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Model for the Evaluation of Due Time for GE Frame 9E Gas Turbine Hot Gas Path Inspection (HGPI)

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ABSTRACT

This research study entails the determination of the due time required for carrying out hot gas path inspection of a gas turbine. Delay in execution of HGPI may result in machine failure, extra cost and loss in revenue while early execution may result in unnecessary cost, waste, and loss in revenue due to downtime. Hence, the aim of the research study, to model and evaluate the due time for carrying out hot gas path inspection for a GE frame 9E machine. This study was conducted using GT17 of Transcorp Power Limited, Ughelli, Delta State. The methodological approach considered for this study was to carry out a mathematical modelling approach in determining the due time for carrying out HGPI. A corrosion rate formula was developed, presented and used in the modelling process. The two main parts considered for the experiment were turbine buckets and shroud blocks, which is considered critical for the turbine clearance when undertaking HGPI. Based on the mathematical modelling analysis, the due time for the turbine buckets were 24134.9hrs for stage 1, 235456hrs for stage 2 and 24727.5hrs for stage 3. In correspondence, turbine shroud blocks due time were computed at 24805.3hrs, 24497.8hrs and 23346.1hrs for stages 1, 2 and 3 respectively. Based on the efficiency computed, it was discovered that the efficiency of the gas turbine reduces gradually until maintenance activities are carried out to improve the efficiency, reliability and availability of the gas turbine.

1. INTRODUCTION

Electrical power is considered as one of the greatest inventions by man and it is significant to the development of modern society (Almasi, 2014). Economic development of any nation depends on the use of electrical power to drive domestic, commercial and industrial activities, and as such there should be no reason for power outage. As opined by a study, power outage has a significant weight on the systems of a country and as such the need for power cannot be over emphasize as it is key to the survival of practically all businesses and institutions (Oluwole, et al., 2012). However, electrical power doesn't just play into existence as it is generated, transported, distributed before it can be consumed based on demand (Zhao, 2005). Hence, there has to

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be demand for electrical power (electricity) before it can be produced otherwise there will be no electricity market (Oluwole, et al., 2012). On a global scale, electricity consumed by a country comes from a national electricity grid which involves the use of multiple turbomachinery equipment to generate electrical power. Most countries make use of power turbines such as steam and gas turbines in the generation of electricity consumed by the country, although there are other types of power systems which include solar power systems, wind turbine power system, hydro turbine power system, etc. In Nigeria, most power plants operate using gas turbines to generate electricity for the national grid and at the moment there are more than ten power plants in the country with the top players being Egbin Power Plant, Transcorp Power Plant, Azura Power Plant, and Kainji Power Plant (Okeke & Mbamaluikem, 2020).

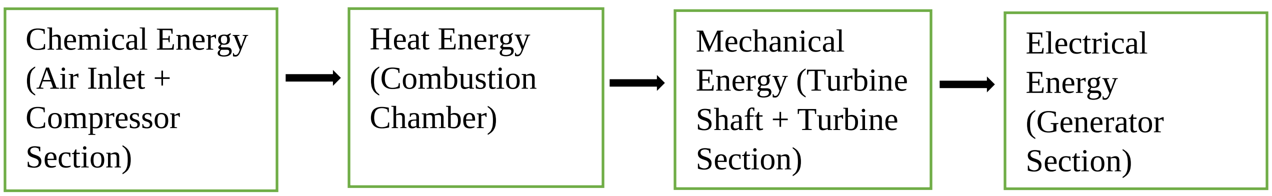

Figure 1. Block flow diagram of energy conversion process (Hitachi 2020).

The block flow energy conversion process of a Gas Turbine (GT) presented above indicates that chemical energy in the form of natural gas (methane) is burnt in compressed air for which the heat energy produced is used to drive the GT. The combustion process takes place in a combustion chamber and into creating combustible gas used to drive the shaft of the GT through the turbine nozzles attached to it, which in turn drives a generator rotor coupled to it into producing electricity. It was opined that the temperature in the combustion chamber of a GT can be greater than 1000°C which is enough to melt most materials (Fadipe & Biebuna, 2010). However, the materials used in the design of a GT are special steels mixed with alloy elements, so as to increase its melting point. It is important to note that the parts of a GT been subjected to high temperature over a period of time makes it capable of corrosion and deterioration. According to a study, temperature is one factor that hastens deformation and corrosion of a machine part which makes it unusable (William, 2018). Most GT are designed to operate at a very high speed, with the General Electric (GE) Frame 9E designed to run at 3000 revolutions per minute (rpm) (Kurz, et al., 2013). Consider the fact that an equipment which operates with such a speed and at high temperature will only give rise to part creep, fatigue and failure (Okedu, 2010).

The failure of a GT can be attributed to different factor of which hardware failure is one of the major issues (Fadipe & Biebuna, 2010). This type of failure leads to downtime which renders the machine unavailability and unreliability during the period it is not in service. Before a GT becomes unavailable, it may indicate signs of reduction on its reliability in form persistent trip and shut down, difficult start, and low power output caused by failure of the turbine hardware amongst others. Hence, a GT can be unavailable as a result of failed turbine hardware caused by high temperature exposure for a long period of time. To this end, a GT needs to be inspected for the level of damage and maintained in order to bring it back to service. This aspect can be reflected in the cost generation with respect to cost to repair and loss in revenue (Fadipe & Biebuna, 2010). As a result, a study was conducted so as to understand the need for electrical power availability at all times as well as managing and monitoring the status of a machine used for electrical power generation (Almasi, 2014). Hence, action needs to be taken towards making a gas turbine reliable and available as soon as possible since electricity generation businesses are capital intensive. A power plant can be defined as available, reliable, effective and efficient when it continually performs in accordance with its designed capabilities and function while generating revenue (Fadipe & Biebuna, 2010).

