (RF) and the Hazard Function (HF) [3].

The PDF expresses the instantaneous failure probability at time, t. It is denoted by $f(t)$ and satisfies the relation:

$$\int_{-\infty}^{\infty} f(t)dt = \int_{0}^{\infty} f(t)dt = 1 \tag{1}$$

The Cumulative Failure Function expresses the probability of the failure of a system or equipment within a specific time, t. It is denoted by $F(t)$ and given by:

$$F(t) = \int_{0}^{t} f(t)dt \tag{2}$$

The Reliability Function also called the Survivor Function expresses the probability of no failure within a given time, t. That is, it expresses the probability that a system will function properly beyond a given time, t. It is denoted by R (t) and given by:

$$R(t) = \int_{t}^{\infty} f(t)dt \tag{3}$$

From equations (1), (2) and (3),

i.e., $F(t) + R(t) = 1$ (4)

Hence Cumulative Failure Function and Reliability Function are complementary such that when $F(t) = 0,\ R(t) = 1$ and when $F(t) = 1,\ R(t) = 0$.

Differentiating through (4) with respect to t yields;

$$\frac{dF(t)}{dt} + \frac{dR(t)}{dt} = 0$$

i.e. $\frac{dF(t)}{dt} = -\frac{dR(t)}{dt}$ (5) (5)

The Hazard Rate Function also called the failure rate function expresses the instantaneous rate of failure at time t. It also gives the conditional probability of failure in the time interval between t and $t + \Delta t$ given that a system has survived till the time t. Denoted by $\lambda(t)$, it is given by:

$$\lambda(t) = \frac{f(t)}{R(t)} \tag{6}$$

The failure functions can be obtained for any given Probability Density Function using the relations (1)-(6) above.

1.2 Reliability and mean time between failures

The reliability of a system or component is defined as the probability that the system or component will perform its intended function when operated in a prescribed way within a stated time and under a stated environmental condition. Among the basic indices or measures of reliability are Failure rate, Mean Time between Failures, Mean Time to Repair, Mean down Time and Availability.

In the probabilistic approach to failures, the Time between Failures exhibit a distribution and the Mean Time between Failures is the expected value of the distribution of Times between Failures after a long Time. Usually denoted by $E[f(t)]$, it is given by:

$$MTBF = E[f(t)] = \int_{0}^{\infty} tf(t)dt = \int_{0}^{\infty} R(t)dt \tag{7}$$

where $f(t)$ is the time between failures distributed function.

1.3 Exponential least square plots

Least square plots are useful in obtaining the distribution of an experimental or field data with appropriate transformations. When failure or repair times fit an assumed distribution, the transformed data are linear and the relevant distribution parameters can be obtained from either the slope or intercept of the straight line representation [2]. The least square plots of the exponential distribution which was used in this study is here discussed.

For an exponential distribution, the cumulative distribution function $F(t)$ is given by:

$$F(t_i) = 1 - e^{-\lambda t}$$

i.e. $1 - F(t_i) = e^{-\lambda t}$ (8)

Taking the natural logarithm of both sides of (8) and simplifying gives:

$$\ln[1 - F(t_i)]^{-1} = \lambda t$$

where $F(t_i)$ is the estimate of $F(t)$ represented by the plotting position ordinate of Time between Failure at the i th rank and given by:

$$F(t_i) = \frac{i - 0.3}{n + 0.4}$$

n being the number of items of data used in the study.

1.4 The Nigerian electric power system

The Nigerian electric power system like other power systems has three functional zones; Generation, Transmission and Distribution. This study is concerned with times between failures distribution in the distribution subsystem of the electrical power system in southwestern Nigeria. Three voltage levels exist in the distribution subsystem of the Nigerian electric power system. The voltage levels are: 33 kV, 11 kV, and 0.415 kV. The subsystem is radial and essentially overhead.

