WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Root Cause Failure Analysis for Maintenance Scheduling: A case Study

Abraham-Igwemoh Joy Ejayeta[1]

[1] Mechanical Engineering Department, University of Port Harcourt , East West Road Choba, Port Harcourt. P.M.B 5323, , Nigeria.

A B S T R A C T :

Machine downtime is an inhibiting factor to just in time service delivery in any industry and results in wastage of materials and investments for the period of occurrence.. Having a viable maintenance plan is useful in cubing this issue as failures are detected and tackled before they actually occur, rather than waiting for machines to eventually break down before repairs are carried out, resulting in idle time. The mean time between failures (MTBF), mean time to repair (MTTR), machine operating and down time, availability and reparability as well as the reliability of the components of a gas turbine power plant equipment were investigated to evaluate areas of higher failure to enhance proper maintenance schedule.. For the four basic gas turbine components investigated, the combustor had the highest operating time followed by the alternator, turbine and then the compressor. The downtime is the reverse of the operating time, hence, least value was observed for the combustor followed by the alternator, turbine and then compressor. More so, the reliability analysis showed that, the combustor had the highest reliability of 76.567% while the compressor equipment had the lowest reliability of 36.15%. MTTR was lowest for the combustor, followed by the alternator, turbine then compressor. The reverse was the case for the MTBF. Maintenance schedule based on these parameters on a priority scale would begin with components having a higher MTTR value to prevent failure occurrence which would result in a longer downtime for job operation, material wastage and higher production cost.

Keywords::Gas Turbine, Failure rate, Reliability, compressor, combustor, MTTR, MTBF

Introduction

Gas turbine is one of the power-generating machines that have been widely used in various industries such as power plants, refineries and oil and gas industries [2]. Gas turbine is a complex stationary machine used for the efficient generation of electric power to run industrial equipment to meet production needs. It is also used to power ships,, racing cars, jet engines and aircrafts. Most gas turbine systems consist of three main parts: compressor, combustor, gas turbine..Gas turbine engines is a type of I.C enginethatderive their power from burning compressed air-fuel mixture in a combustor and using the resulting fast-flowing high pressure- high temperature combustion gases from the burnt compressed air-fuel mixture, to rotate and kinetically drive a turbine with some of the gases exhausted [4]. A generator connected to the turbine via a shaft receives this kinetic energy from the rotating turbine and converts it into electrical energy. Gas turbine power plant equipment such as compressor, combustor, and turbine are very essential for power generation in the oil and gas industry to run industrial equipment to meet production needs and as such should be readily available and operating effectively. Equipment failures can adversely affect or halt the plant ability to perform its intended function of generating electrical power .However, with effective maintenance of plant equipment, the gas turbine plant functionality can be sustained consequently reducing the frequency of system downtime and improving equipment's' operation [7]. Maintenance is considered as an activity where a system or equipment has its failure arrested, reduced or eliminated. It can be defined as all actions appropriate for retaining an item/part/equipment or restoring it to a given condition or to a state in which it can perform its designated functions. Maintenance has to do with tasks and actions that extend or prolong the ability of plant or equipment to perform its intended function. Several research has been conducted on failure rate analysis and even on gas turbine maintenance, [2] studied effective maintenance of gas turbine power plant to improve productivity with the aim of determining the effect of a good maintenance culture on the reliability of gas turbine power plant operation and evaluating revenue loss due to high rate of intervention (or failure) in the power plant. Through manual and mechanized method as well as questionnaire administration, they were able to analyse the mean time between failures (MTBF), mean time to repair (MTTR), production yield, and loss of revenue and also determine the effect of adequate maintenance of the power plant on productivity. A negative growth rate in productivity resulting from poor performance of the gas turbine power plant in the year (2013-2017) was observed and also incessant shutdown of power plant which also affected the process plants resulting in the loss of about N0.851Billion in a year. [8] carried out a study and analysis of reliability centred maintenance (RCM) in the energy industry. Five (5) key components of a functional Gas Turbine (GT) located in Afam Power PLC in the South-South region of Nigeria were analysed. Reliability centred maintenance planning technique using computational methods was employed to plan the maintenance schedule of the gas turbine plant. First, a maintenance cost function that reflects the present maintenance and operation conditions of the system's components was derived. Secondly, an estimation of maintenance of the components of the GT using evolutionary algorithm (EA) was carried out, of which the desired subsystem reliability was determined, and maintenance reliability allocated. Thirdly, a reliability growth analysis was used to derive the reliability indices. Two (2) optimization procedures were executed to ascertain the optimum reliability. The results showed that 16.2% maintenance cost was saved when the 2 optimization procedures were compared. A significant correlation between conflicting objectives was achieved by using these optimization procedures thereby converting them to a single optimization model.[9] studied evolution of maintenance strategies in oil and gas industries: the present achievements and future trends They reviewed evolution of systems or equipment maintenance strategies practiced over the years in complex industrial and manufacturing systems such as oil and gas production systems, satellite communication system, spacecraft navigational system, nuclear power plants, etc. with emphasis on current maintenance and reliability philosophies and limitations. A novel approach to complex engineering systems maintenance and reliability sustainment was proposed which reintegrated operation and maintenance phase into system development life cycle and adopts advanced engineering tools and methodology in developing condition-based predictive maintenance, an intelligent maintenance system with resilient, autonomous and adaptive capabilities. Application of Neural network approach to multi-sensor data fusion for condition-based predictive maintenance system was briefly presented.