Maintenance costs and machine availability are considered the most important concerns to a gas turbine equipment owner. In another study, more than half of a maintenance budget is consumed during major maintenance operations and as such this should not be taken likely (Kister, 2016). Therefore, a well thought out maintenance program and plan that reduces the owner's costs while increasing equipment availability should be designed and implemented. Also, before a GT gets to a point of breakdown and become unavailable, it has to be inspected and maintained accordingly. However, since a GT is designed to operate continuously as a perpetual motion machine, the due date to maintenance activities needs to be ascertained. For a GE frame 9E machine, the expected due date for carrying out hot gas path inspection (HGPI) is designed for 24,000 running hours after the commissioning of the brand-new machine (Kurz, et al., 2013). Gas turbine operation and maintenance, planning, advanced planning for maintenance is necessary for industrial, independent power and other generating plant in order to achieve reliability and availability. Actual implementation of planned maintenance and inspection activities provides the necessary benefits to prevent forced outages and downtime. GT parts require extreme care and attention especially in relation to the combustion process, together with those exposed to the hot gases discharged from the combustion system which is the turbine section and the various associated components (Nicol & Aylett, 2009). This therefore leads to inspection and maintenance activities. Hence, such inspections are referred to as the combustion inspection and hot gas path inspection. This research study therefor focuses on evaluating and modelling the due date of GT with respect to carrying out hot gas path inspection activities, in order not to run the machine into catastrophic breakdown. A frame 9E gas turbine is a General Electric (GE) machine which is driven by combustible gas as the prime mover of the turbine shaft. The turbine buckets are attached to the turbine shaft and as the combustible gas impedes the bucket, causes the turbine shaft to move at a high speed. The turbine shaft is coupled to the generator shaft and as such turns together. The rotation of the generator shaft generates electricity based on the principle of electromagnetic induction. A GE frame 9E gas turbine is basically made up of six main sections namely; Air Inlet Section, Compressor Section, Combustion Chamber Section, Turbine Section, Exhaust Section and Generator Section.

Atmospheric air enters the turbine through the air inlet section for which this air is filtered from contaminants and debris before it is channeled into the air compressor through the inlet guide vane. There are a total of 1280 air filters split into two banks in a GE frame 9E gas turbine. The air compressor is an axial configured type with seventeen (17) stage blades for which the filtered air gets compressed to high pressure and temperature according to pressure law. The pressurized air is thereafter channeled into the combustion chamber section where it mixes with the natural gas (methane) being supplied from the gas supply line at high pressure. The compressed air is mixed with the high-pressure gas in the right proportion and ignited using two spark plugs to establish ignition which is detected using two flame scanners. The combustible gas is distributed throughout the combustion cans with the aid of crossfire tubes, which are fourteen in number and simultaneously channeled into the turbine section. The combustible gas impedes the buckets of the turbine thereby causing further rotation of the turbine shaft. As the combustible gas passes through the turbine buckets, it expands and loses heat energy before been vented through the exhaust section consisting of the exhaust plenum. The temperature at the combustion section is estimated to be as high as 1200^{o}C. The compressor shaft is coupled to the turbine shaft which is also coupled to the generator shaft and as such makes it into one shaft. The initial start of the gas turbine begins with a starting means which begins with a cranking motor to provide the initial torque and rotation to the shaft to enable the compressor take in air through the air filter housing and compress for use in the combustion chamber. Hence, the moment combustion is complete, and the combustible gas begins to impede the turbine buckets, the speed of the shaft increases, and the rotation of the entire gas turbine shaft becomes self-sustaining. The gas turbine shaft rotates at 3000 rpm as so does the generator shaft and through the principle of electromagnetic induction, electricity is generated at a terminal voltage of 11.5 KV before been transformed to a higher voltage of 330 KV using a step-up power transformer and transmitted for distribution to final consumers. Maintenance is a vital concept of engineering that addresses the breakdown of machines or equipment for the purpose of prolonging their useful life. This section of engineering can be seen as an action that helps to preserve a machine or equipment in terms of its reliability and availability over its life cycle. Therefore, the concept behind this research topic requires that certain terminologies are defined and explained in relation to turbo machinery (gas turbine) and its connection to outages.

Reliability of a machine or equipment can be defined as the period of time it takes for any given machine or equipment to perform its function based on required performance (ReliabilityWeb, 2019). It is also the measurement with regards to the probability for which a component will execute its intended function under certain working conditions over a specified period of time (ReliabilityWeb, 2019). This essence is to further express the measurement categories associated with reliability and some of them include mean time before failure (MTBF), mean time to repair (MTTR) and failure rate. The fist concept is concerned with the total time an equipment has been in service to the number of occurred failures within the time period, the second concept is concerned with the time taken for an equipment which has failed to be restored back to service and finally, the last concept is concerned with inverse description of MTBF (ReliabilityWeb, 2019). With regards to gas turbine, an outage period can be considered MTTR while the mean of the failure rate before an outage is considered MTBF.

