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Reliability Analysis of Generator Shaft

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Abstract In this work, the aim is to carry out reliability analysis of generator shaft components of various companies used in Nigeria. The generator shaft components were analyzed using Monte Carlo model of reliability tool and techniques for evaluating reliability, unreliability, availability and to also determine number of failure (NF), corrective time per failure (CTPE), mean time between failure (MTBF), failure rate (FR), loss time per year (LTPY), gross margin, scrap disposal cost and breakdown maintenance cost. Key results of this research work show that reliability of components decreases with increase in utilization time. In comparison, the reliability and unreliability values were within the range of 71.7% to 13.5% and 28.3% to 86.5% for company A, B and D whereas 84.6% to 36.7% and 15.4% to 48.7% for company C and E respectively for half a year to three years of studies. From the comparison, these results revealed that the generator shaft components from company C and E has the highest reliability and is better than other shaft products used by other companies. This sought of analysis will aid the user in decision making on the make of generator shaft to buy. The benefits of the result of this research work is to provide generator end users with sound engineering options when considering buying a generator shaft from manufacturers with emphasis on reliability, quality of spare components, availability with low failure rates, affordable, easy to replace at minimal maintenance cost and time.

Keywords Reliability, shaft, analysis, generator, tools, techniques

Introduction

The problem associated with component failures are enormous, frequent failure of generator components in our environment and its consequent effect on the Nigeria economy has resulted in adverse economic effect in world operational cost and other reasons. Quality, utilization approach, that is, effect resulting from poor installation and usage, substandard products, expired products and poor maintenance concepts are some known common causes of failures of components. In any of these instances, the generator components may loss its efficiency and performance, after failure has been initiated, the failed components are predominantly observed to be the major problem that reduces the output of the generator efficiency. These failed components have serious adverse effect on the generator life and to those that depend on such generator for their livelihood. These failures could be corrected through mechanical processes [1-2].

Similarly, there are methods used in detecting faults in engines, which includes manual or mechanical methods. Growing in safety and environmental demands are forcing industries to look for more powerful and new techniques for detection of process faults [3]. A fault is defined as an unexpected change of the system functionality which may be related to a failure in physical component or in a system, sensor or actuator. The early detection and isolation of faults in engineering and industrial systems is a critical factor for avoiding product deterioration, major damage to machinery, loss of production, performance degradation, poor plant economy, environmental pollution and damage to human health or ever loss of life [4-5].

Fault Detection and Isolation (FDI) is an active area of research due to growing demand for safety and reliability and increasing complexity of process plants. Many FDI techniques have been proposed in the literature. These techniques can in general be classified as model based approaches, data-driven approaches, logic based or information flow graphs, hardware redundancy, knowledge based system and analytical redundancy techniques [6-7]. Research activities in these areas have shown that there are beneficial fault detectors system which can be used in generator components failure [8]. Recent studies showed that generator components failure when subjected to FDI process indicate that several properties of generator components are affected such as qualitative and quantitative changes from the initial characteristics due to work load and utilization [9-11].

The action of analysis of different generator shaft components using reliability tools and techniques has attracted the interest of researchers in recent years. The reason was to check increasing rate of failure of shaft components and quality of components installed by various operating companies within Nigeria and the cost implication to the Nigeria economy.

Downtime can significantly affect plant wide operations, for example, failure of shaft can cause the entire plant to stop functioning. In order to ensure reliable operations, improvement analyses are usually carried out in order to identify critical components that can significantly affect generator components performance and device.

Change management policies for critical components often focuses on effective inventory, spares and preventive maintenance management, but beside these, reliability related improvement efforts are made, the reliability of different generator components are considered in evaluating the impact of capital investment. New and improved equipment does not always translate into improved reliability and evaluating the performance of manufacturing system in presence of failure prone components is a non trivial task [12].

The aim of this research is to carry out reliability analysis of some shaft components of various generator make and used in Nigeria environment.

Materials and Methods

Reliability Tools and Techniques Methodology

There are many reliability tools and techniques methodologies available for failure of plant components. For the one case study described herein, we have the Monte Carlo Reliability models which can realistically assess plant conditions when combined with cost, repair time and statistical events. Monte Carlo simulation model is very helpful for considering approximate operating conditions in a plant including cost effectiveness and sizing to provide protection for short duration failures.

