A STUDY OF THE EFFECT OF DEGRADATION ON INDUSTRIAL GAS TURBINE PERFORMANCE

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Abstract
Component degradation is a very common problem associated with operating industrial gas turbines. The major components so affected by this phenomenon are compressor, combustor and turbine blades. This paper studied the effect of degradation on gas turbine performance. The study involved the analyses of operating parameters effects for Siemens gas turbine engines model SGT5 – 2000E coded GT11 and GT21 in the power stations at Geregu power stations. The parameters considered were ambient temperature, exhaust temperature, combustion chamber pressure and turbine entry temperature, GT11 is degraded while GT21 is newly installed engine both in the same location at Geregu I and II power stations in Ajaokuta, Kogi State in the North central part of Nigeria.Simulations were carried out using Gas turb 11 simulation software, results of engine performance parameters were compared and it was revealed that due to component degradation, the turbine entry temperature (TET) increased to 1049.67°C, the fuel flow increased by 8.49% and power fell by 7.14%. Consequently, the cost of power loss is one hundred and eighty-seven million, one hundred and eleven thousand, seven hundred and fifty-three naira ninety-two kobo (₦187,111,753.92k) over a period of one year for the degraded gas turbine.

Keywords: Gas Turbine Degradation, Turbine Entry Temperature and Combustion Chamber Pressure

Introduction
The history of the gas turbine can be traced back to 1791 when John Barbar conceived the ideas for gas and steam turbines. In 1903, a Norwegian, Aegidius Elling, built the first successful gas turbine using a rotary/dynamic compressor and turbines, and is credited with building the first gas turbine that produced excess power of about 8kW. Frank Whittle in England also patented a jet turbine similar to Elling's gas turbine in 1930. The engine consisted of a centrifugal compressor and an axial turbine and was subsequently tested in April 1937 according to (Tony, 2005; Razak, 2007). Today, gas turbines are used widely in various industries to produce mechanical power and are employed to drive various loads such as generators, pumps, process compressors and propeller (Nasir et al., 2013; Zhihong, 2007). The performance and satisfactory operation of gas turbines are of paramount importance to the profitability of industries, varying from civil and military aviation to power generation, and also oil and gas exploration and production. However, as a result of long operation period, all turbo machinery experience loss in performance (Wolfgag, 2013; Zakwan et al., 2013; Rehab et al., 2008). Degradation is a decline to a lower condition in performance, quality or level as a result of aging, operating and environmental conditions (Bacos et al., 2011).

Gas turbine degradation is classified as either recoverable loss or non-recoverable loss. Compressor fouling is usually classified as recoverable loss and can be corrected by water washing or by mechanically washing the compressor blades and vanes after operation (Ezanwa, 2011). Non-recoverable losses are mainly due to increase in clearance of turbine, compressor and changes in surface finishing and airfoil contour, since this loss is as a result of reduction in components efficiencies. It is hardly recovered by means of external maintenance or compressor cleaning and operation procedures, except by means of replacement of the affected parts at recommended inspection periods. The economic effect of degradation in a gas turbine power can be severe. All gas turbines deteriorate in performance during operation, leading to reduction in capacity and thermal efficiency (Jonathan, 2002). Loss of capacity results in lost production, affecting revenue. Loss in thermal efficiency increases fuel consumption and therefore leads to higher fuel costs. Both of these factors reduce profit. However, degradation in a gas turbine can only be minimized and cannot be eliminated completely (Salihu et al., 2015). Figure 1 shows a degraded gas turbine blade.

Plate 1: Degraded turbine blade tips (Bacos, 2011)

Materials and Methods

Field Stations and Materials

The major materials used in this research work are the newly installed and old Siemen gas turbines (SGT 5 – 2000E) located at Geregu, in Ajaokuta Local Government Area of Kogi State, Nigeria. The gas turbines were installed in 2005 and 2013 respectively. Simulation software called Gas Turb 11 was also used to generate engine parameters using ISO and design conditions i.e standard atmospheric pressure, temperature and design pressure and temperature. This was done to provide bases for comparison.

