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Performance Monitoring Of Industrial Gas Turbine

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ABSTRACT: *The performance of an engine is the ultimate demand of its users. Deterioration of components has turned this important factor and has caused downtime increasing unavoidable cost. To achieve the availability and reliability of any engine is the constant enforcement of condition monitoring processes to maintain good working condition for engines in operation. Thus, the objective of the paper is to predict the performance of an industrial gas turbine using Data Analyzing procedure to check, balance and monitor the behavior of gas turbine while in service. This process is actualized using the Kolo-Greek SK30 Gas Turbine Power Plant with design output power of 20MW and thermal efficiency of 40%. The construction of the power station is to supply maximum electricity of 18 – 20MW to the Bayelsa State capital and its environs in the Niger Delta region of Nigeria but reverse is the case due to lack of maintenance culture. This has led to the production of low gross electric power distribution, decrease in thermal efficiency and high specific fuel consumption.*

Established facts shows that this drastic reduction of the measurable performance parameters which causes this low performance could be corrected and regulated with an improved ambient temperature by means of controlling the intake supply fluid with a dense air close to its designed specification. Therefore, it is necessary for gas turbine operators to be acquainted with such knowledge for quick prognosis to avoid and reduce total downtime of gas turbine.

KEYWORDS: *Gas Turbine, Performance Monitoring, Measurable Parameters, Ambient Condition, Data Analyzing Process.*

I. INTRODUCTION

The performance degradation of gas turbine components while in-service is inevitable. This likely occurrence is caused by the operating range of the engine in terms of temperature, speed, power and perhaps the environment it is installed. Gas turbine needs large quantities of air ingestion to enhance combustion processes, though the limitations to this are contamination of air foils and annulus surfaces. An ambient operating condition of gas turbine is a demanding factor for the variation of thermal efficiency and electricity production of the engine. A close observation reveals the cause of low power production as due to reduction intake of air mass flow rate [1]. The density of the air as a function of the temperature surely declines as the operating ambient temperature of the machine deviate from its design specification by an increment; however gas turbine power output and the thermal efficiency is a strong function of the ambient temperature [2,3,4]. A review literature reported that Changes in ambient conditions; pressure, temperature, and humidity affect the exhaust emission system of the engine [1].

Nevertheless, the introduction of hard particles into the gas path is capable of damaging the aero foil and seal surfaces of industrial gas turbines and this blunting of air foil leads to roughness of component surfaces, thinning of trailing edge of components such as rotor blades, stator vanes and out-shrouds [5]. Gas turbine installation on sea shores is exposed to chemical reaction within the engine components and contaminants enter the flow path of the engine through the inlet air, fuel or injected water/steam. All this reduces the performance of gas turbine by a corresponding decrease in component flow capacity, efficiency and surge margin [6,7]. It is shown by the epileptic nature of power distribution, excess fuel consumption, less efficiency distribution of industrial gas turbine. However, monitoring the performance of gas turbine online is not only maintaining or preventing engine breakdown but predictive measures to minimize maintenance cost. Therefore, monitoring the condition of gas turbine engine components is an outstanding tool to check and regulate the operating condition of the machine as it runs against its design point performance and specifications. Research has shown Condition monitoring as an early engine deterioration indicator which possibly facilitates quick diagnosis to avoid unplanned shutdown, future fault Predictions, reduction of unnecessary engine removals from operation, rapid increase of Time Before Overhaul (TBO) and gain of experience during engine operation to be used as feedback for manufacturer for better future engine design [8].

Collective research works over the time has improved maintainability of gas turbine engine from the preventive form to a predictive monitoring. This is a sensitive and reliable prognostics assessment of monitoring engine's future health. This monitoring system includes collection of engine measureable information through an instrumentation system known as Data Acquisition system; a diagnostic system which uses different Engine Health Monitoring System (EHMS); a maintenance management system that provides corrective predictive actions and Data Fusion system which is responsible for the production of high level of conclusion from diagnostic system [5]. Several excellent paper presentation are made concerning the possibility of using a detailed thermodynamic models of gas turbine and its component which is capable of separating these natural effects from the actual equipment degradation. Correct performance monitoring system provides the plant with relevant information that can help identify the cause and location of overhaul performance degradation; quantify its impact on plant operating costs, and allow better optimization of plant equipment given the current level of degradation [9,10].