Reliability model stimulate creative ideas for solving costly problems and prevents replication of old problems. Reliability models offer a scientific method for studying actions, responses and costs in the virtual laboratory of the computer using actual failure data from existing plants. It is noted that the Monte Carlo Model is never better than the data supplied or obtained as a result of failures that occurs.

The Monte Carlo provide a way to search for lowest cost operating alternatives and conditions by predicting the outcome of events and equipment. Monte Carlo model aids in finding the lowest long term cost of ownership.

Mathematical Language of Reliability

The following approaches were used in resolving the analysis of generator components using reliability tools and techniques

- Start reliability improvement program with simple arithmetic and spreadsheets to quantify important cost and failure numbers.
- Gaining momentum with good maintenance practices will improve team work using total productive maintenance program such as root cause analysis to efficiently solve problems.
- The application on improvement of program by using statistics to quantify the results.
- Application of Monte Carlo model to simulate generator components availability, reliability, maintainability, capability and life cycle costing for deciding reliability strategies.

Model Formulation and Development

The mathematical model for this research was established by considering three years study interval (SI) as well as the number of failures (NF) and the corrective time per failure (CTPE).

Mean Time between Failures (MTBF)

Mean time between failures (MTBF) for the generator shaft component was evaluated using the mathematical expression given below:

$$(MTBF) = \frac{SI}{NF} \quad (1)$$

Total mean time between failures

To determine the total mean time between failures (TMTBF) for the five company's generator components under investigation. We must first establish the total failures per year (TFPy) of the five company's generator shaft components under assessment. Thus:

Total failures per year (TFPy) =

$$\left[\left(\frac{1}{MTBF}\right)_A + \left(\frac{1}{MTBF}\right)_B + \left(\frac{1}{MTDF}\right)_C + \left(\frac{1}{MTBF}\right)_D + \left(\frac{1}{MTBF}\right)_E\right] x \ Annual\ hours\ per\ year \quad (2)$$

Therefore, the total mean time between failures (TMTBF) for generator shaft component is expressed as:

$$\text{TMTBF} = \frac{Annual\ hours\ per\ year}{Total\ failures\ per\ year} = \frac{AHPy}{TFPy} \quad (3)$$

Failure Rate

To determine the failure rate for each generator component, the mathematical expression stated below can be applied, thus:

$$FR = \frac{1}{MTBF} = \frac{1}{SI/NF} = \frac{NF}{SI} \quad (4)$$

For the various companies generator shaft components investigated the mathematical expression is applied in the form of,

$$(FR)_A = \left(\frac{1}{MTBF}\right)_A = \left(\frac{NF}{SI}\right)_A \quad (5)$$

Total Failure Rate (TFR)

The total failure rate (TFR) is determined by the summation of each failure rate of companies generator shaft components investigated is expressed mathematically as:

$$\text{TFR} = \left[(FR)_A + (FR)_B + (FR)_c + (FR)_D + (FR)_E\right] \quad (6)$$

Block Diagram of each Company Generator Component

The flow diagram for each company generator shaft component is illustrated in Figure 1

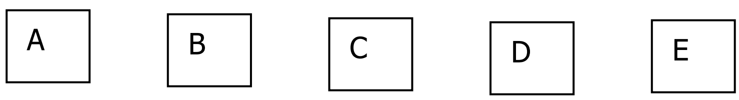

Figure 1: Block Diagram for each Companies Generator Shaft Component

Mathematical Model on Functional Parameters of Generator Components Failure

To determine the time lost from unreliability per year of the generator components for each company generator components is as follows:

Failures Per Year (FPy)

To determine the failures per year (FPy) for each generator shaft component investigated, the following mathematical expression is applied, thus:

FPy = [failure rate for each product] x [annual hours per year] (7)

FPY = (FR) (AHPy) (8)

$$FPy = \left(\frac{NF}{SI}\right)(AHPy) \quad (9)$$

$$FPY = \left(\frac{1}{MTBF}\right)|AHPy| \quad (10)$$

Total failure per year (TFPy)

Therefore the total failure per year (TFPy) is the summation of failure per year (FPy) for the each company generator component investigated, thus:

$$TFPy = \Sigma(FPy)_A + (FPy)_B + (FPy)_C + (FPy)_D + (FPy)_E \quad (11)$$

Total Corrective Time Per Failure (TCTPF)