Availability on the other hand can be seen as the measure of time in terms of percentage for which an equipment is in a functional state (ReliabilityWeb, 2019). This means that the ratio between the time it takes for an equipment to be functional as against expected time required of it to function. Hence, there is a possibility for an equipment (GT) to be available for use but actually possess a low reliability base on its intended function especially (Rao, 2014). With consideration to such parameters, it is expected that data are obtained, analyzed and evaluated in order to determine the due time before failure (Rao, 2014). It brings to mind, the need for what the user of such equipment wants but the fact is for equipment GT to function continuously. This has led to what is known as maintainability for which it is a key aspect of engineering that is designed to address the issues associated with availability and reliability.

Maintainability can be defined as the ease and rate with which an equipment like GT, can be restored back to operational state after failure have occurred (Surupa, 2019). There are various types of maintenance activities expressed as preventive maintenance, corrective maintenance, and finally predictive maintenance. HGPI as regards to gas turbine is considered as a form of preventive maintenance which has resulted in carrying out certain maintainability analysis using predictive maintenance. The main aim is to restore the equipment and make it available for use by ensuring the right maintenance (Rouse, 2019).

A standard GT requires adequate periodic inspection, repair, and replacement of its parts in order to continuously achieve optimum reliability and availability. There are certain structural components of a GT that are considered major and has to be designed to standard base on requirements due to the fact that the machine gets exposed to high temperature (Kurz, et al., 2013). Hence, these parts are exposed to combustion process which involves the burning of gas in air to make it hot gas. Most of these parts include turbine nozzles, combustion liners, turbine buckets, and transition piece (Kister, 2016). Aside the maintenance of the hardware components subjected to extreme temperature, other components such as control devices, gauges, metering system, and other auxiliary devices need to be maintained regularly (Kister, 2016). The inspection and repair of GT parts and auxiliary components lead to the establishment of patterns and programs of maintenance which begin from minor repairs, change of parts to major overhaul and the cycle continues in that manner. For a GT, this schedule program is known as turbine inspection and it has different types of which they include standby inspection, running inspection, combustion inspection, hot gas path inspection and major inspection (Bohlin, et al., 2009). Standby inspection relates specifically to GT used in intermittent service for which starting reliability is the main concern (TWI, 2022). Hence, this maintenance service includes change of filters, battery check, oil and water level check and device calibration checks. These services can be performed offline but during off peak period and as such it is essential to establish periodic test as part of standby inspection. This type of inspection consists of both general and continuous observation of the GT while it is in service (Knorr & Jarvis, 1995). The continuous duty and unattended machine should be observed on a one-to-four-week basis, while intermittent duty units should be observed between the five to ten starts based on accessibility. Operation data of the GT are continuous recorded and evaluated with regards to expected performance criteria. Example of running inspections include observing the load against the exhaust temperature, startup timer duration, etc. Hence, there should be a good relationship between the exhaust temperature profile and the load, and these data should always be compared with previous data. Research shows that the ambient temperature of the atmospheric air influences the performance of the machine. A high exhaust temperature could be an indication that the internal parts of a GT is deteriorating which lead to power loss. The vibration level as well as fuel flow against the load of the GT is also observed and recorded as a high vibrating unit indicates ineffective performance of the turbine. The running inspection also contains the exhaust temperature control, exhaust temperature variation and startup time.

A combustion inspection is considered a short shutdown inspection to check the fuel nozzles and combustion liners of a GT. This particular inspection process recognizes that continued operation with a deteriorated combustion part and system can result in accelerated deterioration of other downstream parts, such as the turbine buckets, shroud blocks and nozzles (Knorr & Jarvis, 1995). This inspection recognizes the fact that the fuel nozzles and combustion liners are parts of the GT that require repair or replacement so as to improve its overall maintenance cycle with regards to the combustion system (TWI, 2022).

2. MATERIALS AND METHODS

The model approach considered for the study entails calculating the due time taken for some of the parts on the GT to deteriorate using primary data. The primary data were obtained by physically measuring some parameters of selected parts of the GT and recording the value before using it to calculate the due time required to conduct HGPI on the turbine. Also, the efficiency of the GT was calculated from secondary data obtained from the organization, chosen for the study. A particular GT was identified, selected, and experimented upon by estimating the due time and comparing value with certain periods reflecting efficiency of the turbine over a period of time. Both primary and secondary data were analyzed using Microsoft Excel tool and presented as findings. Before proceeding with the model approach, it was necessary to highlight the parameters considered for the process and they include:

2.1 Mathematical Modelling of the HGPI Due Time

In other to model the due time of the Hot Gas Path Inspection of a GE frame 9E gas turbine, there is the need to access some of the associated components of which for this procedure the following where considered:

(a) The Turbine Buckets, stages 1, 2 and 3

(b) The Shroud Blocks, stages 1, 2 and 3

Three stages of both the turbine buckets and shroud blocks were considered because it is a three-stage turbine configuration.

Identification and selection of parts

Five old and new parts of each stage of the turbine buckets were selected at random and same number was selected at random for the turbine shroud blocks also. These are pictures of the randomly selected turbine buckets and shroud blocks for Figures 1, 2 and 3 of a GE frame 9E gas turbine.