Research reveals that turbine losses 0.4% power for every 1°F rise in the inlet temperature at the intake of gas turbine. On the other hand, a 1°F drop in temperature by evaporative cooling of the inlet raises the gas turbine power output by 0.4% [4,10,11]. Every engine is designed by its manufacturer with a specific loading range. Hence, excessive loading of gas turbine in its operations will lead to abnormal engine performance from its design specification of the machine. Although, a given gas turbine performance rises gradually with an increasing operating load but do not exceed its peak capacity designed for. However, studies unveils that increased loading of gas turbine system will eventually reduce the thermal efficiency performance of the machine [11]. To accurately evaluate the engine performance, the deviation between the expected and actual performance must be evaluated independently of all operating conditions using the expression in equation 1 [6].

$$\text{Deviation} = \frac{\text{Real} - \text{degrated}}{\text{Real}} \times 100\% \qquad 1$$

II. DESIGN POINT SPECIFICATIONS

The gas turbine engine used in this research is the Kolo-Greek SK30 Gas Turbine Power Plant with design specification of 20MW of gross electrical power output (PW), 40% thermal efficiency (ETATH), a compressor pressure ratio (PR) of 11:1 and a corresponding exhaust gas temperature (EGT) and mass flow (W_c) of 415℃ and 93.6kg/s respectively. It is also capable of using 1.16kg/s rate of fuel flow (FF) and 5.8Kg/KWh of specific fuel consumption with a standard fuel calorific valve (FCV) of 43124KJ/kg and the natural gas used as fuel for the engine operation [6]. This power station was built to supply maximum electricity to the Bayelsa State capital and its environs in the Niger Delta region of Nigeria have reversely turned a mirage due to its epileptic drop-age of power. This low performance of the gas turbine is an attribute to the deteriorating nature of the engine components and needed diagnostic measures.

III. GAS TURBINE OPERATIONAL DATA AND ANALYSIS

Data assemble analysis were carried out with the aid of the corresponding sensors in the control room of the said gas turbine engine. This is to collect and ensure the real performance of the engine for Data Analyzing processes. Hence, the following observations were recorded for five (5) different days according to the classification on the gas turbine operations log-sheet on table 1 while engine is in-service. Meanwhile, hours between 7 – 10am and 15.00pm on the first day, 1 – 2am on the second day; and 8 – 9am and 15.00pm on the third day were period when engine suffered shut down. Other tripped – off time of the gas turbine during the period of investigation is 18.00 – 20.00pm and 13.00pm for the fourth and fifth days respectively. However, values of thermal efficiency (ETATH), specific fuel consumption (SFC) and ambient temperature (T_{amb}) were analyzed using equations 2 – 7 below. This is to estimate the relationship between the working hours of the gas turbine to its performance parameters whereas expressions used for this determination were obtained from [12,13]. Expression 7 is possible for single spool engine; where the turbine is required to derive the compressor; so no useful work is produced.

$$\text{ETATH} = \frac{100 \times \text{PW}}{(\text{FF} \times \text{FCV})} \qquad 2$$

$$\text{SFC} = \frac{\text{FF} \times 3600}{\text{PW}} \quad \text{for shaft power engine} \qquad 3$$

