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PERFORMANCE ANALYSIS OF GAS TURBINE POWER PLANT (A CASE STUDY OF DELTA III GT9 TRANSCORP GAS TURBINE POWER PLANT, UGHELLI, NIGERIA)

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KeyWords

Gas turbine power plant, Performance, Analysis, Thermodynamic principle, Data, Thermal efficiency

ABSTRACT

This research work is focused on the analysis and performance evaluation of a gas turbine power plant. The gas turbine power plant was evaluated using thermodynamic principles and the technical data of the plant. The data used for the study were obtained from the plant records of Delta III GT9 plant. The results of the analysis for a period of twelve (12) months (January to December, 2016) show that 92% of the expected capacity was available in the period under study. The thermal efficiency of the plant ranged from 26% to 32%, and the plant's capacity factors ranged from 68% to 80%. The reliability of the plant ranged from 21% to 98% (average 58%). For the period under study, only 20 MW of energy (power) was lost out of the expected power of 240 MW. The study revealed that the above performance parameters analyzed for Delta III GT9 plant are within the range of best industrial practice. Also, the efficiencies achieved for the period under study are within the best international value for a single cycle gas turbine plant.

Introduction

A gas turbine, also known as a combustion turbine, is a rotary engine that removes energy from a flow of hot gas produced by the combustion of gas or fuel oil in a stream of compressed air. It has an upstream air compressor with radial or axial flow mechanically coupled to a downstream turbine and a combustion chamber in between. Energy is released when compressed air is mixed with fuel and ignited in the combustion chamber (combustor) [1]. Energy is removed from gas turbine in the form of shaft power, and this is used to power electric generators and other machineries [1]. Gas turbines are becoming increasingly used for power generation for wide variety of applications around the world. The gas turbine performance is affected by the component efficiencies and turbine inlet temperature [1-3].

Gas turbine performance is critically limited by temperature variation, especially in hot and rain region like Sub-Sahara Africa [4]. The increases in inlet air temperature become more noticeable especially in the hot weather, and this causes a significant decrease in gas turbine power output. It occurs because the power output is inversely propor-tional to the ambient temperature and because of the high specific volume of air drawn by the compressor [5]. The efficiency and power output of gas turbines changes according to the ambient conditions [6]. The resulted amount of these disparities greatly affects electricity generation, fuel consumption and plant incomes [7]. The effect of temperature is very predominant; for every 56 degree Celsius increase in turbine temperature, the work output increases approximately 10% and gives about 1.5% increase in efficiency [8]. The overall efficiency of the gas turbine cycle depends primarily upon the pressure ratio of the compressor [8].

The performance analysis of a gas turbine power plant is geared basically towards the determination of the energy efficiency of the plant [9]. A plant's energy efficiency has definite economic significance since the heat input at high temperature represents the energy that must be purchased and the net energy output represents the return for the purchased energy. Basically gas turbine which operates at lower turbine inlet temperatures will result in low performance and decreased efficiency. Lower efficiency of gas turbine means that low power output is produced [10]. According to Kakaras [11], the gas turbine output and efficiency is a strong function of the ambient air temperature. For every 1^oC rise in ambient temperature above ISO-rated conditions, the gas turbine losses 1% in terms of thermally efficiency and 1.47MW of its gross power output. At the same time the specific heat consumption increases by a percentage between 1.5% and 4%. The ISO ratings for ambient conditions are: ambient temperature, 15^oC, ambient pressure, 1bar (100.16kPa), and relative Humidity of 60% [12-13]. Lamfon [14] investigated the performance of a 23.7 MW gas turbine plant operated at ambient temperature of 30^oC to 45 ^OC. The net power output is improved by 11% when the gas turbine engine is supplied with cold air at the inlet. At the ambient temperature of 30^oC the net power output increases by 11% at ISO-rated condition, accompanied by a 2% rise in thermal efficiency and a drop in specific fuel consumption of 2%. Mohanty [15] reported that increasing the inlet air temperature from the ISO-rated condition to a temperature of 30^oC, would result in a 10% decrease in the net power output. For gas turbine of smaller capacities, this decreased in power output can be even greater. He also indicated that a rise in the ambient temperature by 1^oC resulted in 1% drop of the gas turbine rated capacity. Ameri [16] reported that when the ambient temperature decrease from 34.2^oC to ISO-rated condition, the average power output can be increased by as much as 11.3%. He also pointed out that 1^oC increase in ambient air temperature resulted in the power output and decreased the efficiency by 0.74%.