Determination of the weight loss of identified turbine parts

Firstly, five parts each for both the old and new turbine components were selected at random with respect to their different stages.

The weight of the different parts was obtained using a digital personal scale, model

2003A and the values recorded for each stage as seen in Tables 1, 2, 3 and 4 for both old and new parts. The average weights of each stage for both turbine bucket (new and old) and shroud block (new and old) were computed using equation 1.

$$\text{Average weight} = \frac{\text{Sample 1} + \text{Sample 2} + \text{Sample 3} + \text{Sample 4} + \text{Sample 5}}{5} \quad (1)$$

Table 1; Weights of New Turbine Buckets Parts

New Turbine Bucket Parts						
Stages	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Sample 4 (kg)	Sample 5 (kg)	Average (kg)
1	12.4	12.4	12.35	12.4	12.35	12.38
2	12.05	12.10	12.05	12.00	12.05	12.05
3	11.13	11.15	11.17	11.14	11.13	11.144

From Table 1, it can be seen that the difference between the highest weight and the lowest weight value was not more than 0.05kg for stage 1, 0.1kg for stage 2 and 0.04kg for stage 3 into given an average value of 12.38kg, 12.05kg and 11.14kg for stage 1, stage 2 and stage 3 respectively. Hence, similar parts had uniform weights values with little deviation.

Table 2: Weights of New Turbine Shroud Blocks Part

New Turbine Shroud Blocks Part						
Stages	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Sample 4 (kg)	Sample 5 (kg)	Average (kg)
1	24.55	24.55	24.45	24.50	24.35	24.48
2	19.85	19.85	19.80	19.85	19.80	19.83
3	19.50	19.55	19.55	19.50	19.50	19.52

From table.2, it can be seen that the difference between the highest weight and the lowest weight value was not more than 0.2kg for stage 1, 0.02kg for stage 2 and 0.03kg for stage 3 into given an average value of 24.48kg, 19.83kg and 19.52kg for stage 1, stage 2 and stage 3 respectively. Hence, similar parts have uniform weights with little deviation.

Table 3: Weights of Old Turbine Bucket Parts

Old Turbine Buckets Part						
Stages	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Sample 4 (kg)	Sample 5 (kg)	Average (kg)

1	11.68	11.75	11.82	11.70	11.77	11.74
2	11.30	11.60	11.20	11.40	11.50	11.40
3	10.32	10.58	10.20	10.44	10.43	10.39

From table 3, it can be seen that the difference between the highest weight and the lowest weight value was up to 0.14kg for stage 1, 0.4kg for stage 2 and 0.38kg for stage 3 into given an average value of 11.744kg, 11.4kg and 10.394kg for stage 1, stage 2 and stage 3 respectively.

Table 4: Weights of Old Turbine Shroud Blocks Part

Old Turbine Shroud Blocks Part						
Stages	Sample 1 (kg)	Sample 2 (kg)	Sample 3 (kg)	Sample 4 (kg)	Sample 5 (kg)	Average (kg)
1	24.21	23.96	22.20	23.92	24.35	23.72
2	19.25	19.12	19.36	19.18	19.30	19.24
3	18.95	19.11	18.70	18.70	19.00	18.89

From table 4, it can be seen that the difference between the highest weight and the lowest weight value was up to 0.39kg for stage 1, 0.18kg for stage 2 and 0.41kg for stage 3 into given an average value of 23.728kg, 19.242kg and 18.892kg for stage 1, stage 2 and stage 3 respectively.

In order to compute the weight loss for each stage of the turbine bucket and shroud block, equation 2 was employed.

$$Weight\ loss\ (W_L) = New\ average\ weight - Old\ average\ weight \qquad (2)$$

For the turbine stage 1 bucket,
$W_L = 12.38 - 11.744 = 0.636kg$

For the turbine stage 2 bucket,
$W_L = 12.05 - 11.4 = 0.65kg$
For the turbine stage 3 bucket,
$W_L = 11.144 - 10.394 = 0.75kg$

For the turbine stage 1 shroud block,
$W_L = 24.48 - 23.728 = 0.752kg$

For the turbine stage 2 shroud block,
$W_L = 19.83 - 19.242 = 0.588kg$

For the turbine stage 3 shroud block,

$W_L = 19.52 - 18.892 = 0.628kg$

Summary of the various computed weight loss for the different stages is seen in table 3.5.

Table 5: Weight loss for Turbine Components

Components	Turbine Bucket	Shroud Block
Stages	Weight Loss (kg)	Weight Loss (kg)
1	0.636	0.752
2	0.65	0.588
3	0.75	0.628

Determination of Due Time for Turbine Parts

In order to mathematically model and determine the due time for both the turbine buckets and shroud blocks for the different stages, equation 3, was employed.

$$The\ corrosion\ rate\ factor\ (r)\ is\ given\ as:\ r = \frac{22.273W_L}{\rho AT} \quad (3)$$

By change of subject formula to due time (T),

$$T = \frac{22.273W_L}{\rho Ar} \quad (4)$$

Where,
$T = Due\ Time$
$W_L = Weight\ Loss$
$r = Corrosion\ Rate\ Factor$
$A = Total\ Surface\ Area\ of\ Part$
$\rho = Density\ of\ Part$

