Post Bi-annual Maintenance Performance of Geregu Thermal Power Plant

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ABSTRACT *-The continuous firing of a gas turbine engine make it become fouled with airborne contaminants like sand, dust, oil, salt and smoke which encrust the compressor and turbine components. Generally, the deterioration of axial flow compressors is a major cause of loss in gas turbine output and efficiency. The cleaning of the gas turbine compressor is the most effective method of preventing fouling. Cleaning maximises fuel efficiency, the life of the machine and recovers majority of lost power output. The most effective technique of cleaning the compressor and the air-filter of a gas turbine is the offline method. The technique includes injecting water into the compressor when the turbine is turned at cranking speed and requires the turbine to be shut down. This paper presents the performance evaluation of Geregu power plant gas turbine after a bi-annual maintenance operation. The performance parameters such as compressor pressure ratio, compressor discharge temperatures, turbine exit temperatures and power output improved significantly after the bi-annual maintenance operation. The generation utilization index increased from 0.55 to 0.90 andthe capacity utilization Index increased from 0.51 to 0.85 after the bi-annual maintenance operation. The station reliability index was 0.47 two months before the bi-annual maintenance operation but increased to 0.99 two months after maintenance, resulting to a total power generation increase from 66,000MWh two months prior to the bi-annual maintenance operation to 140,000MWh two months after the maintenance.*

Keywords:*Turbine, Compressor, Bi-annual maintenance, Air filter, Geregu power station.*

1.INTRODUCTION`

Gas turbine engines are fired continuously for the purpose of power generation, marine and jet propulsion. Overtime, the performance of the gas turbine deteriorated. If not checked, the deterioration will lead to non-recoverable damagesof the gas turbine engine. In Nigeria and other tropical and arid countries where gas turbines are made to operate in harsh climatic edaphic and topographical conditions, gas turbine performances deteriorate rapidly away from the design performance parameters. In some cases lost performance output could be as high as 15% [1]. The major pollutants ofgas turbines in these countries are: Salt, Oil, Dust storms and Smoke. The major indicators of performance deterioration of turbines are: Decrease in Turbine and compressorpressure ratios, decrease in turbine exhaust temperature,increase in the compressor discharge temperatures, Low thermal efficiencies,low massflow of turbineand decrease in the quantity of gas flowthroughturbine nozzles [2]. In other to sustain performance, availability, profitability and life span of the engine, it becomes inevitable for turn-around maintenance or bi-annual maintenance operations. It has become a norm worldwide for a bi-annual maintenance to be carried out on gas turbine engine after firing continuously for around 6000-8000hrs [3].However, in regions like Nigeria during the peak of the harmattan season where the parts per million (ppm) of dust particles is at its highest, it result to a greater differential pressure across the filters. And gas turbines operating offshore, where the salinity and the degree of pollutants within the sea body are extremely high, the maintenance operations are usually brought forward [4].Maintenance operations are relatively cheaperwhen compared to the cost of lost output in production that will result due to lake of carrying out such maintenance.Typically, a loss of just 5% of output could lead to a revenue loss of over $3million (3million US Dollars), because over time the revenueaccrued or invariably the profit obtained is a direct variation of the megawattsproduced [1].Typically, the thermal efficiency of a gas turbine ranges from about 33-39% at design or optimal points.Other parameters like the compressor pressure ratio, the plant heat rate, mass flow rate vary from one model to another.But they are the performance determinants of a thermal plant which invariably affect the longevity and profitability of the plant [5].These performance determinants parameters deviate from design points at specified off design conditions, like ambient temperature and altitude. However, if such deviations go beyond certain limits at any point in time, it will definitely leads to maintenance in order to recover lost output in the gas turbine.

Gas turbine engines, when fired become fouled with airborne contaminants like sand, dust, oil, salt and smoke which encrust the compressor and turbine components. Generally, axial flow compressor deterioration is a major cause of loss in gas turbineoutput and efficiency. The washing of gas turbine compressor is the most effective method of preventing fouling. Cleaning maximises output, fuel efficiency, life of machine components(bearing and blades) and recovers majority of lost output.