This Siemens gas turbine is used mainly for power generation and designed to the capacities of 145MW and 160 MW at base and peak loads respectively. Geregu power stations I (GT 11) has been in operation since 2005 and Geregu power stations II (GT 21) started operating in 2013.

Gas Turbine Performance Data

Performance data of the gas turbine units under investigation are ambient temperature, turbine entry temperature (TET), exhaust temperature (EXT), combustor chamber pressure in bars (CCP) and power output in megawatts (MW). Degraded physical components were also considered. Data collected from Siemens gas turbine SGT5 – 2000E coded GT11 and GT21in the power stations (Degraded and Newly Installed) engines were analyzed by comparison. Gas Turb 11 was used to produce Design point simulation for the engine. Table 1 shows the specification of SGT 5–2000E gas turbine. The data were collected from the period of May to October, 2014.

Table 1: Specifications of ISO and Siemens Gas Turbine SGT 5–2000E for performance

Parameters	SGT 5 – 2000E	ISO performance
Ambient temperature (°C)	15	15
Turbine Entry temperature (°C)	1050	1013
Pressure ratio (bar)	12.0	12.0
Relative humidity (%)	70	70

Results and Discussion

Influence of Ambient Temperature on Power Output

The variation of ambient temperature and load from day to day are shown in Figure 2. The power output at the terminals decreases from 155.8 MW to 140 MW as the ambient temperature increases from 18°C to 32°C respectively as shown in Figure 3. The range of ambient temperature in Geregu power station varied typically between 29°C to 34°C in June. In gas turbines, generally, temperature variation leads to change in the maximum engine power output as shown in Figure 3. Due to component degradation on GT 11 and the changes in the ambient temperature, it was difficult to achieve the base load requirement of 145MW, unless the parameters were varied. However, all the engine parameters such as mass flow, efficiency and TET fluctuates as a result of changing ambient temperature.

The new and old engines were meant to operate on base load at anoutput of 145MW. However, it could be observed that as a result of component degradation, the degraded engine (GT11) could not achieve the expected output at base load, while the newly installed engine (GT21) could achieve above the expected Megawatts if the operating conditions are favourable as shown in Figure 4.