This model considered the use of U500 as the material composition of both the turbine buckets and shroud blocks. The U500 is an alloy steel with the following characteristics:

$\rho = 8.027kg/m^3$
$melting\ point = 1360^oC$
$r =$
$0.0004\ per\ hour\ at\ temperature\ not\ exceeding\ 1360$
^oC

The total surface area of the different stages of turbine bucket and shroud block were computed by measuring the area of the parts in segments and summing them to get a final area.
By application of equation 3,

For turbine bucket stage 1 with weight loss of 0.636kg, and total surface area (A) of $0.1828m^2$

$$T = \frac{22.273 \times 0.636}{8.207 \times 0.1828 \times 0.0004} = 24134.9\, hrs$$

For turbine bucket stage 2 with weight loss of 0.65kg, total surface area (A) of 0.1915m^2

$$T = \frac{22.273 \times 0.65}{8.207 \times 0.1915 \times 0.0004} = 23545.6\, hrs$$

For turbine bucket stage 3 with weight loss of 0.75kg, total surface area (A) of 0.2104m^2

$$T = \frac{22.273 \times 0.75}{8.207 \times 0.2104 \times 0.0004} = 24727.5\, hrs$$

For turbine shroud block stage 1 with weight loss of 0.752kg, surface area (A) of 0.2103m^2

$$T = \frac{22.273 \times 0.752}{8.207 \times 0..2103 \times 0.0004} = 24805.3\, hrs$$

For turbine shroud block stage 2 with weight loss of 0.588kg, total surface area (A) of 0.1665m^2

$$T = \frac{22.273 \times 0.588}{8.207 \times 0.1665 \times 0.0004} = 24497.8\, hrs$$

For turbine shroud block stage 3 with weight loss of 0.628kg, total surface area (A) of 0.1866m^2

$$T = \frac{22.273 \times 0.628}{8.207 \times 0.1866 \times 0.0004} = 23346.1\, hrs$$

Summary of the due time calculated for the considered turbine components .

Table 6: Due Time for Turbine Components

Components	Turbine Bucket	Shroud Block
Stages	Due Time (hr.)	Due Time (hr.)
1	24134.9	24805.3
2	23545.6	24497.8
3	24727.5	23346.1

Calculation of Efficiency for GE Frame 9E Gas Turbine

The gas turbine efficiency was calculated and modelled after a particular gas turbine that have been in operation and considered due for HGPI in the Transcorp Power Limited, Ughelli, Delta State facility. The gas turbine considered has the nomenclature of GT17 and located in Delta IV. This machine is a 100 MW installed capacity and the last date for its Major Inspection and commissioning to service was 11th November 2019. In order to compute for the efficiency of the gas turbine, equation 5, was deployed.

$$Efficiency\ (\eta) = \frac{Energy\ Output\ (Btu)}{Energy\ Input\ (Gas\ Consumed)(Btu)} \times 100 \qquad (5)$$

Where,

$$Energy\ output\ (MWh) = Power\ output\ \times number\ of\ hours \qquad (6)$$

$$Energy\ output\ (Btu) = Power\ output\ \times number\ of\ hours \times 3412000 \qquad (7)$$

$Where\ 1MWh\ equals\ 3412000\ Btu$

$$Energy\ Input\ (Btu) = Gas\ consumed(Scf) \times 1020 \qquad (8)$$

$Where\ 1Scf\ equals\ 1020\ Btu$

3. RESULTS AND DISCUSSION

3.1 Result Presentation

This section contains the results obtained from the computation and estimation of the due time for conducting HGPI of a GE frame 9E gas turbine. Also, this result was evaluated alongside the efficiencies of a unit taken under consideration in order to validate the due time computed in this study and also as recommended by the Original Equipment Manufacturer (OEM). In determining the due time, corrosion rate formula was considered which required estimating weight loss of two most significant parts of a gas turbine subjected to hot gas and designed to have most lasting period before been corroded beyond specification. A GE frame 9E gas turbine of 100MW in a selected power plant was considered for the model and evaluation.

HGPI Due Time Results

The due time of the different turbine parts were calculated using a corrosion rate factor formula and table 7 and 8 shows summary of the results.

Table 7: HGPI Due Time of Turbine Buckets

Turbine Buckets				
Stages	Weight Loss (kg)	Area (m2)	Density (kg/m3)	Due Time (hr.)
1	0.636	0.1828	8.207	24134.9
2	0.65	0.1915	8.207	23545.6
3	0.75	0.2104	8.207	24727.5

Table 7 shows the computed due time for the various turbine bucket stages with consideration to the weight loss experience since the last completed major inspection of the gas turbine (GT17) till this research study period, total surface area of new turbine buckets, and standard density value of the material (U500) used in the production of the parts. For stage 1 turbine buckets, the calculated due time was 24134.9 hours, stage 2 was 23545.6 hours and stage 3 were 24727.5 hours after the commissioning of a newly installed GE frame 9E gas turbine which can be taken as the commissioning of a gas turbine after Major Inspection. With reference to GE Frame 9E maintenance manual, the gas turbine is due for hot gas path inspection (HGPI) after 24000 running hours or 900 starts.