The cleaning of a gas turbine is done either by abrasive, online or offline [6]. The abrasive technique is also known as shot blast method. Walnut shell is the main abrasive used in this method. It has adequate strength and toughness due to its modulus of elasticity of about117MPa.The blasting isdoneusingcrushed,nuts, shells and peachstonesfedinto the inletair streamwhile the engine is running, to remove the contaminants. Theperformance improvements using this technique tend to be short livedwiththeaddeddrawbackofpossible damage toprotective coatings on theblades. Though is the most effective in removing corrosiondeposits, it is generally ineffective at high temperatures, its removes only low quantity deposit, its restore only low percentage of lost output and could block blade cooling passages.The online compressor washing technique is also known as hot wash because it isconductedwhile the engineis still running. Itaimsatextendingthe periodsbetweenoffline wash through frequentwashingofshortperiods. The washing is done by theutilisation of a set of built in spray nozzles thatinjectheated distilledwater and/ordetergent into the compressor whileatabout80%load. Thewashingcontinues forabout15minutes.This recovers much of the deterioration thathas accumulated in the past24hours.It can however not restore optimal power output when compared to offline wash.Also water based online cannot sufficiently remove oily deposits. Chemical based method cannot adequately remove salty deposits and if not properly timed could lower the surge margin of the compressor. It is only performed before a significant foulingof the compressor.The offline method is also known as crank soak or cold method and is performed when the compressor performance degrades by 10% due to heavy compressor fouling. It is undertaken about 2-3 times a year. The technique includes injecting water into the compressor when the turbine is turned at cranking speed and requires the turbine to be shut down. It is the most effective form of cleaning as it occupies less space and so decreases nozzle installation cost. It also provides longer and efficient cleaning and restores nominal power to near optimum [7].

Filters aredeemeddirty when the differential pressure across the filters exceed 12mbar for Donaldson filters [4]. A minor or semi majorcleaningwillbedone even ifvisual inspectionstates otherwise. The same cleaning is carried out when runninghoursofthe unitexceeds 6000-7000hrs and with acorresponding percentage decrease in component isentropicand thermalefficiencies,fuel flow rate capacity andoutput when compared with that of a clean engine performances.

This paper presents the use of the offline technique in the maintenance operation of the air intake-compressor systems of the gas turbine unit after large depletion of performance parameters was discovered. Emphasis will be placed on the effect of cleaning of the air intake, and the compressorduring the bi-annual maintenance operations to ascertain the impact of the maintenance operation on the overall performances.

1.1 Overview of Geregu power station Ajaokuta

The Geregu thermal power station (GPS) Ajaokuta was commissioned in 2006 by the then Nigeria president Olusegun Obasanjo. The plant consists of three independent units, each being rated at 138MW.The total installed capacity is 414MW. The Plant is located in Ajaokuta, Kogi state, Nigeria. Below is the detailed specification of a unit at design point. The plant is also served by a water treatment plant which produces demineralised water for cooling of the various sub systems making up the units. The Natural gas for firing the turbine is provided by the Nigerian gas company.

Table 1. ISO performance of Siemens V94.2[8].

Description	Values
Length (m)	6.7056
Width (m)	2.5654
Height (m)	2.04216
Weight (kg)	1500
Overall pressure ratio	22:1
Exhaust tempt (^{0}C)	540
Massflowrate (kg/s)	500
Number of compressorstages	10
Number ofturbinestages	4
Poweroutput (MW)	138
Power turbine speed (rpm)	3600
Thermalefficiency (%)	34