The Nigerian electric power system has attracted increasing attention within the last decade essentially because of the glaring unreliability of the system. In spite of reported huge investments and policy innovations, the performance of the system is far below expectation being characterized by frequent failures and long outage durations. Reportedly, billions of Naira has been pumped into the system within the last few years, for generation system reactivation, for transmission and distribution system reinforcement and expansion [4]. Independent Power Producers (IPPs) have been encouraged to invest in power generation to boost output. An amount of unbundling has been introduced to decentralize the management of the system. There has been little or nothing to show for all these. Incessant and high frequency failures, under voltage supplies, system collapse, regular load shedding, protracted outages are still the order of the day.

In the bid to understand the problem in the power system, increasing studies are being carried out on the

ARPN Journal of Engineering and Applied Sciences

system. Adediran and Jenyo (1999) [5], carried out an availability analysis of Shiroro hydro electric power station. Jenyo (2001) [6] used the analytical technique and the exponential model to

Determine the maintainability of Shiroro hydro electric power system. Adeyemi and Abutu (2004) [7] did a study on the problems of transformers in the Nigerian national grid. Megbowon and Oyebisi (2005) [8] assessed the reliability of the transmission lines in South western Nigeria and in Megbowon and Oyebisi (2004) [9], the duo reported a study carried out on the feeder lines of Molete District of the power system using time-series technique. This study is a contribution towards unearthing the problems in the Nigerian electric power system.

1.5 The selected feeder lines

The four 11 kV feeder lines for this study were Secretariat Feeder Line in Ibadan, Oke-Eda Feeder Line in Akure, GRA feeder Line in Abeokuta, and GRA Feeder Line in Oshogbo. The customers on these feeder lines belong to the middle and upper classes of the society. As a result of their socio-political status, they are believed to be able to wield influence to ensure that the feeder lines receive much more attention and care, in terms of regular preventive maintenance and power supply than customers in the lower rungs of the society. The relevant parameters of the feeder lines are shown in Table-1.

Table-1. Parameters of 11KV feeder lines selected for failure distribution analysis.

Name of feeder line	**Length** (km)	**Load** (Amps)	**Load classification**
Secretariat (Ibadan)	16.00	300.0	High density residential
GRA (Abeokuta)	12.00	260.0	High density residential
Oke-Eda (Akure)	7.00	300.0	High density residential
GRA (Osogbo)	7.50	290.0	High density residential

2. METHODOLOGY

The data on the feeder lines were obtained from the log books kept in the undertaking offices of the Power Holding Company of Nigeria (PHCN). In each case, the data included the time failure occurred on the feeder line, the nature of fault, the steps taken to clear the fault, and the time when fault was cleared. The times between failures within a period of two years were extracted from the log book data.

The cumulative frequency plot of the times between failures on each feeder line was prepared so as to have a first indication about their distribution. An exponential least squares plot was then obtained to support the indication of exponential distribution given by the frequency polygon. The exponential distribution of the times between failures data was confirmed using Bartlett's Test and the Maximum Likelihood Estimate of the failure rate (λ) parameter were obtained.

3. ANALYSIS AND RESULTS

3.1 Least square plots

The plots of time between failures distribution and the least squares plots of time between failures on the feeder lines are as shown in Figures, 1.1 to Figures, 1.4 and Figures 2.1 to Figures, 2.4 below. Observe that the cumulative frequency plots are approximately exponential. From the least square plots the failure rates of the feeder lines are as shown in Table-2.

Table-2. Failure rate of feeder lines from least square plots.

Name of feeder line	**Failure rate** (λ)
Secretariat (Ibadan)	0.0076 failures per hour
G.R.A (Abeokuta)	0.0315 failures per hour
Oke-Eda (Akure)	0.0175 failures per hour
G.R.A. (Oshogbo)	0.0050 failures per hour