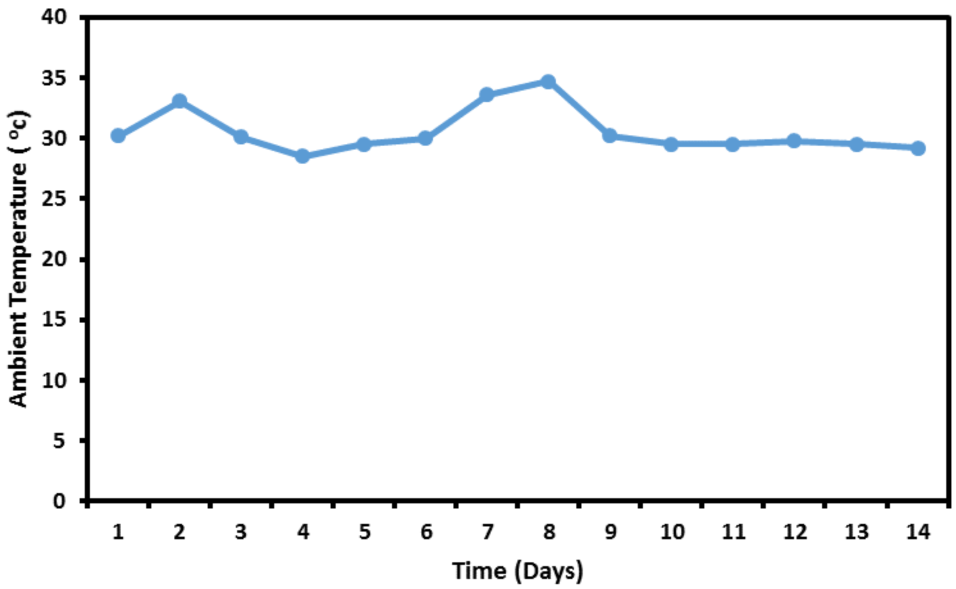

Figure 2: Variation of ambient temperatures

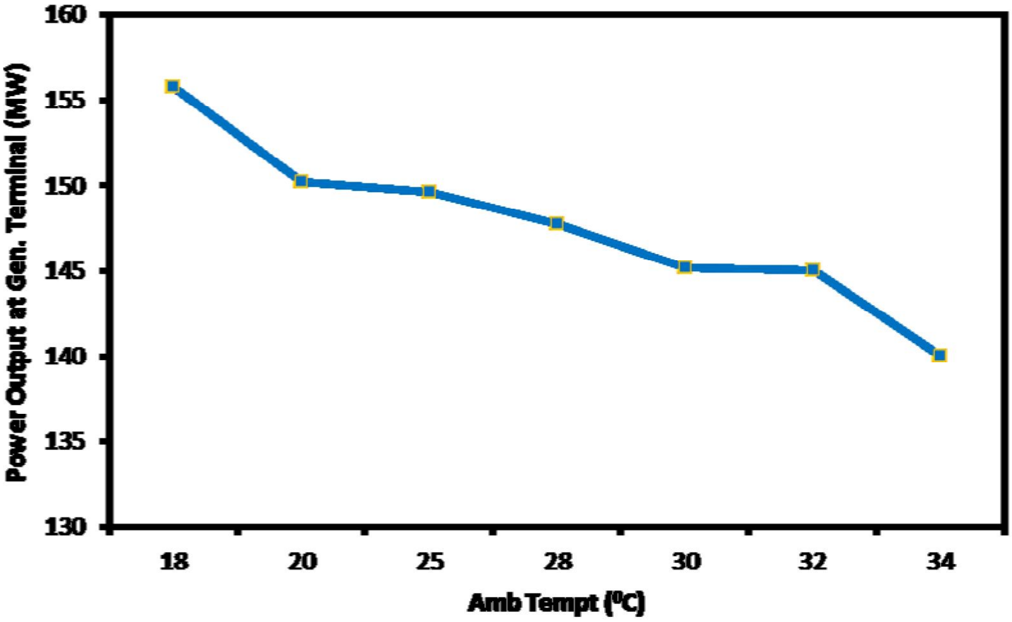

Figure 3: Effect of ambient temperature on engine power output

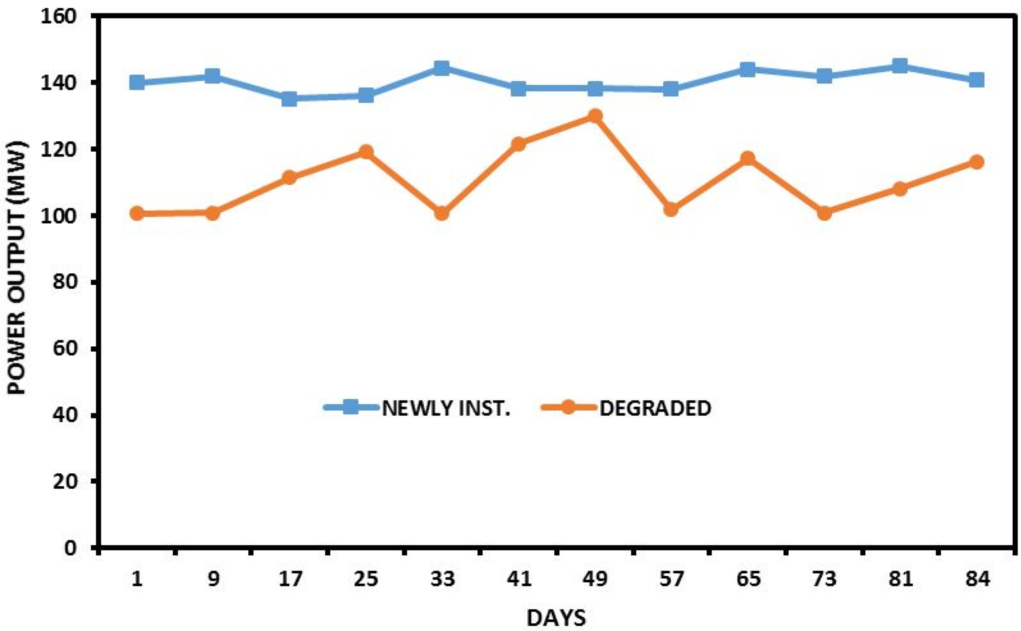

Figure 4: Power output performance of new and old engines

Turbine entry temperature (TET) deviations analysis

Figure 5 shows that onthe 29th day of the study, the degraded engine shows a lower TET, with the progress of time especially at day 78; however, this deviation was observed as a result of increase in TET of the degraded engine due to component degradation. Eventually, the degraded engine TET becomes higher than the newly installed engine TET. The results, however shows that the degraded engine TET at day 29 was 1328.2 K. The newly installed engine TET was 1317.52 K and deviation between them was 10.68 K, also on day 78, the degraded engine TET reached 1333.35 K and