1.2 Indexes Theory

Theoretically, the clean engine figures are obtained from thermo dynamical relationships obtained from Carnot equation stated below:

$$T_t = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \quad (1)$$

Where $T_t$is the temperature of clean engine at particular temperature (^{0}C), (P_2/P_1) is the pressure ratio across

compressor section (bar) and (γ -1)/γ is the critical air ratio index which is constant at 1.4.
The total generation of the gas turbine is given as:

$$G_T = 24 * N_m * U \quad (2)$$

The average generation index is defined as:

$$I_G = \frac{G_A}{G_T} \quad (3)$$

The unit reliability is defined as:

$$I_R = U_n * R_h - \frac{D_{unav\,u}}{N_{RH}} \quad (4)$$

The availability index in terms of running hours is given as:

$$I_{Ava} = \frac{R_H}{R_T} \quad (5)$$

The total expenditure is defined as:

$$E_T = C_R + C_G + C_P * D_P \quad (6)$$

Taking the plant profitability index into consideration, the generational unit cost is defined as:

$$G_C = \frac{E_T}{T_E} \quad (7)$$

Where$G_T$is the total generation (MWh),$U$is the number of units available,$N_m$is the number of days (month),$I_G$is the average generation index,$G_A$is the actual generation,$I_R$is the unit reliability index,$N_{RH} D_{unav\,u}$is the downtime of unavailable unit, $R_h$is the running hours,$U_n$is the number of available units,$E_T$is the total expenditure,$D_P$is the percentage depreciation,C_P is plant cost, $C_G$is the cost of gas,$C_R$is therecurrent cost,G_C is the generation unit cost and $T_E$is the total energy sent.

2.MAINTENANCE OPERATION

2.1 Introduction

The first step in the maintenance process is the isolations of various sub-systems in the gas turbine unit and the principal central control (PCC)hallin order toenhancesafetyofoperation.

2.1.1 Isolation of the power supply unit

Theunit 6.6KVA feeder circuit breaker was opened and rackedoutandequallytaggedto alertmaintenancepersonnel.Thestatorfrequencyconverter (SFC) transformer control and the statorexciter equipment (SEE)transformer control were racked outandequallytagged.Thehighvoltagetransformer earthing was then restored inorder to enhanceadequategrounding. Finally, the isolators (transmission equipment) were opened to ensure safety of operation.

2.1.2 Isolation of the air intake unit

Theair intake subsystem was de-energisedtoenhance safety of workmen. Theintakefilters andcoalescersremovedandstackedtogetherfor cleaning. AtthePCChall, the 415VAC supply breaker was racked out to the compressor air shutoffvalve.The 415V circuit breaker of the compressor was racked out and tagged. The415Vcircuit breaker supply to theinletguide vanes (IGV)adjuster wasalso racked out andtagged. The last stage of isolating the air intake unit was to rack and tag the 220V DC supply to thecompressor blow off valve.

2.1.3 Isolation of the generator cooling system

Theunit 415V AC supplyto the generator coolingfanssub groups A &B wereracked out. Thecircuit breakersfor the415V AC supply to the generator cooling pumps 1&2 wererackedoutappropriately.

2.1.4 Isolation of the lubrication system

The 415V circuit breakersupplytothe oil vapourextractorfans was racked out. The 415V circuit breaker supply to the lift oil pumpwas racked out. The415Vcircuitbreakers supply to the auxiliaryandmain lube oil pumps areracked out. Thesupplybreakers to the emergency lube oil pumps and the turning gear shutoffvalves arealso racked out. And the415Vcircuit breaker supplyto the lube oil cooler fans isalsoracked out.

2.1.4 Isolation of the gas supply system

Theunit 220Vcircuit breaker supply to the Natural gas unloading valve isracked out. The 220V circuit breaker supply to the line vent valve wasracked out. The 220V circuit breaker supply to the main fuel inlet valve and the fuel gas bye-passvalves 1 & 2were racked out. Theunit inlet valve gas shut off valves and the inlet gas vent valves were fully opened.

2.2 Air filter cleaning

Afterthevarious isolations,theintakeairsystem, the pulsefilters and thecoalescers wereallvacuumed. Damaged and worn out filters were replaced with new ones. The cobwebs and dirt were cleaned off from the filter housing. The above process took two (2) weeks.

Figure 1. Pulse filters before cleaning

Figure 2. Pulse filters after cleaning

2.3 Compressor washing

The constituent of the solvent used in the compressor wash are made of100ppmtotal solids, 25ppm total alkali metal and 1.0ppm of other metal. The pH of the solvent was 6.5-7.5. The solvent solution mixture of 500 litres composed of mixed washing fluid of 100litres and demineralised water of 400 litres was used for the washing of the compressor.