The total corrective time per failure (TCTPF) is determined using the mathematical expression as shown below, thus:

$$(TCTPF) = \frac{Corrective\ time\ per\ Failure\ of\ each\ product\ x\ failures\ per\ year\ of\ each\ product}{Total\ failure\ per\ year}$$

$$Thus\,(TCTPF) = \frac{(CTPF)_A(FPy)_A + (CTPF)_B(FPy)_B + (CTPF)_C(FPy)_C + (CTPF)_D(FPy)_D + (CTPF)_E(FPy)_E}{(TFPy)} \quad (12)$$

Lost Time Per Year (LTPy)

To determine the lost time per year (LTPy) for each company generator shaft component, the mathematical expression stated below can be applied, thus:

$$LTPy = [failures\ of\ each\ product\ per\ year]\ x\ [Corrective\ time\ failure\ for\ each\ product] \quad (13)$$

Total Lost Time Per Year (TLTPy)

The total lost time per year (TLTPy) is calculated using the mathematical expression stated below, thus:

$(TLTPy) = (LTPy)_A + (LTPy)_B + (LTPy)_C + (LTPy)_D + (LTPy)_E$ (14)

The Block Diagram Time Lost from Unreliability

The block diagram of function and generator components time lost from unreliability is presented in Figure 2

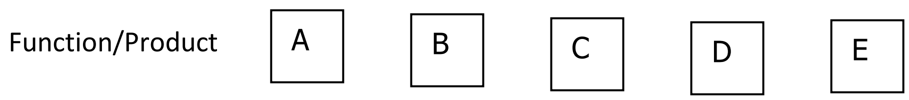

Figure 2: Block Diagram for Generator Shaft Components Time lost from unreliability

Time Lost From Unreliability

To determine the cost of unreliability for each company shaft component, the following functions will be evaluated such as (i) gross margin (ii) total gross margin, (iii) scrap disposal (iv) total scrap disposal (v) break down maintenance (vi) total breakdown maintenance (vii) total lost cost of each component and (viii) total lost cost of components investigated.

Gross Margin (GM)

Gross Margin (GM) is evaluated by applying the mathematical expression given as:

GM = [lost time per year (LTPy)] x [lost gross margin $ x hour] (15)

Therefore.

GM = (LTPy) (lost gross margin of $ x per hour] (16)

Total Gross Margin (TGM)

To determine total gross margin (TGM), the following mathematical expression can be used such as:

$$(TGM) = [(LTPy)\ (LGM\ at\ \$\ x\ per\ hour)]_A + [(LTPy)\ (LGM\ at\ \$\ x\ per\ hour)]_B + [(LTPy)\ (LGM\ at\ \$\ x\ per\ hour)]_C + [(LTPy)\ (LGM\ at\ \$\ x\ per\ hour)]_D + [(LTPy)\ (LGM\ at\ \$\ x\ per\ hour)]_E \quad (17)$$

Scrap Disposal Cost Per Incident (SDCPI)

Scrap disposal cost per incident (SDCPI) is evaluated using the mathematical expression below:

$$SDCPI = \begin{bmatrix} Filure\ per\ year\ (FPy) \\ for\ each\ product \end{bmatrix} \begin{bmatrix} Scrap\ disposal\ \cos t \\ of\ \$Z\ per\ incident \end{bmatrix} \quad (18)$$

Breakdown Maintenance Cost (TBdMC)

Breakdown maintenance cost per incident (BdMC) is evaluated using the mathematical expression below:

$$BdMC = \frac{Gross\ M\arg in\ x\ Scrap\ Disposal\ Cost}{Total\ Breakdown\ Ma\operatorname{int} enace\ Cost} \quad (19)$$

Total Breakdown Maintenance Cost (TBdMC)

To determine the total breakdown maintenance cost (TBdMC) for various companies generator components investigated, we have

$$TBdMC = (BdMC)_A + (BdMC)_B + (BdMC)_C + (BdMC)_D + (BdMC)_E \quad (20)$$

Total Lost Cost (TLC)

To determine total lost cost (TLC) for various companies generator components investigated, we have

$$(TLC)A = (GMC)A + (SDC)A + (BdMC)A \quad (21)$$

Block Diagram of Losses Per Company Generator Components

The block diagram of losses per company generator shaft is illustrated in Figure 3.