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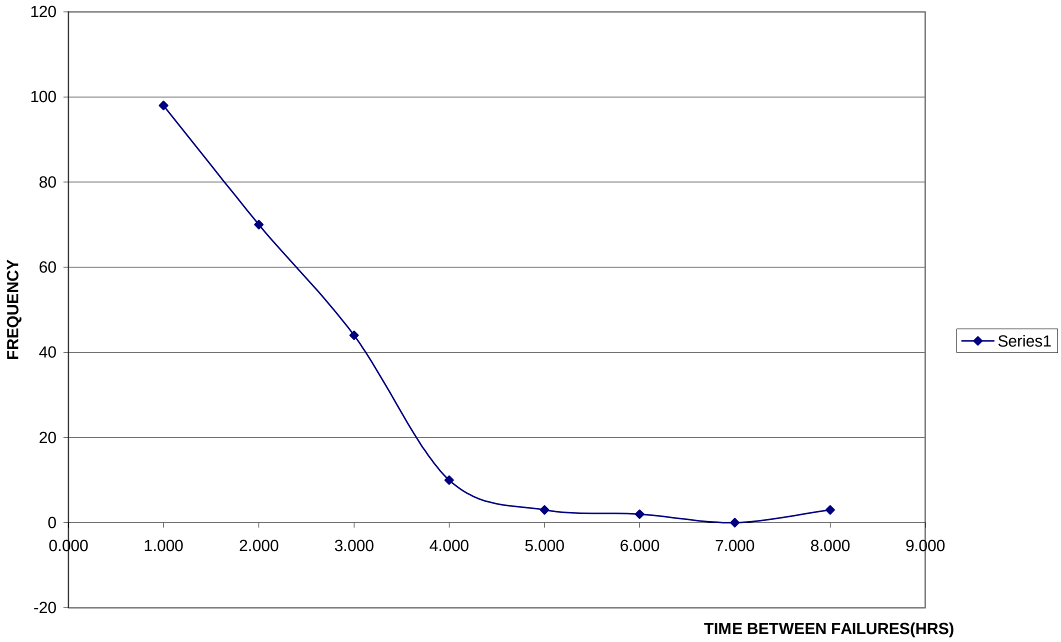