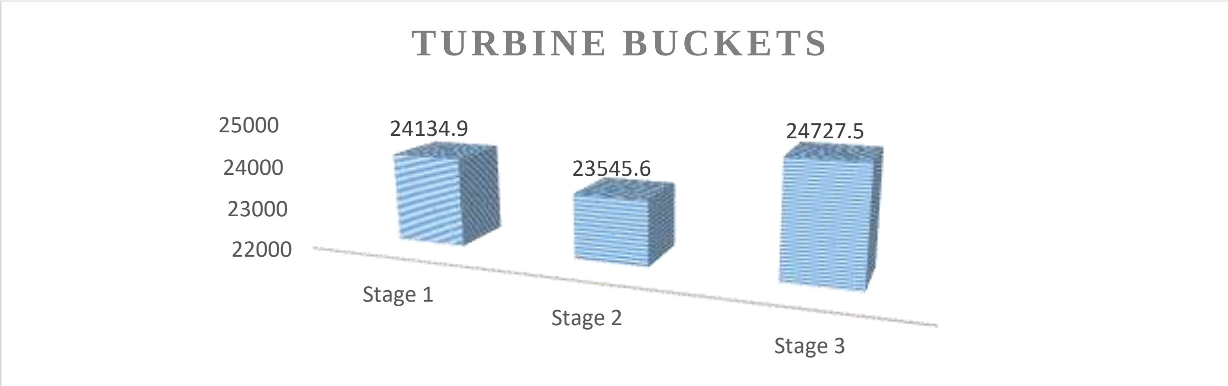

Figure 1: HGPI Due Time of Turbine Bucket

From figure 1, it can be seen that the lowest due time hour value was computed for stage 2 turbine bucket at 23545.6 hours while the highest was for stage 3 at 24727.5 hours. Hence, when compared to the recommended standard due time operation hour for HGPI by OEM (GE) of 24000 hours, deviations are +134.9 hours, -454.4 hours and 727.5 hours for stage 1, stage 2 and stage 3 turbine bucket respectively. Hence it can be said that the due time for HGPI with reference to the use of turbine buckets is 24000 ± 1000 hours where the upper limit is 25000 hours and lower limit is 23000 hours as seen in Figure 2.

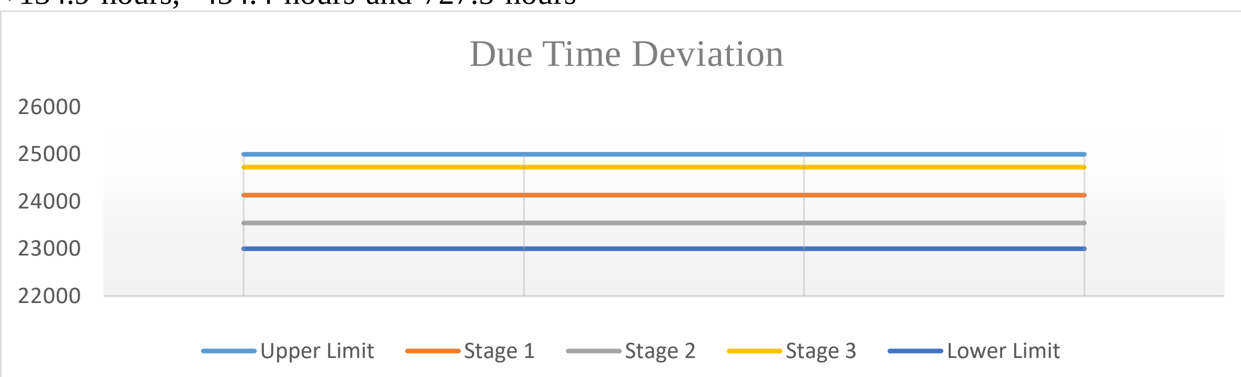

Figure 2: Turbine Buckets HGPI Due Time Deviations from Upper and Lower Limit

Table 8, shows the computed due time for the various turbine shroud blocks stages with consideration to the weight loss experience since the last completed major inspection of the gas turbine (GT17) till this research study period, total surface area of new turbine buckets, and standard density value of the material (U500) used in the production of the parts. For stage 1 turbine shroud block, the calculated due time was 24805.3 hours, stage 2 was 24497.9 hours and stage 3 was 23346.1 hours after the commissioning of a newly installed GE frame 9E gas turbine which can be taken as the commissioning of a gas turbine after Major Inspection. With reference to GE Frame 9E maintenance manual, the gas turbine is due for hot gas path inspection (HGPI) after 24000 running hours or 900 starts.

Table 8: HGPI Due Time of Turbine Shroud Blocks

Turbine Shroud Blocks				
Stages	Weight Loss (kg)	Area (m2)	Density (kg/m3)	Due Time (hr)
1	0.752	0.2103	8.207	24805.3
2	0.588	0.1665	8.207	24497.9
3	0.628	0.1866	8.207	23346.1