Losses/Product

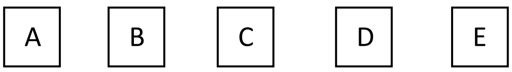

Figure 3: Block Diagram of Losses per Company Generator Components

Reliability, Unreliability and Availability Model

Reliability Model

To determine the generator shaft components reliability (GSCR) the equation used is expressed mathematically as:

$$GSCR = \ell^{-}\left(\frac{1}{MTBF}\right)xt \quad (22)$$

Whereas for the various companies generator shaft components investigated, the reliability is determined by the summation of each company generator component reliability, as stated below,

$$BR = \ell^{-}\left(\frac{1}{MTBF}\right)_A + \left(\frac{1}{MTBF}\right)_B + \left(\frac{1}{MTBF}\right)_C + \left(\frac{1}{MTBF}\right)_D + \left(\frac{1}{MTBF}\right)_E\ xt \quad (23)$$

Where BR represent GSCR

Unreliability Model

To determine the generator shaft components unreliability (GSCUR) we use the expressed:

$$BU = 1 - \ell^{-}\left(\frac{1}{MTBF}\right)_{T} xt \quad (24)$$

Where BU represent GSCUR

Availability Model

To determine the generator components availability (GCAV) we have:

$$GCAV = \frac{Mean\,Time\,between\ Failure - Lost\,Time\,Per\ year}{Mean\,Time\,between\ Failure} \quad (25)$$

Data Collection on Failures of Generator Shaft Components

This study was inspired by using some generator manufacturers' models as a case study. The number of failure was obtained from the various companies generator set plant maintenance checklist and spread sheet data covering the period of 1st January, 2014 to 31st December, 2016. The generator shaft components of common interest were chosen for the investigation.

Samples for the investigation were collected from five different companies located in Port Harcourt in Rivers State of Nigeria. The data collected was evaluated using the necessary engineering tools and techniques in the determination of the time lost from unreliability, the cost of unreliability and annual availability, reliability and unreliability.

Root Cause Analysis (RCA) of Generator Shaft Component

There are many RCA methodologies available for failure events investigation. For the two case studies describe herein, we have the structured methodology originally developed by Apollo Associated Services [13] which is designed to minimize personal bias and maximize solution oriented thinking, stating an event problem definition statement based on a meticulous evidence data gathering and managing process – followed by a detailed cause effect tree analysis and finalizing with a complete investigation report which indicates the most effective solutions, including preventive and corrective actions to modify or prevent causes to avoid the event repetition. This methodology is associated with software for the graphic cause-effect analysis representation, evident capture and report facilitation. This methodology is based on the most accepted failure theory, which demonstrates that any failure event is based on multiple causes and each single event or effect is a consequence of a group of immediate causes occurring at the same time and place Alessandri, [9]. These causes can be understood as a group of specific conditions set in motion by an action or behaviour. In addition to the operational and physical aspects involved in the failure event, a complete and structured RCA methodology shall take into consideration all types of possible causes [14], especially regarding behaviour based aspects [15], like psychological conditions, human errors [16] and operational discipline aspects [17].

Event Description

The investigation data inventory covers the period of 1st January, 2014 to 31st December 2016, by considering a normal generator set of 100KVA in operation, failures during operation produces unexpected sound, as well as stop the base load causing immediate generator set shutdown. The generator maintenance team with a troubleshooting device and technical support personnel examine the failed components.

During the abnormal shutdown, the control monitoring system demonstrates a discharge pressure decrease, followed by a decrease in suction pressure and combustion fuel system. It was also observed that the radiator water temperature increased which lead to the malfunctioning and automatic shutdown of the generator. All the generator components considered in this research work can cause such effect. It was also observed that vibration oscillation can cause failure since the generator components investigated in this research work undergoes rotational motion which is influenced by fractional force when installed for operation.

Results and Discussion

The results obtained from the investigation are presented in Figures 1 to 4 and Tables A1, whereas results in Tables are shown in the appendix.