[10], studied simulation models for analysis and optimization of gas turbine cycles. He employed simulation model to analyze the gas cycle theory and the models present in literature starting from the simplest to more complex ones. Aspen HYSYS was used to develop models for conceptual design, optimization, business planning, asset management, and performance monitoring. Furthermore, parametric analysis was undertaken for each model to find out which variables had the most significant effect on overall efficiency. In this study four basic components of a gas turbine would be analyzed for possible failures to mitigate operation downtime via preventive maintenance scheduling.

2. Research Design

2.1 Materials and Methods

The materials used in this study are failure data of the gas turbine power plant equipment obtained from Nigerian Liquefied Natural Gas (NLNG) Company, Rivers State and available maintenance manpower/ labour resources for the gas turbine power plant equipment in the Company including log books, annual report sheets as well as manufacturer's manual and specification data sheets for the gas turbine power plant equipment.The reliability of the gas turbine power plant equipment is determined using Mean Time between Failures (MTBF), Mean Time to Repair (MTTR), failure rate, repair rate and availability parameters.The MTBF is a basic measure of reliability for reparable items, and is estimated by the total time in operation of the gas turbine power plant and its subsystems divided by the total number of failures (breakdowns) recorded within a specific investigation period., MTTR is the average time required to troubleshoot and repair failed equipment and return it to normal operating conditions. It is a basic technical measure of the maintainability of equipment and repairable parts. Maintenance time is defined as the time between the start of the incident and the moment the system is returned to operation (i.e., how long the equipment is out of production). This includes notification time, diagnostic time, fix time, wait time (cool down), reassembly, alignment, calibration, test time, back to operation, etc. Mean time to repair ultimately reflects how well the system can respond to a problem and repair it. It is suitable for all kinds of system.

Failure rate is the probability of failure per time unit. It is the rate of occurrence of failures. It is the reciprocal of the MTBF /MTTF function. Repair rate is the probability of repair per time unit. It is the rate of occurrence of repairs. A repair rate is used for systems with repairable parts. It is the reciprocal of the mean time to repair (MTTR) function. The "availability" of a system is, mathematically, MTBF / (MTBF + MTTR) for scheduled working time. Equations 1-4 give the mathematical representations.

$$MTBF = \frac{\sum t_O}{n} \tag{1}$$

$$MTTR = \frac{\sum t_R}{n} \tag{2}$$

$$\lambda = \frac{1}{MTBF} \tag{3}$$

$$\mu = \frac{1}{MTTR} \tag{4}$$

$$A = \frac{MTBF}{(MTBF + MTTR)} \tag{5}$$

Where:

$\sum t_O$ = the total operation running time for both failed and non-failed items

n = number of failures (breakdowns) of equipment parts.