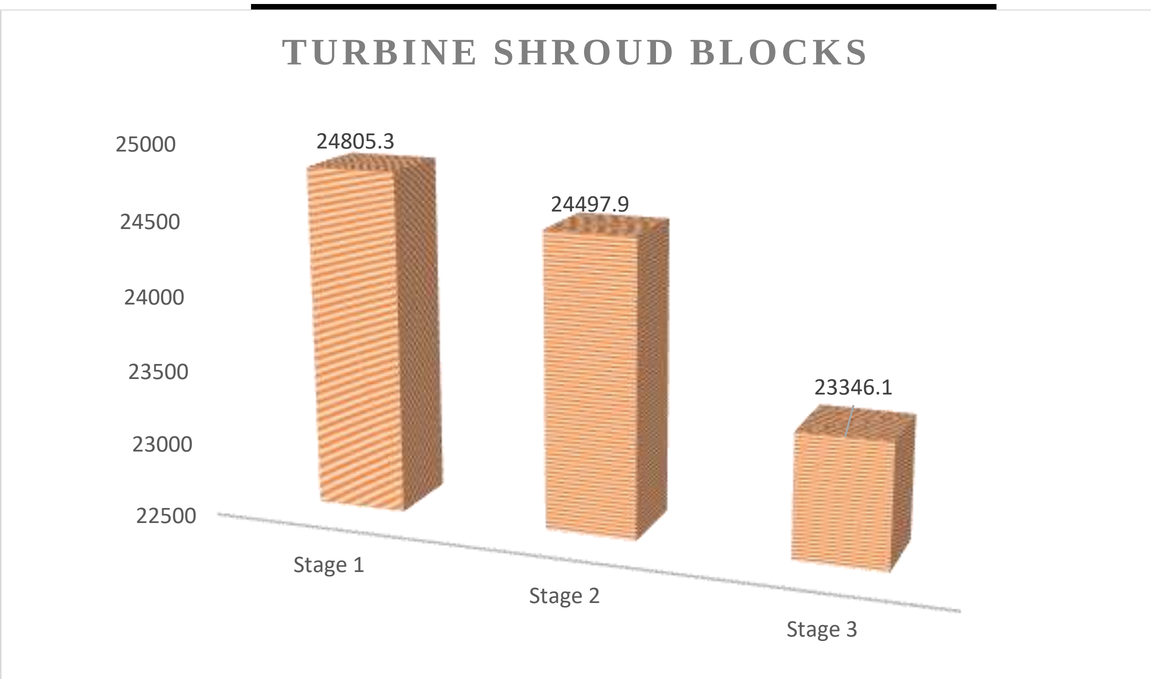

Figure 3 HGPI Due Time of Turbine Shroud Blocks

From Figure 3, it can be seen that the lowest due time hour value was computed for stage 3 turbine shroud block at 23346.1 hours while the highest was for stage 1 at 24805.3 hours. Hence, when compared to the recommended standard due time operation hour for HGPI by OEM (GE) of 24000 hours, deviations are +805.3 hours, +497.9 hours and -653.9 hours for stage 1, stage 2 and stage 3 turbine bucket respectively. Hence it can be said that the due time for HGPI with reference to the use of turbine shroud blocks is 24000 ± 1000 hours where the upper limit is 25000 hours and lower limit is 23000 hours as seen in Figure 4.