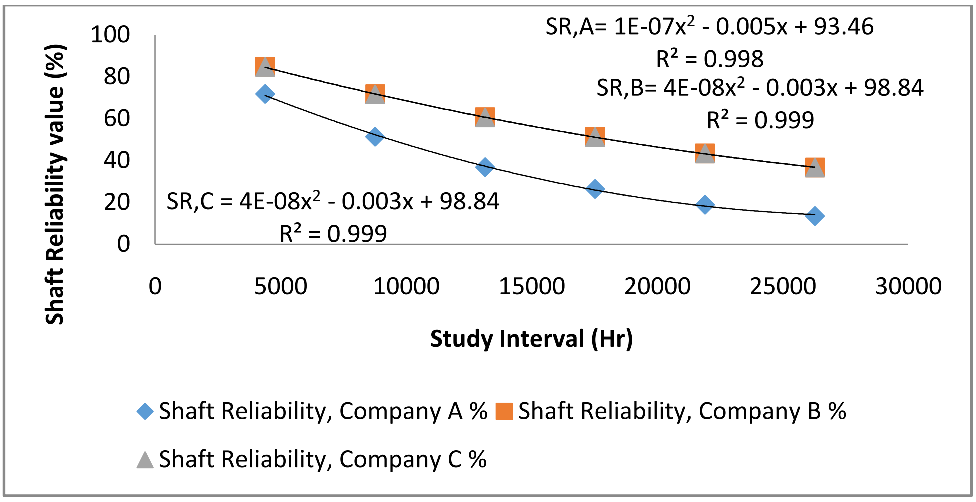

Figure 1: Plot of Shaft Reliability of Company A, B and C against Study Interval

Figure 1 illustrates the relationship between the shaft component reliability of company A, B and C for study interval. The generated polynomial equations can be found useful in monitoring, predicting and simulating the shaft reliability for company A, B and C. The equation of best fit and square root of the curve is expressed as SRA= $1E\text{-}07x^2 - 0.005x + 93.46$ with $R^2 = 0.998$ for company A, SRB= $4E\text{-}08x^2 - 0.003x + 98.84$ with $R^2 = 0.999$ for company B and SRC = $4E\text{-}08x^2 - 0.003x + 98.84$ with $R^2 = 0.999$ for company C. For company A, B and C the reliability of shaft component decreases with increase in study interval (aging). Company C and B has the same level of reliability whereas company A reliability is lower.

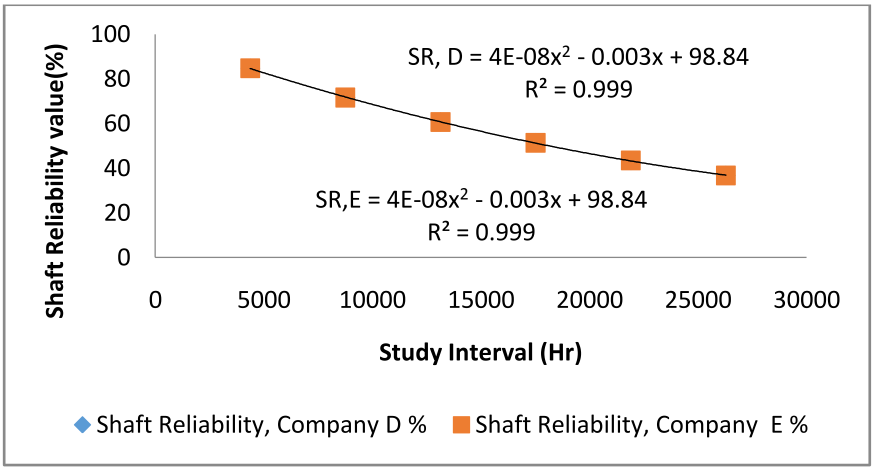

Figure 2: Plot of Shaft Reliability of Company D and E against Study Interval

Figure 2 illustrates the relationship between the shaft component reliability of company D and E for the study interval of the assessment. The generated polynomial equations of company D and E are the same and the obtained mathematical expression can be used in monitoring, predicting and simulating the reliability of company D and E generator components. The equation of best fit and the square root of the curve is expressed as, SRD = $4E\text{-}08x^2 - 0.003x + 98.84$ with the $R^2 = 0.999$ and SRE = $4E\text{-}08x^2 - 0.003x + 98.84$ with the $R^2 = 0.999$ for company D and E as shown in Figure 4.18. The reliability of shaft component decreases with increase in study interval (aging as a contributing factor). Company D and E has the same degree of reliability since their analyses gives the same results.