$\sum t_R$ = total accumulative time to repair or maintain in statistical time.

n = number of repair actions during the specified investigation period.

$\sum t_I$ = the total running time for both failed and non-failed items.

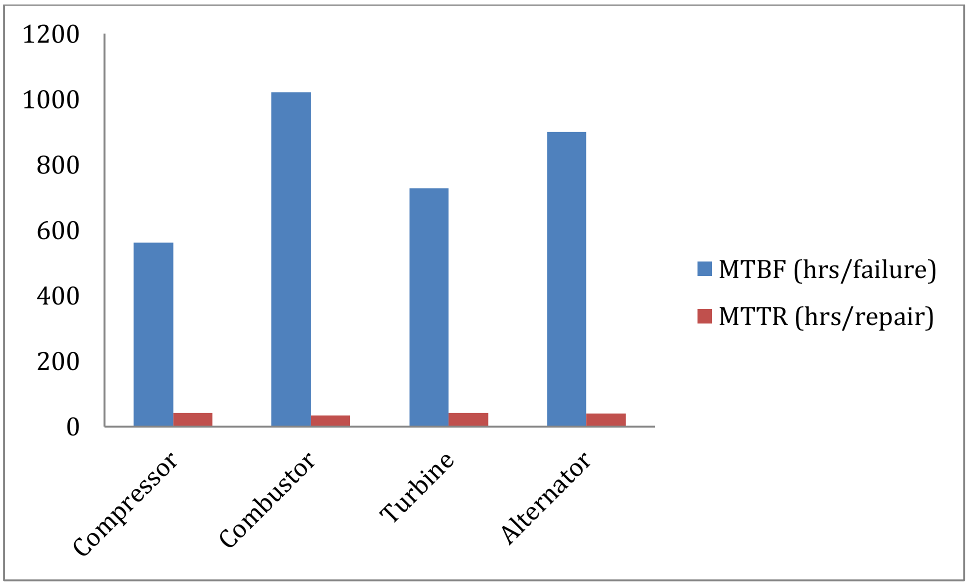


Figure 1: Comparison of the Mean time between failures and repair of the turbine

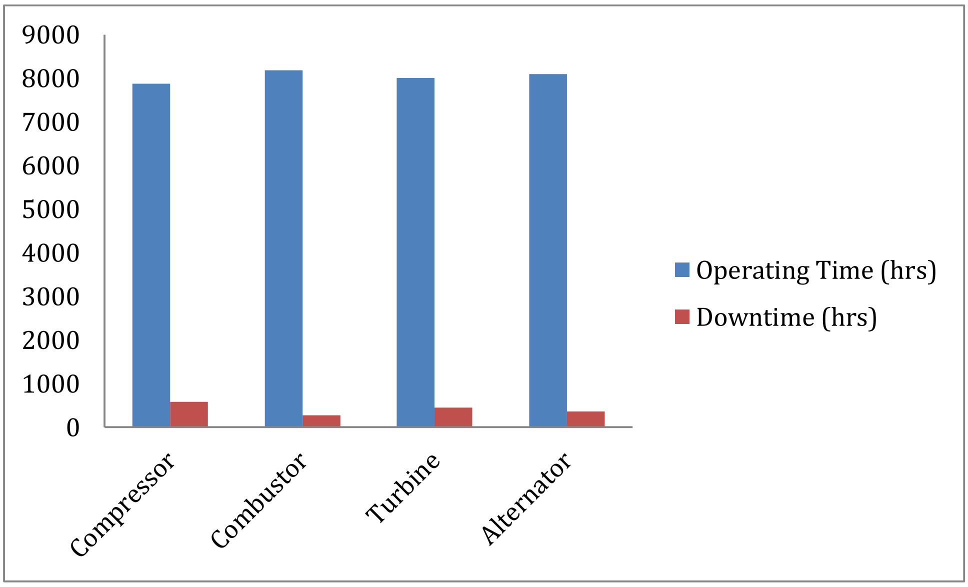


Figure 1 Comparison of the downtimes of the turbine components

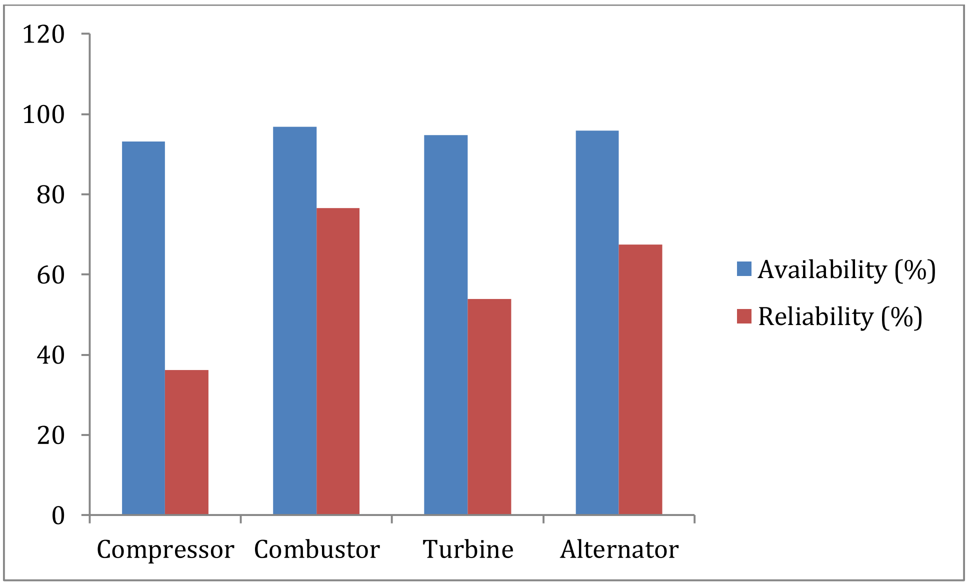
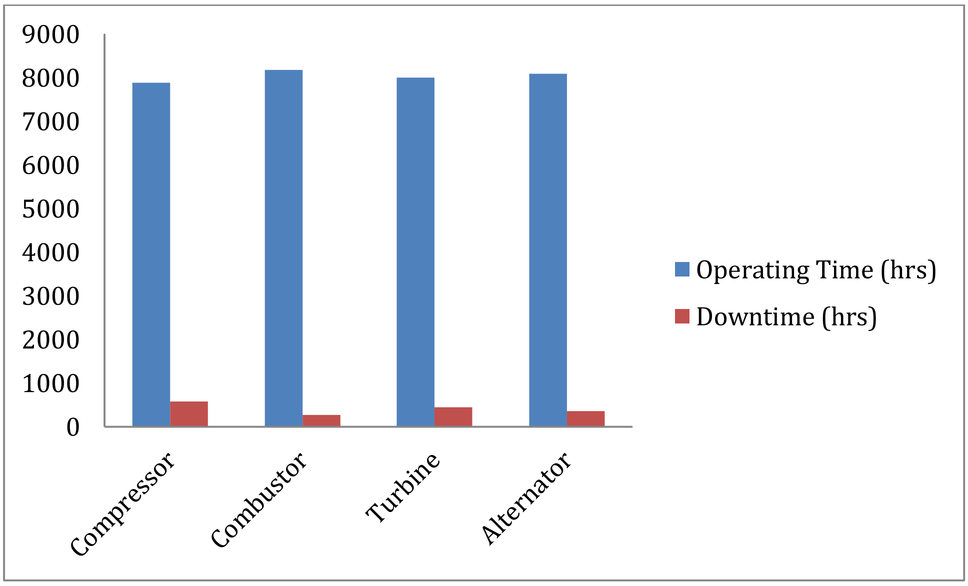


Figure 3 Comparison of the availability and reliability of turbine component.



3. Results and Discussions

MTBF, MTTR, repair rate, failure rate, availability and reliability maintenance metrics parameters were used to analyze the gas turbine, evaluate the failure rates and develop an appropriate maintenance schedule system among existing alternatives. Failure data of the gas turbine power plant equipment comprising the number of failures, operating time, downtime and the total time available for the gas turbine power plant equipment operation, obtained from the preventive maintenance records and troubleshooting log book as well as manufacturer's manual was employed to assess the gas turbine power plant equipment. Table 1 presents the failure data of the gas turbine power plant equipment.