FIG. 1.1: PLOTS OF TIME BETWEEN FAILURES DISTRIBUTION ON ABEOKUTA FEEDER LINE

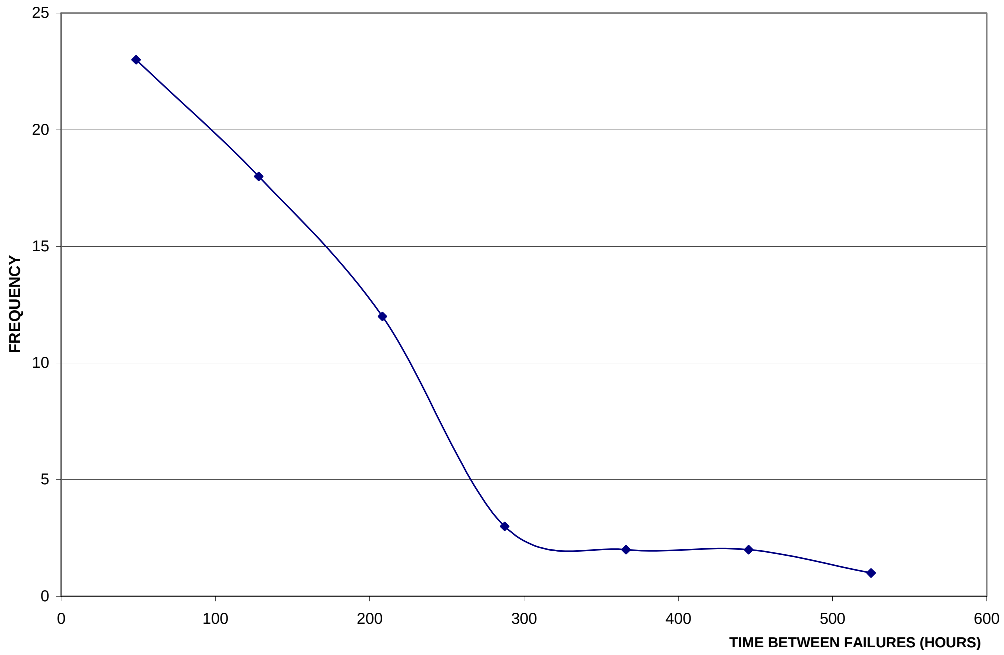

FIG.1.2: PLOTS OF TIME BETWEEN FAILURES DISTRBUTION ON SECRETARIAT(IBADAN) FEEDER

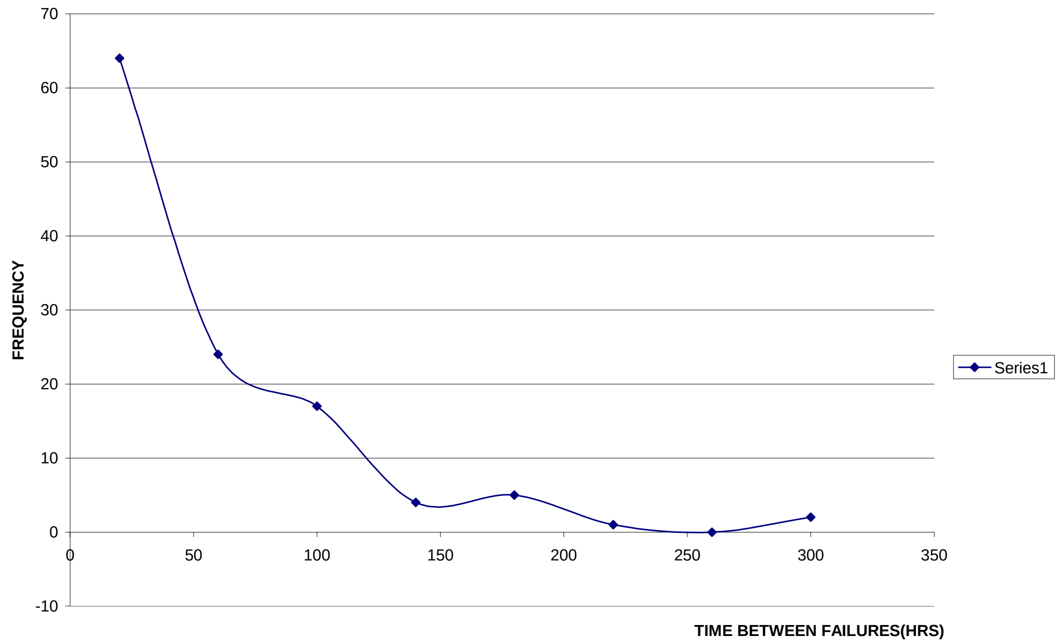