Considering the vital role energy plays in a country's economic development and its expected significant future demand, energy conservation and efficient use becomes a major option. This research work therefore, evaluates the performance (in terms of efficiency and reliability) of Delta III GT9 (Hitachi H25 Gas Turbine Generator) plant of Transcorp Power Station Ughelli, over a period of one (1) year (January to December, 2016).

Research Methodology

The performance analysis was carried out on Delta III GT9 (Hitachi H25 Gas Turbine Generator) plant. Several trips were made to the plant during which operational data were collected from plant records from January to December, 2016 prepared by the Efficiency Department. The performance analysis is done based on thermodynamics principles, and the technical data of the plant.

2.1 Data Collection

The data used for this work were collected from Delta III GT9 (Hitachi H25 Gas Turbine Generator) plant's operational data from January to December, 2016. Information on the following parameters was used in the analysis:

i. Energy (power) generated by the plant (MW)
ii. Mass of fuel consumed (kg)
iii. Installed capacity of the plant (i.e. 25 MW)
iv. Gross Calorific value of fuel (Natural gas)(i.e. 52590kJ/kg)
v. Running Hours
vi. Downtime

2.2 Data Analysis

The performance of a gas turbine depends on several parameters and the most important are:

i. Compressor efficiency
ii. Turbine efficiency
iii. Thermal efficiency
iv. Plant heat rate
v. Plant fuel rate
vi. Capacity factor
vii. Reliability

In this study, the above parameters for a period of twelve (12) months (January to December) of the year 2016 were determine as the performance indicators of the plant. The key parameters are the plant capacity factor, plant fuel rate, plant Heat rate, and the thermal efficiency of the plant.

2.2.1 Power Generated and PLANT Capacity Factor

Table 1 shows the power generated and the capacity factor per month. The power generated is gotten from the data provided by the Efficiency Department.

Table1: Power Generated and the Capacity Factor of the Plant

Months	Power Generated (MWH)	Running Hours	Power Generated (MW)	Available Power (MW)	Capacity Factor (%)
January	11,817	607	19	20	76
February	5,967	329	18	20	72
March	2,681	159	17	20	68
April	11,612	609	19	20	76
May	10,381	593	18	20	72
June	5,067	281	18	20	72
July	5,388	275	20	20	80
August	9,861	523	19	20	72
September	5,602	322	17	20	68
October	7,786	428	18	20	72
November	4,200	230	18	20	72
December	13,809	731	19	20	76
Total			220	240	
Average			18.33	20	

The drop in the capacity factor below 70% in the month of March and September was as a result of major inspection that was carried out on the plant.

2.2.2. Capacity Factor (CF)

From the table above the capacity factor was gotten by dividing the power generated by the plant capacity by the plant installed capacity.

$$Capacity\ Factor = \frac{Power\ Generated}{Plant\ Installed\ Capacity} \times 100\% \quad (1)$$

2.2.3 Plant Heat Rate (HR)

$$Plant\ Heat\ Rate = \frac{Heat\ Supplied\ (KJ/h)}{Power\ Output\ of\ Turbine\ (MW)} \quad (2)$$

The values for the plant heat rate were obtained by calculations based on the operational data obtained. Table 2 shows the plant heat rate per month for the year 2016.