2.3.1 Compressor washing Procedures

The gas turbine unit was shut down and allowed to cool. The differential temperature between the wash water and inter stage wheel space was check to ensure that it was below 67^{o}C.The operating compressor was de-energised during the pulse mode waterwash cycle and the intakeairflapwasopenedtoenhance airflowto prevent excess collection of waterwithin thecompressor assemblywhichcouldaffect the compressor blades. TheInletguidevanes were manuallyopened to 100% toensure entrance of goodqualityairmass flow tohastenloss of moisture to theatmosphere. Themedium pressure pumps wereon toensure continuousflowofpressuriseddemineralised water. On theoperation monitor,the compressorturbinewashandthestator frequency converter (SFC) option wereselected and allwater drains wereopened.

The actual wash Commenced with the shutting down of the turbine for 12hrs while ignitionswitch and gas pipe to exhaust manifold while fully disconnected. The compressorwash option was activated on the monitor and the pump sprayer was filled with crank solution. The turning gear valve of the crank unit was on. A jet spray valve was used to spray the compressor turbine with 25% of the crank solution. The turning gear valve of the crank unit was then off and the wash solution was allowed to stay in the turbine for 15 minutes. The speed of the machine was then taken to compressor washing speed of 600rpm (SFC initiated). While at this speed, the remaining 75% of the washing solution was injected into the compressor after which thejet and the SFC wereputoff.

After about 10 minutes,the turning gear of the crank unit was and about 25% of demineralised water solution only wasintroduced usingthe jet spray.TheSFCwas then initiated with the compressor taken to 600rpmagain. The remaining 75% of the demineralised water was injected using the conical sprayand thewater solutionwas then flush out. All the drain valves were then closed. Finally, themachine was then returned to turninggear speed awaiting startup.

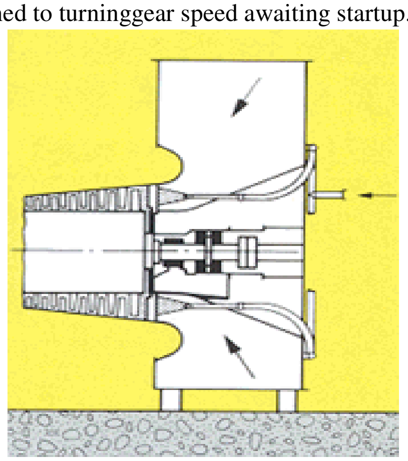

Figure 3. Offlinesystemswith direction of nozzles [1]

Figure 4. Compressor blades *before* cleaning

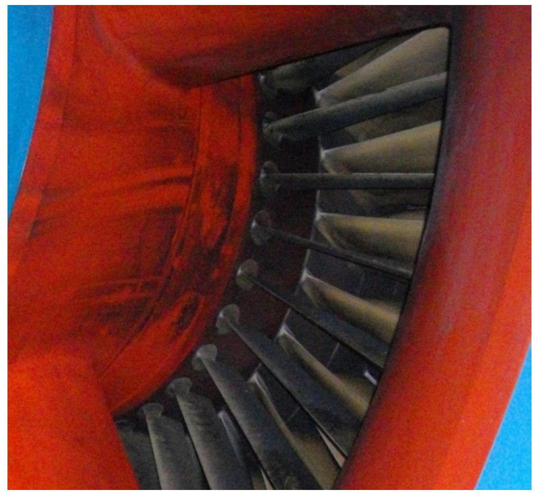

Figure 5. Compressor rotor and stator blades *after* cleaning

3. RESULTS

The performance of was recorded at 2 months and I month before the bi-annual maintenance and is shown in table 2 and table 3 respectively. The performances of a clean engine and 2 months after maintenance were recorded and the results shown in Table 4 and Table 5 respectively. Figure 6 to Figure 9 are graphical comparison of the performances of the engine at various temperatures.