FIG. 1.3: PLOTS OF TIME BETWEEN FAILURES DISTRIBUTION ON OKE-EDA FEEDER LINE

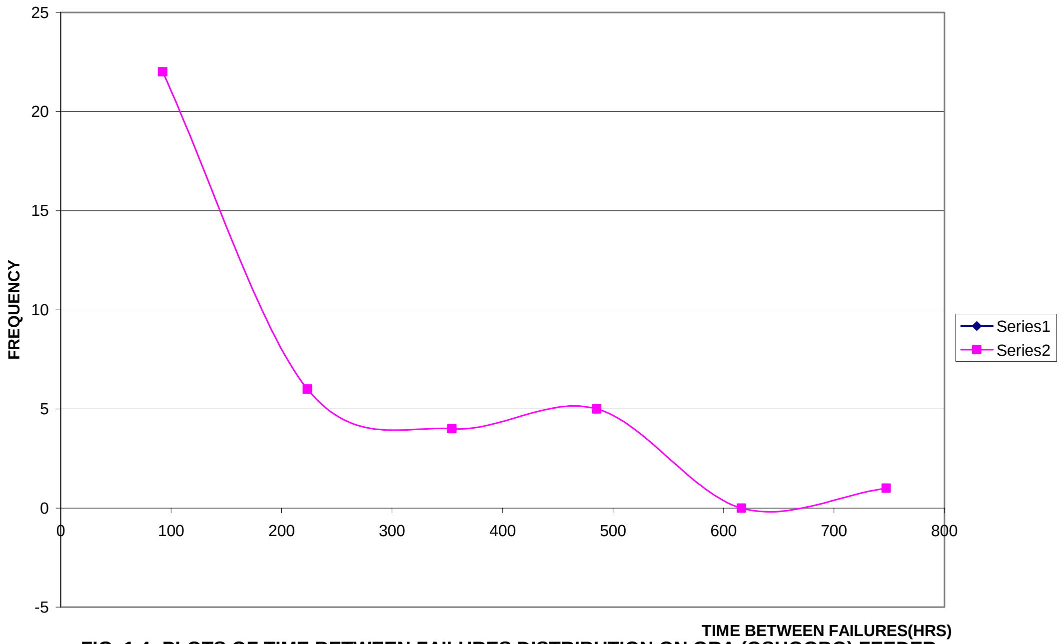

FIG. 1.4: PLOTS OF TIME BETWEEN FAILURES DISTRIBUTION ON GRA (OSHOGBO) FEEDER LINE

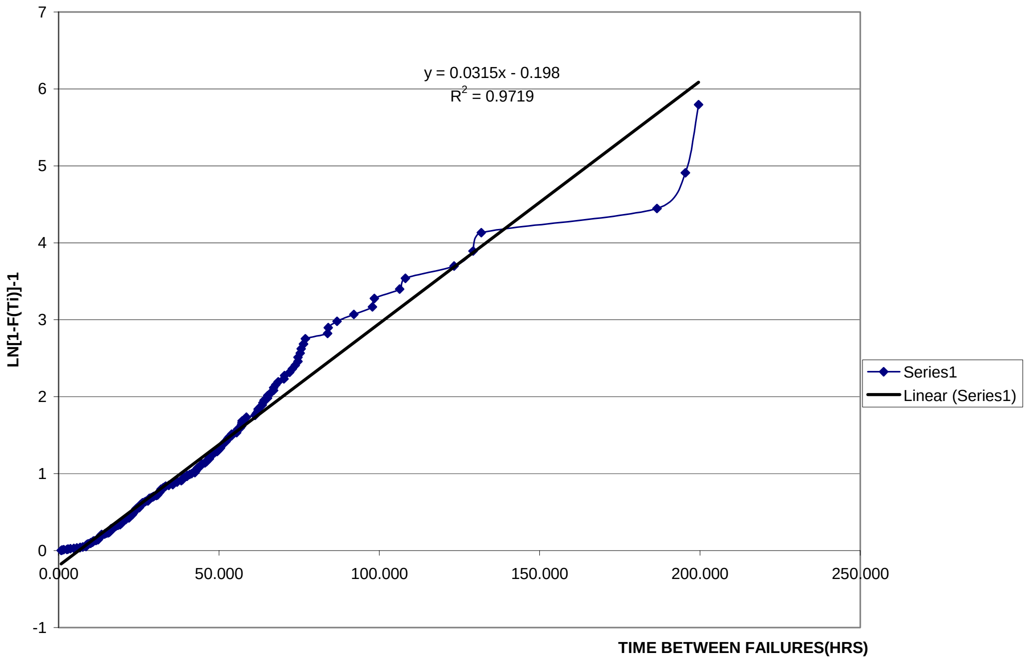

FIG.2.1 LEAST SQUARES PLOT OF TIME BETWEEN FAILURES ON ABEOKUTA FEEDER LINE