Tale 1: Gas turbine components failure record for year 2024

Gas Turbine components	Number of Failure	Operating Time (hrs)	Downtime (hrs)	Total Available Time (hrs)
Compressor	14	7875.72	572.28	8448.00
Combustor	8	8175.09	272.91	8448.00
Turbine	11	7999.37	448.63	8448.00
Alternator	9	8094.23	353.77	8448.00

For each of the gas turbine power plant equipment, the total number of failures = total number of repairs and the total working days under consideration is 352. (excluding holidays). Hence total working hours will be 8448 hours. Each component of the gas turbine was analyzed for MTBF, MTTR etc. Equations 1-4 and Table 1 were used for the computation and the results presented in Table 2..

Table 2: Computation data for the failure rate analysis of the gas turbine components

	Operating Time (hrs)	Downtime (hrs)	MTBF (hrs/failure)	MTTR (hrs/repair)	Failure rate (failure/hr)	Repair rate (repair/hr)	Availability (%)	Reliability (%)
Compressor	**7875.72**	**572.28**	**562.55**	**40.877**	**0.001777**	**0.02446**	**93.22**	**36.15**
Combustor	**8175.09**	**272.91**	**1021.88**	**34.113**	**0.000979**	**0.02931**	**96.76**	**76.56**
Turbine	**7999.37**	**448.63**	**727.22**	**40.784**	**0.001375**	**0.02452**	**94.69**	**53.96**
Alternator	**8094.23**	**353.77**	**899.36**	**39.307**	**0.001112**	**0.02550**	**95.81**	**67.48**

The reliability analysis of the gas turbine showed that, out of the four (4) basic components , the combustor has the highest reliability of 76.567% while the compressor equipment has the lowest reliability of 36.15% during the period investigated. Maintenance priority should be directed towards the least reliable component which contributes more to the gas turbine failure. Hence frequent attention should be given to the compressor compared to other components of the gas turbine, The results from Table 2 shows that, the compressor has the least reliability at 36.15% the lowest availability of about 93.22% which can be attributed to several factors like: worn impeller, faulty thrust bearing, shaft deforming, leaking casing, electric motor faults, and faulty shaft coupling which could be prevented by carrying out simple routines tasks such as: adequate lubrication, checking and replacing impeller, bent shaft, thrust bearings casing and shaft coupling and seals of the air compressor periodically, From Fig 2 the combustor has the highest operating time followed by the alternator, turbine and then the compressor. The downtime is the reverse of the operating time, hence, least value is observed for the combustor followed by the alternator, turbine and then compressor

The MTBF analysis for the different gas turbine components presented in Fig 3 shows the least value of MTTR for the combustor, followed by the alternator, turbine then compressor. The reverse is the case for the MTBF. Maintenance schedule based on these parameters would give priority to components having a higher MTTR value because failure occurrence would result in a longer downtime for job operations affecting the delivery date.

Conclusion

Failure rate analysis of equipment is a useful tool for evaluating the individual components that make up the equipment so as to determine the appropriate maintenance plan the industry should employ. Maintenance priority is directed towards components with higher failure rates and downtimes to minimize job obstruction that may occur during operation due to machine breakdown having a resulting effect of higher production cost from estimated value.

REFERENCES

1. Abdollahzadeh, H., Atashgar, K., Abbasi, M. (2016). Multi-objective opportunistic maintenance optimization of a wind farm considering limited number of maintenance groups. *Renew Enegry*, 88, 247 – 261.

2. Daniel, H., Barinyima, N. & Isaac, O. E. (2019). Effective Maintenance of Gas Turbine Power Plant to Improve Productivity. *EJERS, European Journal of Engineering Research and Science*, 4(4), 35 -42.

3. Abere, M. A., Obarafo, S. A. &Adeleke, K. O. (2020). Application Of Linear Programming To Firm's Decision Making: Hypothetical Example. *British Journal of Management and Marketing Studies*, 3(4), 94 - 105.