Average generation index at 2 months before the bi-annual maintenance operation was33%.Average generation index at 1 month before the bi-annual maintenance was 23.31%.Average generation index at 2 months after the bi-annual maintenance operation was 75%.

The reliability index of the stationat 2 months before the bi-annual maintenance was48%.The reliability index of the station at 1 month before the bi-annual maintenance was 36.5%.The reliability index of the station at 2 months after the bi-annual maintenance was 94%.

The availability index at 2 months before the bi-annual maintenance was 75%.The availability index at 1 month before the bi-annual maintenance was 62%.The availability index at 2 months after the bi-annual maintenance was 97%.

The plant profitability index at 2months before the bi-annual maintenancewas 34%.The plant profitability index at 1 month before the bi-annual maintenance was 38%.The plant profitability index at 2 months after the bi-annual maintenance was 19%.

Table 2. Two months before bi-annual maintenance

Ambient temp. (^{0}C)	Pressure ratio (bar)	Compressor discharge temp.(^{0}C)	Turbine exit temp. (^{0}C)	Power (MW)
30.5	6.99	301	526	59
28.8	7.25	294	528	62
26.4	7.73	297	534	73

Table 3. One month before bi-annual maintenance.

Ambient temp. (^{0}C)	Pressure ratio (bar)	Compressor discharge temp.(^{0}C)	Turbine exit temp. (^{0}C)	Power (MW)
30.5	6.97	300.71	500.9	50
28.8	6.79	291.18	471.7	43
26.4	8.11	307.97	537.4	81

Table 4. Clean engine performance

Ambient temp. (^{0}C)	Pressure ratio (bar)	Compressor discharge temp.(^{0}C)	Turbine exit temp. (^{0}C)	Power (MW)
30.50	11	328	540	138
28.8	11	325	540	139
26.4	11	320	540	140

Table 5.Two months after bi-annual maintenance

Ambient temp. (^{0}C)	Pressure ratio (bar)	Compressor discharge temp.(^{0}C)	Turbine exit temp. (^{0}C)	Power (MW)
30.50	9.1	326	527	100
28.8	10.71	323	524	130
26.4	11.0	318.5	540	138

Table 6. Engine Performance computations

Description	Before	After
Generation (total)	66,328	140,328
Load factor	0.25	0.76
MWh lost to grid disturbance	367.10	0.00
Capacity Utilization Index	0.51	0.85
Generation Utilization Index	0.55	0.9
Station Reliability Index	0.47	0.99
Staff Cost Index(N/STAFF)	43.00	22
Average Plant Heat Rate (J/MWh)	20,129	12,129
Total Volume of Gas Supplied	850.34	865.34
Total Volume of Gas Required	850.34	865.34
Duration(hrs) of Gas Supply Interruptions	170.41	0
MWh Lostto GasSupply Interrupt.	276	0