$$\text{FF} = \frac{\text{Qcc}}{\text{FCV}} \qquad 4$$

$$\text{CW} = W_{cold} \bullet Cp\,(T_2 - T_{amb}) \qquad 5$$

$$\text{Qcc} = W_{cold} \bullet Cp\,(T_3 - T_2) \qquad 6$$

TW = CW   7

Table - 1 Gas Turbine Operations Logsheet of Kolo-Greek G.T.P. Station

Time (hr)	PW (KW)	QCC (KW)	Control PTET, T3 (°K)	ETATH (%)	SFC (kg/KWh)	Ambient Temp, Tamb (°K)
			DAY – 1			
1	5300	40615.7	799	13.049	0.6397371	310.8882085
2	5200	40616.2	803	12.803	0.6520478	315.945954
3	5000	40616.9	814	12.31	0.6781414	329.0646341
4	4900	40617.1	792	12.064	0.6919844	308.1255687
5	4800	40607.7	791	11.82	0.7062372	308.2885572
6	4500	40608	798	11.082	0.7533253	318.4745503
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	5100	35619.1	803	14.318	0.5830372	370.1312242
12	5100	35619.6	808	14.318	0.5830453	375.1259089
13	5300	35620.1	816	14.879	0.5610515	380.9944721
14	5300	35620.7	810	14.879	0.561061	374.9880937
15	0	0	0	0	0	0
16	2600	35620.8	733	7.2991	1.1437044	326.6896713
17	2600	35621.4	734	7.299	1.1437236	327.6832929
18	2700	35621.7	736	7.5796	1.1013728	328.617043
19	3000	35621.9	742	8.4218	0.9912411	331.4257346
20	5300	35622.4	801	14.878	0.5610877	365.9700217
21	5300	35622.9	802	14.878	0.5610956	366.9647064
22	5400	35623.4	805	15.159	0.5507127	368.8963303
23	5200	35623.9	797	14.597	0.571902	363.0171365
24	4800	35624.5	785	13.474	0.6195709	355.2630012

Time (hr)	PW (KW)	QCC (KW)	Control PTET, T3 (°K)	ETATH (%)	SFC (kg/KWh)	Ambient Temp, Tamb (°K)
			DAY – 2			
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	4378	38104.9	760.4	11.489	0.7265885	308.7809585
4	4063	38105.5	760	10.662	0.7829325	311.7232215
5	3968	38105.7	761	10.413	0.8016813	313.7310031
6	3945	38106.7	764	11.079	0.8063764	316.9648765
7	3934	38106.5	771	11.048	0.8086269	324.0839393
8	4201	35606.9	767	11.798	0.7075627	343.8178339
9	4408	35607.1	780	12.379	0.6743393	354.615172
10	5238	35607.7	803	14.71	0.5674948	368.7853893
11	5136	35608.1	805	14.423	0.5787716	371.865459
12	5179	35608.7	808	14.544	0.5739759	374.4019645
13	2746	35608.9	747	7.7114	1.0825339	339.2641068
14	5126	35609.3	810.2	14.395	0.5799203	377.1590084
15	5183	35609.8	810.9	14.555	0.5735507	377.2477484
16	5197	35610.4	810.6	14.594	0.5720152	376.7925416
17	5199	35610.8	811.6	14.599	0.5718016	377.7670281
18	5300	35611.4	810	14.882	0.5609145	375.0869584
19	6058	35611.9	827.1	17.01	0.4907376	384.1236425
20	3722	35612.6	838.4	10.451	0.7987498	420.2493005
21	6657	35613.3	834.8	18.692	0.4465984	385.4410256
22	6287	35614.1	824.6	17.653	0.472892	379.165846
23	5831	35614.6	813.1	16.372	0.5098806	372.5080878
24	5462	35614.6	804.2	15.336	0.544327	367.530782
			DAY – 3			
1	3876	37265.2	753	10.401	0.8026074	315.6440447
2	3616	37266.2	745	9.7032	0.8603401	310.3973721
3	3338	37266.3	745	8.9572	0.9319946	313.351618
4	3319	37267.1	745	8.906	0.9373501	313.545095
5	3316	37267.1	745	8.8979	0.9381981	313.5769869

6	3309	37267.3	745	8.8791	0.9401878	313.649275
7	4142	34767.7	764	11.913	0.7007278	350.3662457
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	3888	34768.9	772.2	11.182	0.7465315	361.2536633
11	3888	34768.9	772.2	11.182	0.7465315	361.2536633
12	3893	34769.3	772.8	11.197	0.7455813	361.796258
13	3850	34769.7	773.2	11.073	0.7539172	362.6491219
14	3882	34770.1	777	11.165	0.7477112	366.1046902
15	0	0	0	0	0	0
16	3413	34770.5	764	9.8158	0.8504683	358.086193
17	3806	34770.8	772	10.946	0.7626572	361.905175
18	4410	34771.3	784	12.683	0.658212	367.4789727
19	5123	34771.7	799	14.733	0.566611	374.8950972
20	5306	34772.2	801	15.259	0.5470769	374.9443807
21	5203	34772.7	796	14.963	0.557915	371.0340179
22	5029	34773.3	783	14.462	0.5772285	359.8773653
23	4743	34773.8	784	13.64	0.6120438	363.9124038
24	4515	34774.1	778	12.984	0.6429565	360.3329932