the newly installed engine TET reached 1311 K. Normally the higher the TET the higher the power output but due to degradation of GT11 increase in TET does not result in increase in power output.

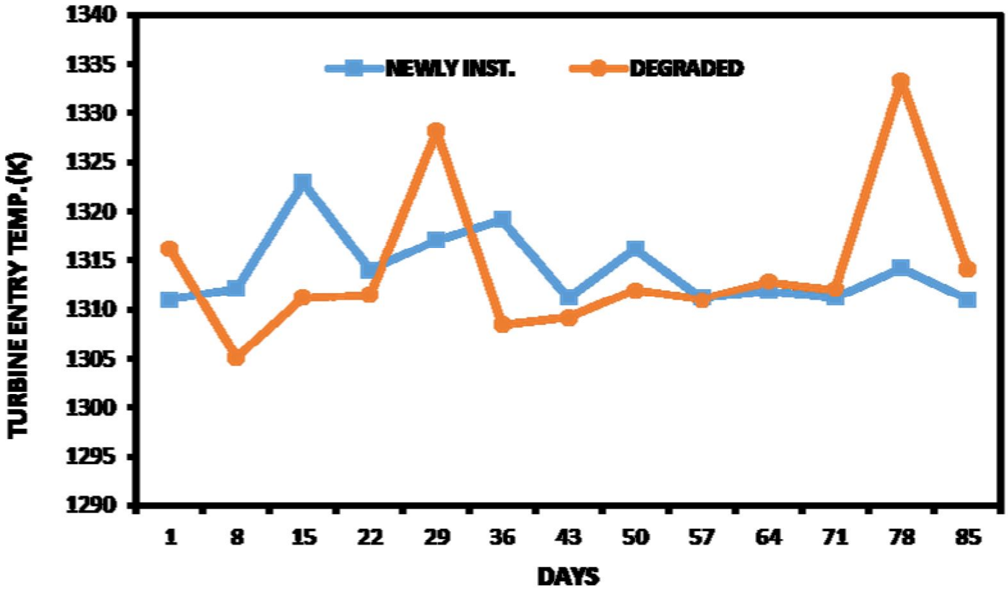

Figure 5: Variation in turbine entry temperature deviation

Combustion Chamber Pressure Deviation Analysis

The combustion chamber pressures (CCP), which wereobtained from the engines is shown in Figure 6 and compared for both SGT 21 and SGT 11. From the graph, at day 8 degraded engines CCP indicates relatively low value of 1015Kpa, in day 84 the degraded engine CCP reaches 1067Kpa while CCP for newly installed SGT21 was maintained at 1030 Kpa. The deviation of 37Kpa that occurred in the CCP for SGT11 was due to component degradation. The increasing of CCP as result of increasing turbine entry temperature verified that, the engine performance has degraded with time progress.