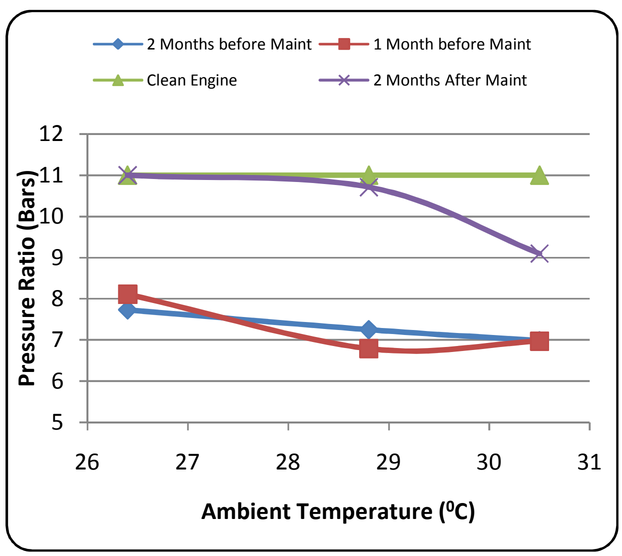

Figure 6.Compressor pressure performance

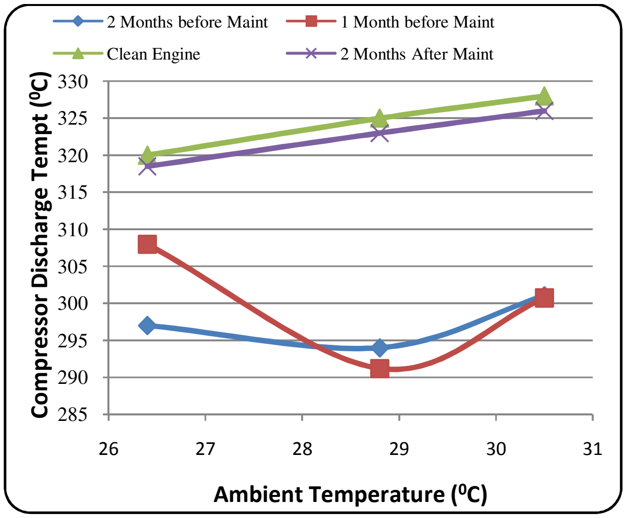

Figure 7.Compressor discharge performance

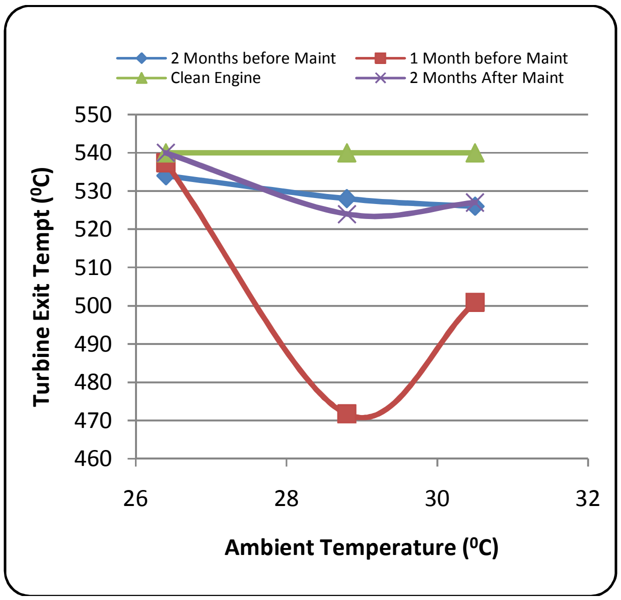

Figure 8.Turbine exit temperature performance

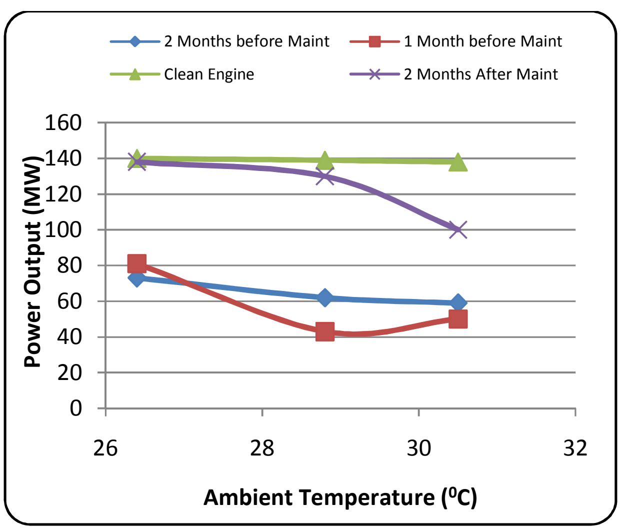

Figure 9. Power output engine performance

4. DISCUSSIONS OF RESULTS

4.1 Maintenance

In figure 6, the compressor pressure ratio was compared at different ambient temperatures for four scenarios: clean engine, 2 months before, 1 month before and 2 months after the bi-annual maintenance operation. The higher the pressure ration, the better the performances of the plant. The clean engine pressure ratio remains constant, an indication of a perfect condition. Two months before the maintenance, the ration of the plant reduces with increase in ambient temperature. At 30.5^{o}C, the pressure ratio of the plant two months maintenance has a deviation of 37%. This deviation increases to 37% at one month before the maintenance. A tremendous improvement was noticed two months after the maintenance as the deviation reduces to 8%.