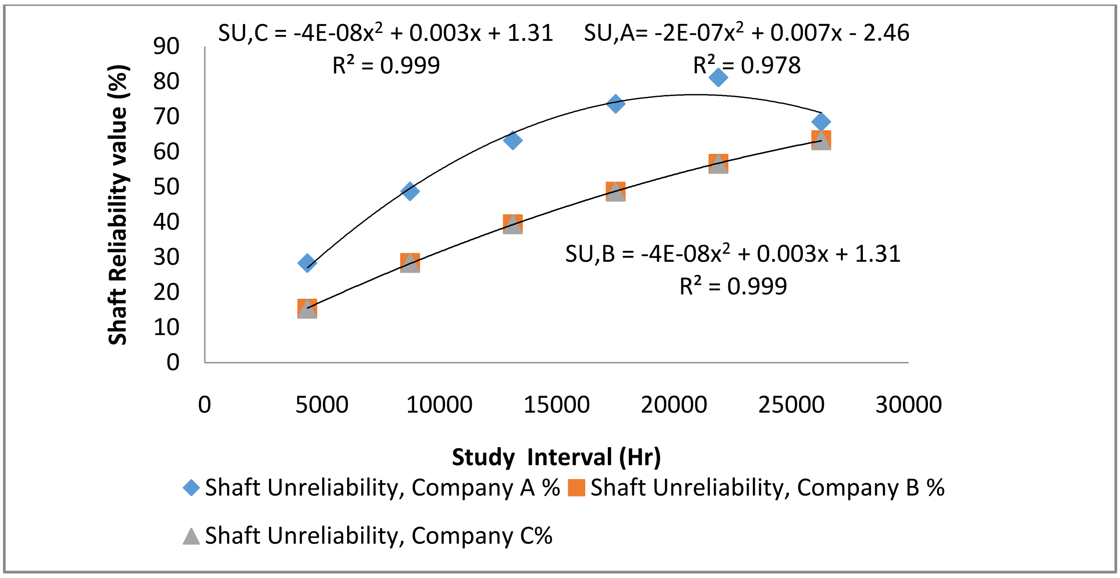

Figure 3: Plot of Shaft Unreliability of Company A, B and C against Study Interval

Figure 3 illustrates increase in unreliability of the shaft component with increase in study interval. From Figure 3 it is seen that the efficiency or performance of the generator company components assessed increases with respect to increase in study interval (aging) as well as the utilization period. The regression model obtained is found useful in monitoring, predicting and simulating the bearing unreliability for the following company A, B and C. The applicable equations for best fit for company A, B and C is given as SU A= $-2E\text{-}07x^2 + 0.007x - 2.46$ with $R^2 = 0.978$ for company A, SUB = $-4E\text{-}08x^2 + 0.003x + 1.31$with $R^2 = 0.999$ for company B and SUC = $-4E\text{-}08x^2 + 0.003x + 1.31$with $R^2 = 0.999$ for company C.

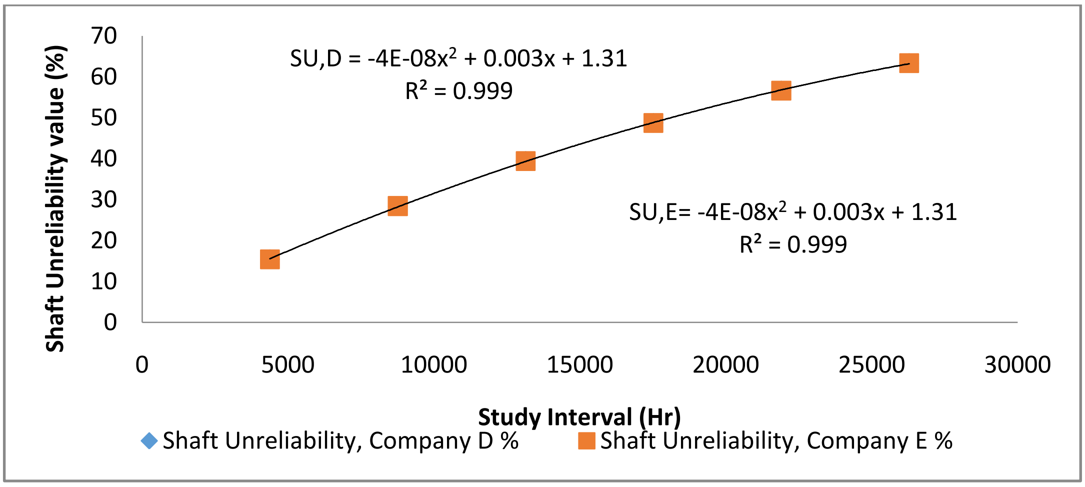

Figure 4: Plot of Shaft Unreliability of Company D and E against Study Interval

From Figure 4 it is observed that the degree of unreliability of the shaft component increases with increase in study interval (increase in aging). Figure 4 indicates that the efficiency or performance of the generator company assessed reduces with respect to increase in study interval (aging). The regression model obtained from the investigation can be found useful in monitoring, predicting and simulating the bearing unreliability for company D and E. The applicable equations for best fit for company D and E is given as SUD = $-4E\text{-}08x^2 + 0.003x + 1.31$ with $R^2 = 0.998$ for company D and SUE= $-4E\text{-}08x^2 + 0.003x + 1.31$ $R^2 = 0.999$ for company E.