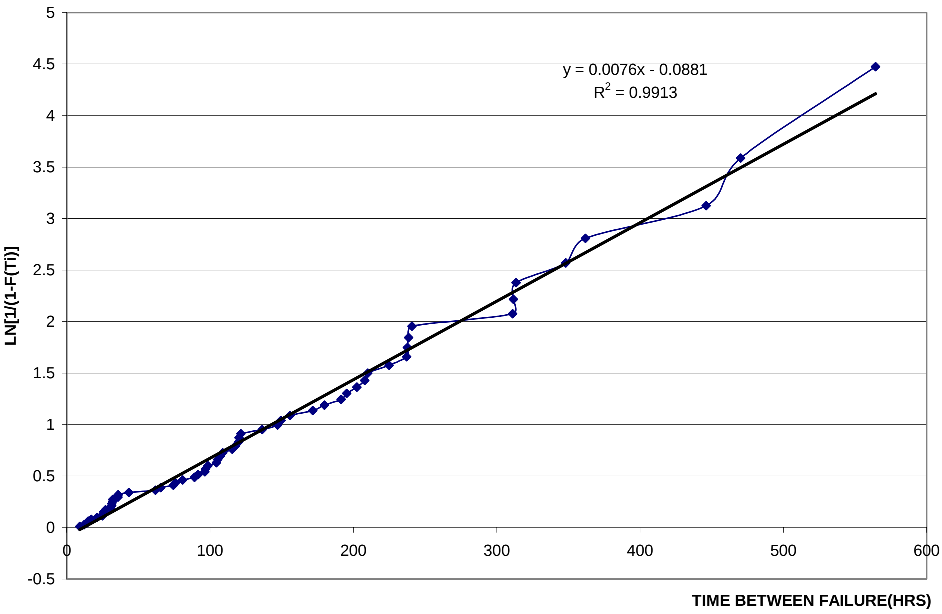

FIG. 2.2: LEAST SQUARES PLOT OF TIME BETWEEN FAILURES ON SECRETARIAT (IBADAN) FEEDER LINE

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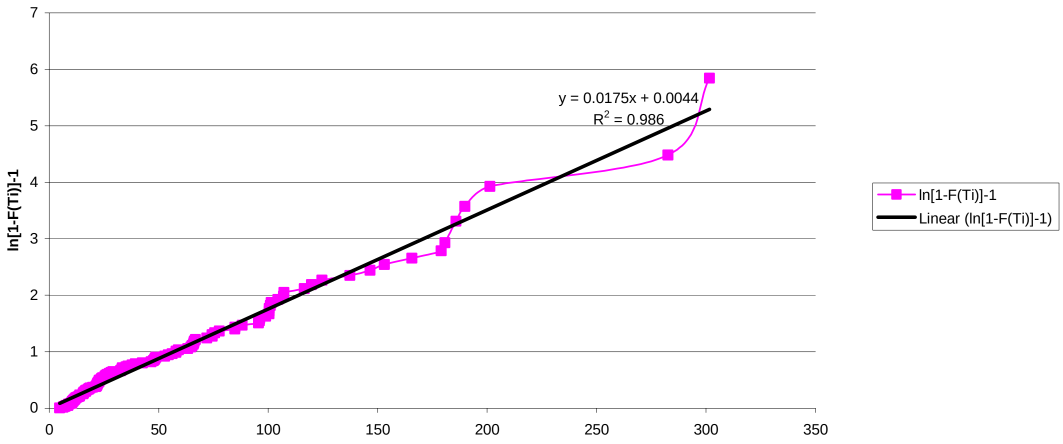