The compressor discharge temperature (CDT) of the plant was expected to increase with increase in ambient temperature. It was observed that twomonthsand one before the bi-annual operation, the compressor discharge temperature reduces with increase in ambient temperature and attained a deviationof 8.3%and 9% respectively. However, two months after the bi-annual maintenance operation, it was minimised to 0.6% as shown in figure 7.

A clean machine should have no change in the turbine discharge temperature (TDT). It was observed that two months and one month before the maintenance, the TDT reduces with increase in ambient temperature and attained a deviations of 3% and 7%respectively. The impact of maintenance was glaring when twomonthsafter the maintenance operations the deviation was less than 2% (figure 8).

The power output of a clean engine 140MW. As the ambient temperature increases, the output was unchanged. Two months before the maintenance operation, the output of the turbine was 76MW at 26.4^{o}C ambient temperature. It was also observed that the output reduces to 60MW at 30.5^{o}C ambient temperature. One month before the maintenance operation, the out was 50MW at an ambient temperature of 30.5^{o}C. After the maintenance operation, the output was observed to be 100MW at 30.5^{o}C. The operation of the turbine was optimal at 26.5^{o}C when the output was observed to be the same with that of a clean engine. In terms of deviations, it was 57.3% and 63.7% for two and one month respectively before maintenance,and dropped to 9.4%two months after the maintenance operation.

4.2 Indexes Compared

The indexes obtained from calculations using equations 1 to 7 show similar trend in the performance of the turbine as discussed above. A significant reflection of the usefulness of the bi-annual maintenance operation can easily be observed in the profitabilityindex values. It is the ratio of expenditure to revenue. It indicate how when the company is doing. The index was 34% and 38% ofgeneration two and one monthbefore maintenance respectively, but reduces significantly to 19%. This reduced value is a clear indication of significant increase in the organisational profit.Table 6 shows that the total generation increased from 66,328 two months before bi-annual maintenance operation to 140,328 two months after the maintenance. The plant has more than 100% increase productivity. At the same time the generation utilization index also increased from 0.55 to 0.90. The capacity utilization Indexincreased from 0.51 to 0.85 after the bi-annual maintenance operation. It is significant to note that the station reliability index was 0.47 two months before the bi-annual maintenance operation but increased to 0.99 two months after maintenance.

4.3 Economic Impact of Maintenance Operation

From table 6, it can be seen that the total generation at two months before the maintenance operation was 66,328MWh and total generation increased to 140,328MWhtwo months after the maintenance operation. This is an increment of about 111%.Assuming 1MWh of generation wassold at $0.06, theprofit obtainable after the maintenance was about $5,000.00.This translates to an increase of 111% assuming equal number of staff strength and a marginal increment in gas consumption. Also, whenpost maintenance generation values were compared to those obtained one month before maintenance, aprofit of 210% was obtained.Thisamounts to an increase of more than $6,000assuming generation being sold at $0.06 per MWh with equal staff strength and a marginal increase in gas consumption.All these positive indices are due to increased availability ofplant as a result ofrecovered output after maintenance which was earlier lost to deterioration.

5. CONCLUSION

A successful bi-annual maintenance operation was achieved by using the offline method to clean the air filter and the compressor.After the maintenance operation, it was discovered that deviations of performance parameters such as compressor pressure ratio, compressor discharge temperature, turbine exit temperatures and power output improved significantly after the bi-annual maintenance operation.A total power generation increase from 66,328MWh two months prior to the bi-annual maintenance operation to 140,328MWh two months after the maintenance can be directly related to the overall turnaround maintenance operations. This is an increase of more than 100% in productivity level and directly implies higher revenue from wattage sold. The generation utilization index also increased from 0.55 to 0.90. The capacity utilization Index increased from 0.51 to 0.85 after the bi-annual maintenance operation. It is significant to note that the station reliability index was 0.47 two months before the bi-annual maintenance operation but increased to 0.99 two months aftermaintenance.

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