Time (hr)	PW (KW)	QCC (KW)	Control PTET, T3 (°K)	ETATH (%)	SFC (kg/KWh)	Ambient Temp, Tamb (°K)
			DAY – 4			
1	2914	35779.3	736	8.1444	1.0250045	324.6667092
2	2770	35779.8	727	7.7418	1.078305	317.1922014
3	2767	35779.9	726	7.7334	1.0794771	316.2230301
4	2755	35780.1	735	7.6998	1.084185	325.3484713
5	2751	35780.8	734	7.6885	1.0857827	324.3835523
6	3246	35781.1	738.2	9.0718	0.9202136	323.3182124
7	3691	35781.4	750.5	10.315	0.8092762	330.8844028
8	4134	35781.9	774.2	11.553	0.7225641	349.8697283
9	3491	35782.2	761.5	9.7562	0.8556589	344.0020198
10	3401	35782.6	761.5	9.5046	0.8783118	344.9545223
11	3516	35782.9	765.9	9.8259	0.8495914	348.1288132
12	3679	35783.3	771.3	10.281	0.8119589	351.7917719
13	3986	35783.7	779.2	11.139	0.7494306	356.4239231
14	3952	35784.1	782	11.044	0.7558866	359.5811115
15	4265	35784.5	794.5	11.919	0.7004214	368.7494791
16	3902	35784.8	776	10.904	0.7655874	354.1052005
17	3939	35785.2	774	11.007	0.7584046	351.7076158
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	2815	35785.6	732	7.8663	1.0612394	321.6521665
22	2814	35785.7	677	7.8635	1.0616195	266.6617341
23	2513	35786.1	721	7.0223	1.1887906	313.8572947
24	2401	35786.2	711	6.7093	1.2442478	305.0468597
			DAY – 5			
1	4117	38529.1	773	10.685	0.7812526	319.6460433
2	4027	38529.1	763	10.452	0.7987129	310.602798
3	3852	38629.8	762	9.9716	0.8371815	310.3926521
4	3837	38530.2	760.7	9.9584	0.8382874	310.3109198
5	3834	38330.8	762.2	10.002	0.8346016	313.9625547
6	4302	35330.9	772.7	12.176	0.6855952	351.3781902
7	4660	35331.4	781.1	13.189	0.632934	355.9671174
8	3911	35331.9	764.8	11.069	0.7541585	347.6241272
9	4100	35332.3	772	11.604	0.7194018	352.8106901
10	3969	35332.7	770.3	11.233	0.7431546	352.4990475
11	3693	35333.1	767.1	10.452	0.7987041	352.228843

12	3500	35334.6	769	9.9053	0.8427827	356.1646043
13	0	0	0	0	0	0
14	3714	35334.1	770.9	10.511	0.7942105	355.7949696
15	3800	35334.5	768	10.754	0.776245	351.9764851
16	3775	35334.8	769	10.684	0.7813923	353.2390611
17	4049	35335.4	778	11.459	0.7285271	359.3198962
18	4151	35335.7	776	11.747	0.7106315	356.2323851
19	4690	35336.1	788	13.273	0.628969	362.4982353
20	5449	35336.7	804	15.42	0.5413681	370.4232258
21	5364	35337.2	800	15.179	0.5499546	367.3215121
22	5173	35337.7	795	14.639	0.5702683	364.3466429
23	4724	35338.2	783	13.368	0.6244792	357.1144704
24	4432	35338.6	775	12.542	0.6656303	352.2143556