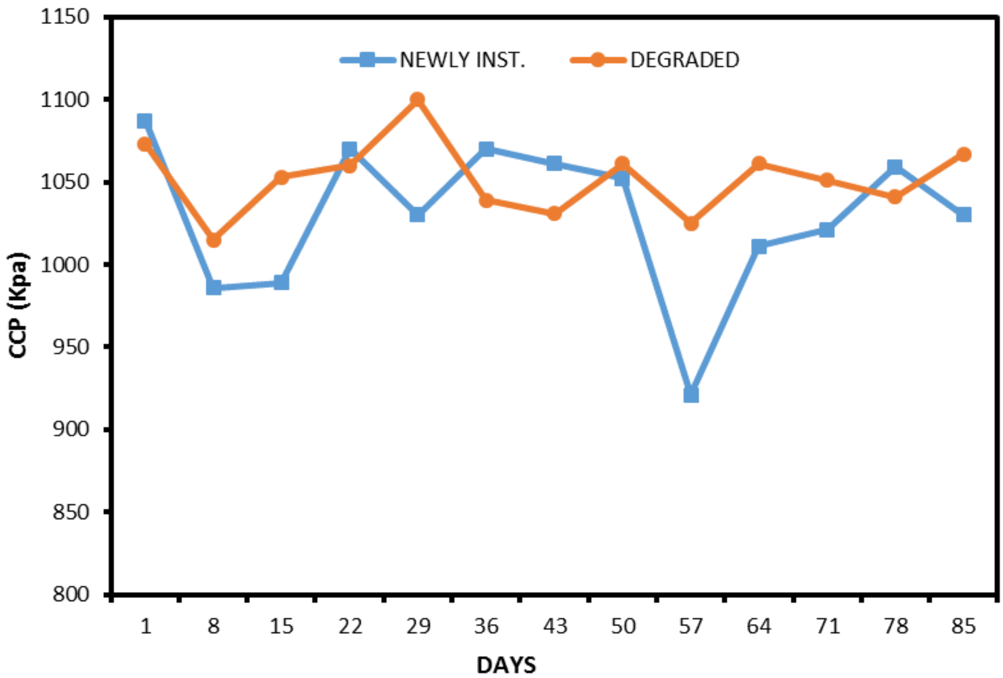

Figure 6: Variation in combustion chamber pressures

Economic Impact of Degradation on Engine Operating Cost

As part of the study of effect of degradation on gas turbine performance, the outcome of degradation has to be discussed from economic point of view. However, to achieve this, the cost penalty has to be analyzed in terms of power loss, increase fuel flow and reduced blade creep life. From the previous section, it was shown that the power reduced from 139.99MW to 130MW as a result of increased TET at 1311K of GT11engine due to degradation, it was shown that power reduced by 9.99MW. In the remaining period of time, the engine is expected to produce the same power output until a major overhaul. Therefore, the power loss cost penalty will be calculated, in order to determine the effect of degradation on engine operating cost from the result. Assuming the engine on same load operation for 78 days (1872 hours), a power output of 139.99MW, cost of electricity of N5/KWh and a power loss of 7.14% for same period, the power loss cost will be ₦93, 555,876.96k.

Conclusion

In this research, effects of degradation on gas turbine performance have been studied. The major components affected by degradation are compressors, combustor and turbine blades but the most common form of performance degradation is compressor fouling and this is as a result of ingestion of dirt and dust from the operation environment. Component degradation resulted to reduced compressor capacity, efficiency, turbine creep life and combustion chamber pressure drop. From the findings of this study, the operating parameters especially, exhaust temperature and turbine entry temperature TET of GT11 increased to 555^{o}C and 1049.67^{o}C compared with 540^{o}C and 1038^{o}C of GT21 for a given output of 130.0MW and 139.99MW respectively. If GT11 engine is not overhauled, in a year the company stands to lose the sum of one hundred and eighty-seven million, one hundred and eleven thousand, seven hundred and fifty-three naira ninety-two kobo(₦187,111,753.92k) only, to component degradation.

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