Conclusion

The results show that the generator component from company C and E has the highest reliability and is better than bearings from other companies.

Also, the result shows that company E made more profit, followed by company C whereas company A, B and D has low gross margin profit when compared with the gross margin profit of company C and E. This means replacing the failed generator shaft components with company C and E will usually cost more money in terms of maintenance. Increase in scrap generated increases the cost of scrap disposal and financial involvement experienced by the various companies are in the following order of magnitude, such as, company E components > company C components > company A components > company B components > company D components

The study presented here affirmed that the aims and objectives have been achieved with some key results using the Monte Carlo model for evaluating the reliability, unreliability and availability of failed generator shaft components. The method allows determination of failure rate, mean time between failures, failure per year, corrective time per failures, lost time per year, gross margin, scrap disposal cost, breakdown maintenance for the various generator shaft components of various companies used in Nigeria.

The analysis of generator components shows that the reliability tools and techniques method adopted in this study allows considerable justification in computing reliability, unreliability and availability as well as the functional parameters that determine generator shaft components quality and man hour lost for repair of failed shaft components. Decrease in reliability with corresponding increase in study interval, as well as increase in unreliability with corresponding increase in study interval was observed for all the shaft components considered in this research work. The reliability tools and techniques approach adopted is a model based concepts for monitoring and predicting the controlling factors that influence failure, quality of components and cost implication. However, in practical applications especially when considering multiple generator components failure or a complex failure system, the straight forward application of such reliability tools and techniques may be difficult to give a good judgment of generator components reliability.

Contribution to Knowledge

Research work in this area may have been previously conducted. However, the contribution of this research work may go a long way in addressing some of the existing knowledge gaps, this will provide relevant information for prospective buyers of generator shaft to decide on what generator make to buy in terms of reliability, cost effectiveness and above all, low maintenance cost.

References

[1]. Biagiola,. S., Solsona, J. (2006). State estimation in batch processes using a nonlinear observer. *Mathematical and Computer Modelling*, 44, 1009-1024.

[2]. Pedregal. D.J., Garcia, F.P., Schmid, F. (2004). RCM2 predictive maintenance of railway systems based on unobserved components models. *Reliability Engineering & System Safety*, 83. 103-110.

[3]. Grossmann, I.E., Halemane, K.P. and Swaney, R.E (1983). Optimization strategies for flexible chemical processes. *Computer Chemical Engineering*, 7, 439-462.

[4]. Brannbacka, J., Saxén, H.(2004). Novel model for estimation of liquid levels in the blast furnace earth. *Chemical Engineering. Science*, 59, 3423-3432.

[5]. Fantuzzi, C., Simani, S., Beghelli, S., Rovatti, R.(2002). Identification of piecewise affine models in noisy environment. *International Journal of Control*, 75(18), 1472-1485.

[6]. Chetouani, Y. (2006). Fault detection in a chemical reactor by using the standardized innovation. *Process Safety and Environmental Protection*, 84, 27-32.

[7]. Chetouani, Y. (2006a). Application of the generalized likelihood ratio test for detecting changes in a chemical reactor. *Process Safety and Environmental Protection*, 84, 371-377.

[8]. Nyberg, M., Stutte, T (2004). Model based diagnosis of the air Path of an automotive diesel engine. *Control Engineering Practice*, 12,513-525.

[9]. Alessandri, A. (2003). Fault diagnosis for nonlinear systems using a bank of neural estimators. *Computers in Industry*, 52, 271-289.

[10]. Chetoüani, Y. (2004). Fault detection by using the innovation signal, application to an exothermic reaction. *Chemical Engineering and Processing*, 43, 1579-l585.

[11]. Edelmáyer. A,, Bokor, .1., Szabo, Z., Szigeti, F.(2004). Input reconstruction by means of systeminversion: a geometric approach to fault detection and isolation in nonlinear systems. *International Journal of Applied Math Computer Science*, 14, 189-199.

[12]. Pedregal, D. J., Carnero, M.C. (2006). State space models for condition monitoring: a case study. *Reliability Engineering & System Safely*, 91,111-180.

[13]. Gatcia, P. P., Schmid, F., Conde, J. (2003). A reliability centered approach to remote condition monitoring. A railway points case study. *Reliability Engineering & System Safety*, 80, 33-40.