Table - 2 Adjusted Tamb to Design Point

Time (hr)	PW (KW)	ETATH (%)	Tamb (^{o}K)
Day - 1			
1	5300	13.049	297
2	5200	12.803	295
3	5000	12.31	293
4	4900	12.064	290
5	4800	11.82	288
Day - 2			
3	4378	11.489	297
4	4063	10.662	295
5	3968	10.413	293
6	3945	11.079	290
7	3934	11.048	288
Day - 3			
1	3876	10.401	297
2	3616	9.7032	295
3	3338	8.9572	293
4	3319	8.906	290
5	3316	8.8979	288
Day - 4			
1	2914	8.1444	297
2	2770	7.7418	295
3	2767	7.7334	293
4	2755	7.6998	290
5	2751	7.6885	288
Day - 5			
1	4117	10.685	297
2	4027	10.452	295
3	3852	9.9716	293
4	3837	9.9584	290
5	3834	10.002	288

IV. RESULTS

Results from this study are presented in the graphical diagrams below. They represent a star plot of some measurable performance parameters against the time duration with readings obtained in the gas turbine operations logsheet of Kolo-Greek G.T.P. station.

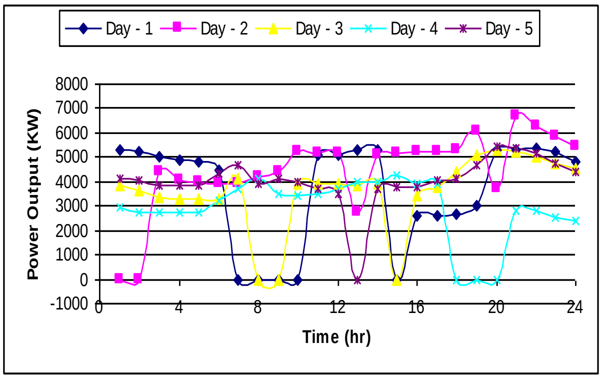

Figure 1: Variation of power with respect to operating hours

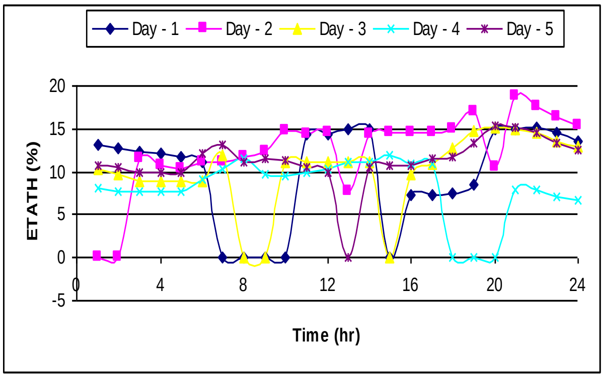

Figure 2: Variation of Thermal Efficiency with respect to operating hours

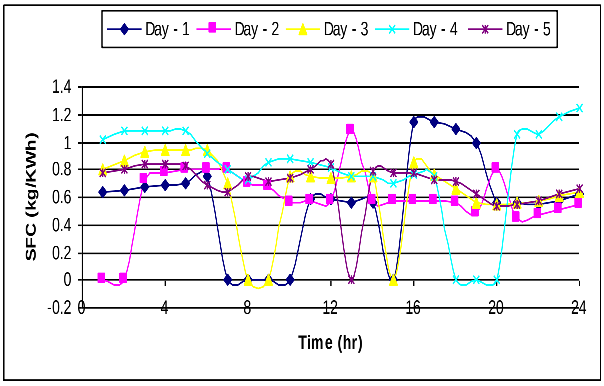

Figure 3: Variation of SFC with respect to operating hours

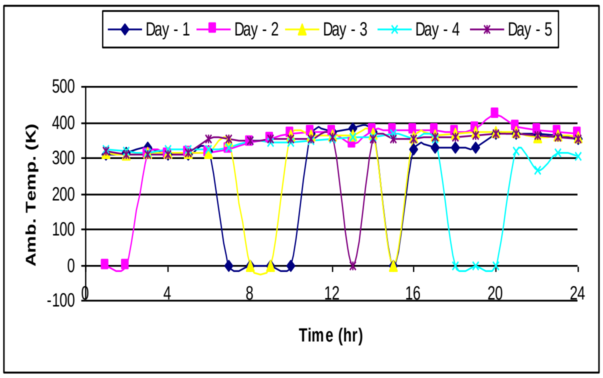

Figure 4: Variation of Ambient Temperature with respect to operating hours

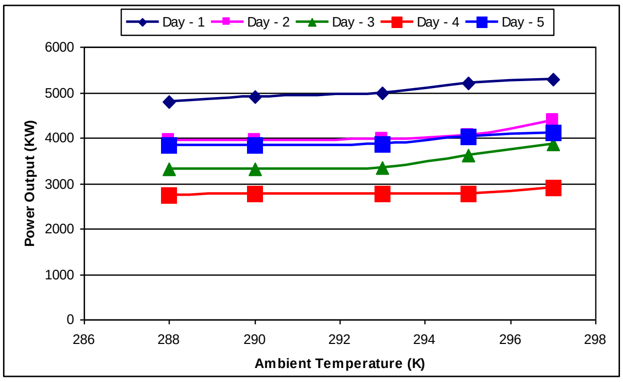

Figure 5: Turbine Power Variation with Ambient Temperature

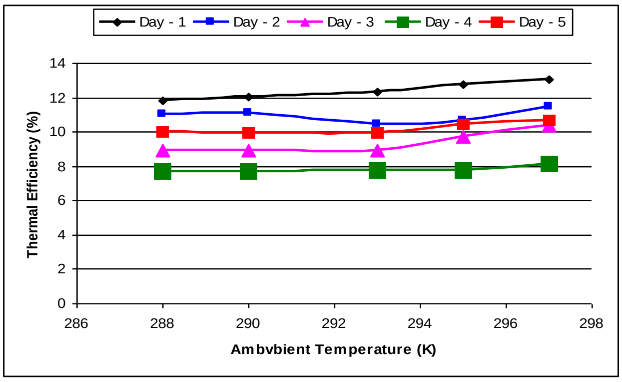

Figure 6: Thermal Efficiency Variation with Ambient Temperature

V. DISCUSSION

It is notable that results presented in figures 1 – 4 takes the shape of a wave. This is a clear picture of fluctuation of power supply from the gas turbine. Another point of discussion is the troughs of the curves in the graphs; which explains the period of shut-down/ tripped – off of the engine at the time of study. Meanwhile, the lowest electric power distribution by the turbine was noticed on the fourth day with an output of 2.41MW; and its corresponding deviation rise up to 87.95%; whereas, a drop in thermal efficiency and high specific fuel consumption rate was equally observed in same day with 6.71% and 1.244Kg/KWh pushing up deviation