FIG.2.3: LEAST SQUARE PLOT FOR OKE-EDA FEEDER LINE FAILURE DATA

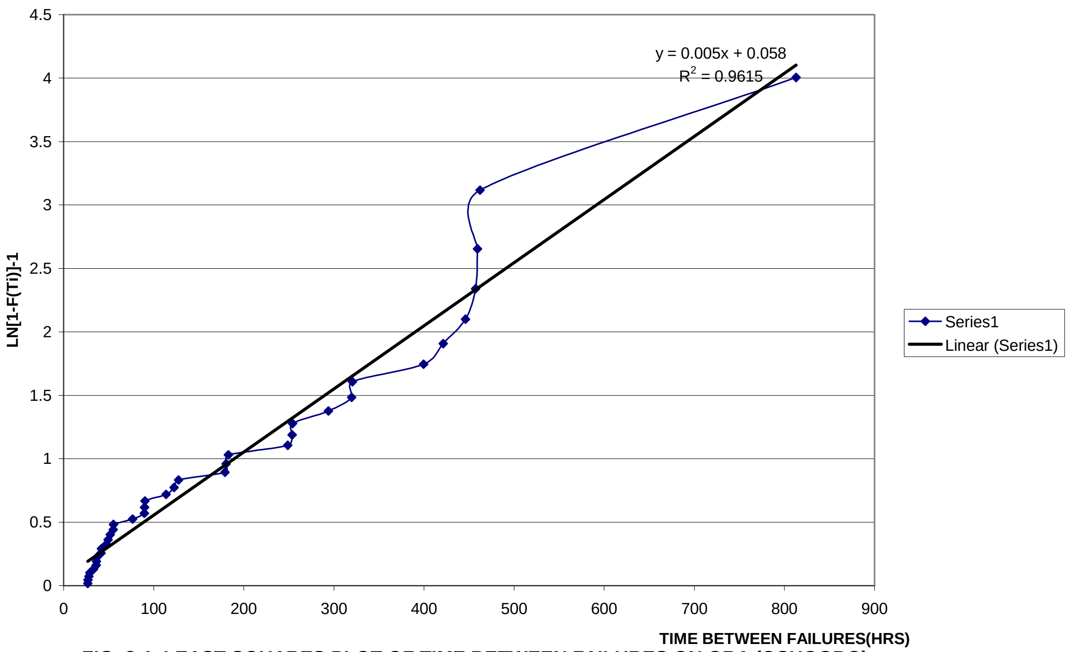

FIG. 2.4: LEAST SQUARES PLOT OF TIME BETWEEN FAILURES ON GRA (OSHOGBO) FEEDER LINE

3.2 Bartlett's test for exponential distribution

Null hypothesis:

H_0: Failure times are exponential

Alternate hypothesis:

H_1: Failure times are not exponential

The test statistic β is given by:

$$\beta = \frac{2r\left[\ln\left\{\left(\frac{1}{r}\right)\sum_{i=1}^{r} t_i\right\} - \left(\frac{1}{r}\right)\sum_{i=1}^{r}\ln t_i\right]}{1+\frac{(r+1)}{6r}} \quad (9)$$

where, t_i is the time between failure at the i^{th} rank, and r is the number of failures [2].

The test statistic β under the null hypothesis has a chi-square distribution with $r-1$ degrees of freedom.

In the test, if $x^2_{1-\frac{a}{2},r-1} < \beta < x^2_{\frac{a}{2},r-1}$

The null hypothesis is accepted at α% confidence level; otherwise the alternate hypothesis is accepted [2]. The application of Bartlette's test to the data on the feeder lines gives the following results:

Secretariat (Ibadan) Feeder line:

$$r = 61, \sum t_i = 856.8, \sum \ln t_i = 275.45$$

$$\therefore \quad \beta = 53.54$$

At 10% confidence from Chi-Square tables

$x^2_{0.95,60} = 79.1$

$x^2_{0.05,60} = 43.2$

$\therefore \quad x^2_{0.05,60} < \beta < x^2_{0.95,60}$

Therefore, the times between failures are exponentially distributed and the null hypothesis is accepted.

GRA (Abeokuta) Feeder line:

$r = 230, \sum t_i = 8706.8, \sum \ln t_i = 766.2$

. $\beta = 120.48$

At 10% confidence from Chi-Square tables

$x^2_{0.95,229} = 264.5$

$x^2_{0.05,229} = 176.7$

The condition $x^2_{0.05,229} < \beta < x^2_{0.95,229}$ is not satisfied here. Therefore, the times between failures are not exponentially distributed and the alternate hypothesis is accepted.

Oke-Eda (Akure) Feeder line:

$r = 117, \sum t_i = 6610.38, \sum \ln t_i = 419.17$

$\beta = 93.29$

At 10% confidence from Chi-Square tables

$x^2_{0.95,116} = 141.77$

$x^2_{0.05,116} = 79.6$

$\therefore \quad x^2_{0.05,116} < \beta < x^2_{0.95,116}$

Therefore, the times between failures are exponentially distributed and the null hypothesis is accepted.