4. Oyedopo, S. O. (2018). Appraisal of the Gas Turbine Power plant maintenance system in Nigeria. *EJERS*, 2(2), 1 -15.

5. Adarsh, K. A. (2022). A critical review on optimization parameters and techniques for gas pipeline operation profitability. *Journal of Petroleum Exploration and Production Technology*, 12(9), 3033–3057. https://doi.org/10.1007/s13202-022-01490-5

6. Afefy, I. H. (2010). Reliability-Centered Maintenance Methodology and Application: A Case Study. *Journal of Engineering*, 2(12), 863–873.

7. Salilew, W. M., Karim, Z. A. A., &Baheta, A. T. (2021). Review on gas turbine condition based [7]diagnosis method. *Materialstoday: Proceeding*, 12, 71-92.

8. Prosper, O. U., Harold, U. N., Dimkpa, U. D., Clinton, N. I. (2022).A study and analysis of Reliability Centered Maintenance (RCM) in the Energy Industry.*Int. j. adv. multidisc. res. stud.;* 2(3), 249-258.

9. Jeremiah, E. & Roy S. K. (2020). Evolution of Maintenance Strategies in oil and Gas Industries: The Present Achievements and Future Trends. *Journal of Scientific & Industrial Research*, 64(9), 249-255.

10. Nicola, P. (2018). *Simulation models for analysis and optimization of gas turbine cycles*. Masters Degree Thesis, Chemical Engineering Department, Universita Di Pita.

11. Benedict, A. K., Rudy, H., Prayogo, N. P. &Nababan, S. (2024) Predictive Maintenance Using Linear Regression. *Syntax Literate: JurnalIlmiah Indonesia*, 9(3),1959 - 1969.

12. Chanda, R. Pabalkar, V., & Gupta, S. (2022). A Study on Application of Linear Programming on Product Mix for Profit Maximization and Cost Optimization. *Indian Journal of Science and Technology,* 15(22), 1067 - 1074.

13. Chienyem, N. O., Ogunwoye, F. O., Ugwu, U. R., Godswill, U. N., Orji, M. C., Odoh, T. M., Ajayi, D. O., Oladokun, Q. M. &Usoro, A. S. (2023). Predictive maintenance of industrial equipment using machine learning in industrial environment of Awka Metropolis, Nigeria. *International Journal of Science and Technology Research Archive*, 5(2), 1 – 9.

14. De Jonge, B., & Scarf, P. A. (2020). A review on maintenance optimization. *European Journal of Operational Research*, 285 (3), 805 - 824.

15. De Jonge, B. (2021). Condition-based maintenance optimization based on matrix algebra. *Operations Research Letters*, 49(5), 741 - 747.

16. Emanuele, M., Falah, A. & Cristina, E. (2021). Design Optimization and Dynamic Simulation of Steam Cycle Power Plants: A Review. *Frontiers in Energy Research* | www.frontiersin.org 9(9), 2-30.

17. Ghamami, M., Fayazi, B. A. &Behbahani, S. (2019). Performance Optimization of a Gas Turbine Power Plant Based on Energy and Exergy Analysis, *Mechanics, Materials Science & Engineering, January 2016 ISSN 2412-5954, 29-41.*

18. Grudz, V., Grudz, Y., Pavlenko, I., Liaposhchenko, O., Ochowiak, M., Pidluskiy, V., Portechyn, O., Iakymiv, M., Włodarczak, S., &Krupi ´ nska, A. (2023). Ensuring the Reliability of Gas Supply Systems by Optimizing the Overhaul Planning. *Energies*, 16, 986. https://doi.org/10.3390/en16020986

19. Hamed, A. A. L. &Dorid, D. (2020).Developing a Model for the Optimization of Maintenance Costs in Commercial Buildings in UAE. Pro*ceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit*, Michigan, USA, August 10 - 14,

20. Han, B. J., Fan, X. M., Ma, D. Z., & Jin, Y. (2003). Optimization of equipment preventive maintenance cycle in production system based on genetic algorithm, *Computer Integrated Manufacturing Systems,* 9(3), 206-209.