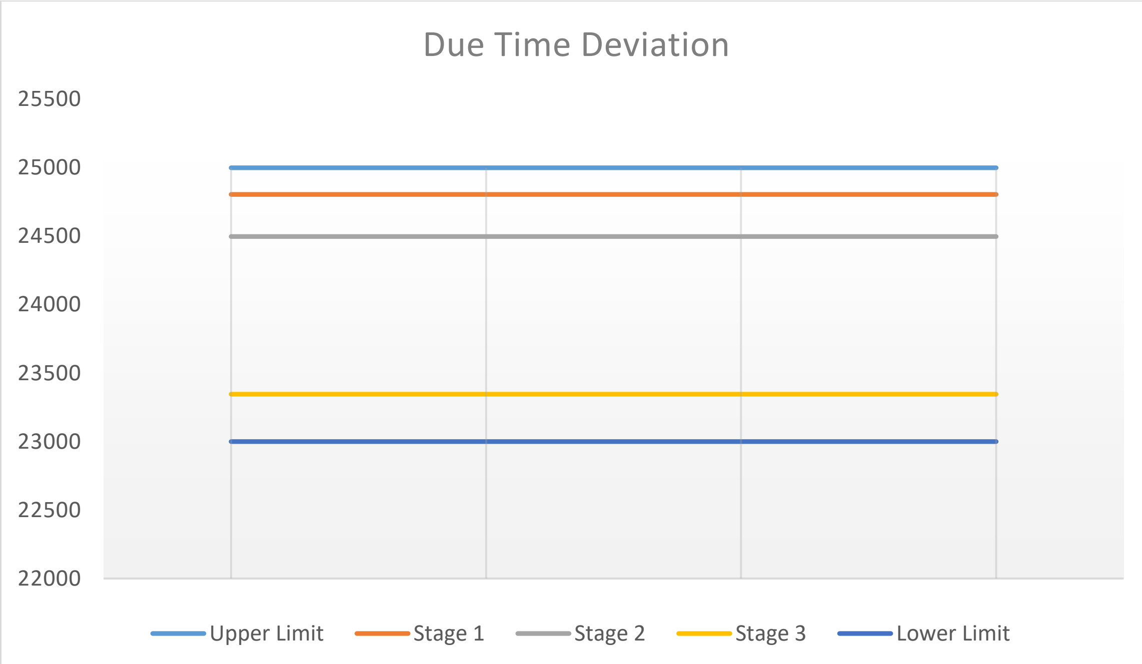

Figure 4. Shroud Blocks HGPI Due Time Deviations from Upper and Lower Limit

Performance Deterioration Evaluation

Every gas turbine suffers reduction in performance during operation with some of the causes attributed to high ambient temperature, deteriorated parts caused by corrosion, ageing and high temperature exposure. The effect of these is made manifest in loss in output, higher fuel consumption and incessant tripping of the turbine which increases the number of starts thereby bringing it closer for an inspection activity. Not to mention the fact that it affects business operation as seen with loss in revenue and increase operational cost. Overall, deterioration of gas turbine parts reduces the lifecycle period as well as increases the lifecycle cost. As much as $1million of operation cost could be added to the lifecycle cost of a gas turbine as a result of 3% power loss and 1% increase in fuel consumption (Araner, 2021). According to a study, altering the characteristics of any turbine component can lead to increase heat rate, power loss and fuel consumption and continuous exposure to high temperature serve as a factor that aids deterioration of turbine pars which invariably brings about performance deterioration as well (Araner, 2021).

To this end, the efficiency of a considered GE frame 9E gas turbine was estimated within a period and the values evaluated. For the purpose of this study, a gas turbine with nomenclature GT17 and located in Transcorp Power Limited, Ughelli, Delta State was selected, due to its certain conditions. First of all, a Major Inspection was carried out on the gas turbine about 30 months ago and there are records of its performance with regards to power output, exhaust temperature, number of trips, etc. In order to estimate the performance of the unit, its efficiencies were computed for each month since after its commissioning in November 2019 to April

2022. The efficiency was calculated by dividing the energy output in terms of power output per hour in Btu by the energy input in terms of gas consumed in Btu. The results obtained are shown below.

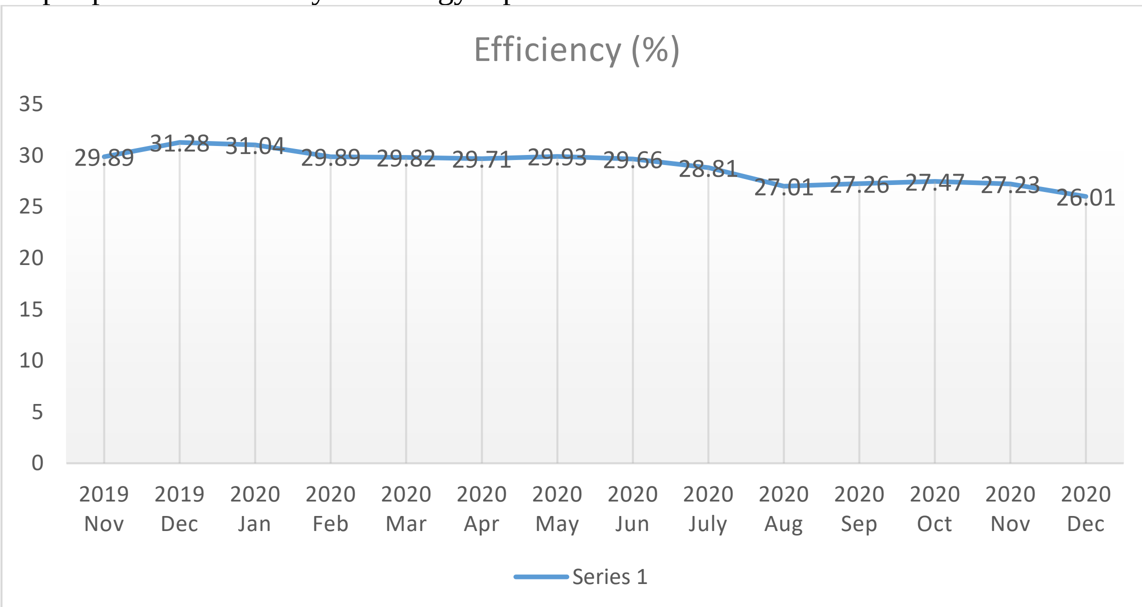

Figure 5: GT17 Efficiencies from November 2019 to December 2020

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4. DISCUSSION OF RESULTS AND CONCLUSION

The development of any nation depends on the use of electrical power to drive domestic, commercial and industrial activities and as such the need for power cannot be overemphasized. However, for electricity to be consumed, it has to be generated and there are certain machines designed for this purpose. Some of this power generating units include petrol generator, diesel generator, gas turbine, steam turbine, hydro turbine, etc. Industrially, electricity is generated and sold commercially to consumers and one of the common machines used by nations include a gas turbine. In Nigeria, there are top players in the electricity generation business and Transcorp Power Limited, Ughelli, Delta State is one of them. This power plant was considered when undertaken this study as it served the purpose of providing the necessary information to aid this study. Just like any other machine, the gas turbine fails and so needs to be maintained. According to study, it is the necessary to have a periodic inspection, based on engineering design, judgement and experience on a gas turbine in operations (Cilindro, et al., 2015). The essence of a GT inspection is to check the status of its hardware components and replace accordingly. However, inspecting a GT requires the unit to be on outage which may take long period of time to dissemble, inspect and assemble components back to position. This outage period could take several weeks, and it results in loss in revenue generation of the GT. Since the turbine is subjected to high temperature, creep, and fatigue, it is important to carry out the necessary inspection at the right time in order to prevent possible failure. Hence, the aim of this study which is to evaluate and model the due time of gas turbine with regards to carrying out hot gas path inspection for a GE frame 9E

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