to 83.23% and 78.55% respectively. Another point of concern is the high increase of the control Power Turbine Entry Temperature (PTET) which drastically rises to 838.8°K with a small amount of power generation of 3.7MW which contributes 35.6MJ/h of the heat supply at the combustion chamber and an ambient temperature of 420.25°K against 288.15°K ambient condition.

In a clear observation of the first 5 – 7 hours of operation of the turbine each day, it seem to increase its operating power before the sudden fluctuation; this might be a clear indication of intake temperature at its starting point close to an ambient temperature but with the rise in temperature due to the environmental conditions enhances the elliptic situation. If this observation is taken into consideration; whereby dense air close to the temperature of the ambient condition is supplied at the intake of the engine, then the performance in figure 5 and 6 is achieved which graphically explains a better power output and thermal efficiency of the machine with respect to its ambient temperature. Meanwhile, the display of figure 5 and 6 is accomplished with the same power output from the logsheet with dense air close to the value of ambient or design temperature. See table 2.

VI. CONCLUSION

Results reveal the effectiveness of using Data Analyzing procedure to monitor the behavior of gas turbine engines as a substitute to gas turbine performance monitoring softwares. This process can be used by turbine users who are not accessible to monitoring tools like prognostic softwares. Meanwhile, research with this process identifies the gross electrical power, the thermal efficiency, and specific fuel consumption of gas turbine as dependent variable to the ambient condition. In other hand, the dependent measurable parameter of gas turbine is a function of its ambient condition. Hence, it is suggested that proficient users of gas turbines are to monitor and control the intake condition such as supply of moist air with the required pressure, temperature and humidity to boost the engine exhaust performance.

VII. ACKNOWLEDGEMENT

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