[14]. Dang, X., Aibright, E., and Abonamah, A. (2007). Performance analysis of probabilistic packet marking in IPv6.*Computer Communications*, 30(16), 3193-3202.

[15]. Coutinho, M., Lambert-Torres, G. Da Silva, L., Da Silva, J., Neto, J., Da Costa Bortoni, E. and Lazarek, H. (2007). Attack and fault identification in electric power control systems: An approach to improve security. *Proceedings of the Power Tech Conference*, 103-407.

[16]. Frank, P. M. (1990). Fault diagnosis in dynamic systems using analytical and knowledge-based redundancy. *A survey and some new results, Automatica*, 3,459-474.

[17]. Bhagwat, A., Srinivasan, R., Krishnaswamy, P. R. (2003). Multi-linear model-based fault detection during process transitions. *Chemical Engineering Science*, 58, 1649-1670.

APPENDIX A1

EVALUATION OF SOME FUNCTIONAL PARAMETERS FOR SHAFT COMPONENTS

Shaft of company product of A, B, C, D and E for Evaluation

The evaluation of the shaft, mean time between failure (MTBF) and failure rate (FR) for the five company generator components are presented in Table A1.1 and as shown in figure A1.1.

Block Diagram of Shaft

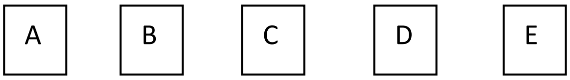

Figure AI.1: Block Diagram for Shaft

Table A1.1: Computational Values for Study interval, number of failure recorded, Mean Time Between Failure and Failure Rate for shaft

Components	**A**	**B**	**C**	**D**	**E**	**Summary**
Study interval	26280	26280	26280	26280	26280	8,760 failure /yr
Numbers of failure	2	2	1	2	1	2.67 failure /yr
MTBF	13140	13140	26280	13140	26280	3,284 hours/failure
Failure Rate (FR)	$7.61 x 10^{-5}$	$7.61 x 10^{-5}$	$3.81 x 10^{-5}$	$7.61 x 10^{-5}$	$3.81 x 10^{-5}$	$3.05 x 10^{-4}$ failure/hr

The evaluation of time lost from unreliability is presented in Table A1.2 and as well as the evaluated values illustrated in Figure A1.2

Block Diagram of Shaft

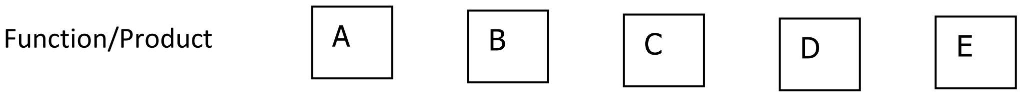

Figure A1.2: Block Diagram for Function and Product of Shaft

Table A1.2: Computational Values for some Functional Parameters of Failure rate, Failure per year and Corrective Time Failure and Lost Time per year for shaft.

Components	**A**	**B**	**C**	**D**	**E**	**Summary**
Failure Rate	$7.61 x 10^{-5}$	$7.61 x 10^{-5}$	$3.81 x 10^{-5}$	$7.6 x 10^{-5}$	$3.81 x 10^{-5}$	$3.05 x 10^{-4}$ failure/hr
Failure per year	0.7	0.7	3.3	0.7	3.3	8.7
Corrective time failure	3	2	3	3	4	3.3hrs
Lost time per year	2.1	1.4	9.9	2.1	13.2	28.7 hrs

The evaluation of cost of unreliability is presented in Table A1.3 as well as the evaluation illustrated in figure A1.3

Block Diagram of shaft

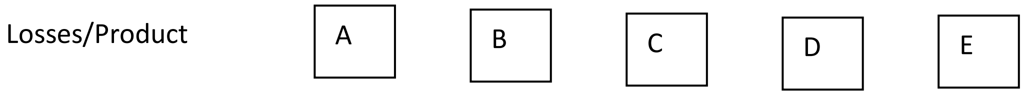

Figure A1.3: Block Diagram of Shaft for Losses and Products

Table A1.3: Computational Parameters of Gross Margin, Scrap Disposal and Breakdown Maintenance

Components	A	B	C	D	E	Summary
Gross margin	1,050	875	8910	1155	14520	26,510
Scrap disposal	28	28	132	28	132	348
Breakdown maintenance	84	56	390	84	528	1142
Total $	1162	1063	9328	1267	15,180	$28,000