GRA (Osogbo) Feeder line:

$r = 38, \sum t_i = 6998.4, \sum \ln t_i = 179.65$

$\beta = 34.3$

At 10% confidence from Chi-Square tables

$x^2_{0.95,37} = 55.8$

$x^2_{0.05,37} = 26.5$

$\therefore \quad x^2_{0.05,37} < \beta < x^2_{0.95,37}$

Therefore, the times between failures are exponentially distributed and the null hypothesis is accepted.

3.3 Maximum likelihood estimate (MLE) of failure rate

The MLE of failure rate (λ) for exponential distribution is given by

$$\lambda = \frac{r}{\sum t_i}$$

where r is the number of failure occurrences and t_i is the time between failure at the i^{th} rank. The MLE of failure rates of the feeder lines and the reliability findings are hereby calculated as follows:

Secretariat (Ibadan) Feeder Line:

$$\lambda = \frac{r}{\sum t_i} = \frac{61}{8568.79.} = 0.00712 \quad \left(f/hr \right)$$

GRA (Abeokuta) Feeder Line:

$$\lambda = \frac{r}{\sum t_i} = \frac{230}{8706.78} = 0.026 \quad \left(f/hr \right)$$

Oke-Eda (Akure) Feeder Line:

$$\lambda = \frac{r}{\sum t_i} = \frac{117}{6610.37} = 0.0177 \quad \left(f/hr \right)$$

GRA (Osogbo) Feeder Line:

$$\lambda = \frac{r}{\sum t_i} = \frac{38}{6998.4} = 0.00543 \quad \left(f/hr \right)$$

Observe that the value of λ obtained in each case here compares with the one obtained earlier from the slope of the least square plots.

3.4 Reliability functions and values of the selected feeder lines

For an exponentially distributed times between failure data, the reliability function $R(t)$ is given by

$$R(t) = e^{-\lambda t} \tag{10}$$

where λ is the failure rate and is constant. With the failure rate parameter determined for each of these feeder lines, the reliability function is completely specified and given as follows for each of the feeder lines.

Secretariat (Ibadan) Feeder Line:

$\lambda = 0.00712 \quad \left(f/hr \right)$

$\therefore \quad R(t) = e^{-0.00712\, t}$

GRA (Abeokuta) Feeder Line:

$\lambda = 0.026 \quad \left(f/hr \right)$

$\therefore \quad R(t) = e^{-0.026\, t}$

Oke-Eda (Akure) Feeder Line:

$$\lambda = 0.0177 \quad \left(f/hr \right)$$

$$\therefore \quad R(t) = e^{-0.0177\,t}$$

GRA (Osogbo) Feeder Line:

$$\lambda = 0.00543 \quad \left(f/hr \right)$$

$$\therefore \quad R(t) = e^{-0.00543\,t}$$

Each of the models is valid when all environmental and operational cum management factors remain unchanged.

4. CONCLUSIONS

The study indicates that distribution feeder lines failures exhibit exponential distribution which is characterized by constant failure rate and completely random and independent failure times. This condition occurs when a component or system is in the useful life period having been operated beyond the infant mortality stage and is yet to get into the wear out stage.

Under this condition, the probability that the system will not fail is independent of how long it has been in operation. Specifically, the probability that the system will not fail within a given time t is independent of its age and the probability that the component or system will operate for the next t hours is a constant, where t is a variable. This is the "memoryless" situation in which the system does not "accumulate stress effects" It is logical to assume that the situation can only be sustained by regular preventive maintenance which ensures that degrading units are replaced before failure occurs.

The reliability $R(t)$ in terms of failure rate, λ, and $MTBF$, is given by:

$$R(t) = e^{-\lambda t} = e^{-\frac{t}{MTBF}} \qquad (11)$$

Hence the reliability for a mission time that is equal to the MTBF, denoted by.

$R(MTBF)$, is given by:

$R(MTBF) = e^{-\frac{MTBF}{MTBF}} = e^{-1} = 0.368.$ It follows therefore that a component or system having a constant failure rate has 36.8% chance of surviving a mission time equal to its MTBF.

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