Table 2: Plant Heat Rate

Months	Total Heat Supplied (KJ/h)	Total Power Output (MW)	Plant Heat Rate (KJ/MWH)
January	261,477,480	19	13,761,973
February	242,965,800	18	13,498,100
March	225,874,050	17	13,286,909
April	216,460,440	19	11,392,655
May	226,189,590	18	12,566,088
June	203,681,070	18	11,315,615
July	247,856,670	20	12,392,834
August	236,812,770	19	12,463,830
September	221,983,390	17	13,057,846
October	233,815,140	18	12,989,730
November	245,910,840	18	13,661,713
December	242,702,850	19	12,773,834
Total			153,161,127
Average			12,763,427

2.2.4. Plant Fuel Rate (SFC)

$$Plant\ Fuel\ Rate = \frac{Mass\ of\ fuel\ consumed\ per\ hour\ (kg/h).}{Power\ Output\ (kW)} \times 100\% \quad (3)$$

The values for the plant fuel rate were obtained by calculations based on the operational data obtained. Table 3 shows the plant fuel rate per month for the year 2016.

Table 3: Plant Fuel Rate

Months	Total Fuel Consumption (Kg/h)	Total Power Output (KW)	Plant Fuel Rate (Kg/KWh)
January	4,972	19000	0.262
February	4,620	18000	0.256
March	4,295	17000	0.253
April	4,116	19000	0.217
May	4,301	18000	0.239
June	3,873	18000	0.215
July	4,713	20000	0.236
August	4,503	19000	0.237
September	4,221	17000	0.248
October	4,446	18000	0.247
November	4,676	18000	0.260
December	4,615	19000	0.243
Total			2.913
Average			0.243

3.2.5 Thermal Efficiency (η_{th})

$$Thermal\ Efficiency = \frac{Power\ Output}{Heat\ Supply} \times 100\% \quad (4)$$

The values for the thermal efficiency of the plant were obtained by calculations based on the operational data obtained. Table 4 shows the thermal efficiency of the plant per month for the year 2016.

Table 4: Thermal Efficiency of the Plant

Months	Power Output (kW)	Total Fuel consumed (kg/s)	Calorific Value (kJ/kg)	Thermal Efficiency (%)
January	19000	1.3811	52590	26
February	18000	1.2833	52590	27
March	17000	1.1931	52590	27
April	19000	1.1433	52590	32
May	18000	1.1947	52590	29
June	18000	1.0758	52590	32
July	20000	1.3092	52590	29
August	19000	1.2508	52590	29
September	17000	1.1725	52590	28
October	18000	1.2350	52590	28
November	18000	1.2989	52590	26
December	19000	1.2819	52590	28

2.2.6 Reliability of the Plant

$$Thermal\ Efficiency = \frac{Expected\ Running\ Hours - Down\ Time}{Expected\ Running\ Hours} \times 100\% \quad (5)$$

Table 5 shows the calculated values of gas turbine plant reliability.

Table 5: Reliability of the Plant

Months	Expected Running Hours	Actual Running Hours	Downtime(Hrs.)	Reliability (%)
January	744	607	137	82
February	672	329	343	49
March	744	159	585	21
April	720	609	111	85
May	744	593	151	80
June	720	281	439	39
July	744	275	469	37
August	744	523	221	70
September	720	322	398	45
October	744	428	316	58
November	720	230	490	32
December	744	731	13	98

The drop in reliability below 40% for the month of March, June, July, and November was as a result of major inspection that was carried out on the plant also the plant was out of service for a period due to gas shortage.

2.2.7. Compressor Efficiency (η_c)

The values for the compressor efficiency of the plant were obtained by calculations based on the operational data obtained. Table 6 shows the efficiency of the compressor in each month for the year 2016.

Table 6: Compressor Efficiency (for 2016)

Months	Compressor Efficiency (%)
January	82
February	81
March	80
April	82
May	81
June	81
July	83
August	82
September	80
October	81
November	81
December	82

2.2.8 Turbine Efficiency (η_t)

The values for the turbine efficiency of the plant were obtained by calculations based on the operational data obtained. Table 7 shows the efficiency of the turbine in each month for the year 2016.

Table 7: Turbine Efficiency

Months	Turbine Efficiency (%)
January	79
February	78
March	77
April	79
May	78
June	78
July	80
August	79
September	77
October	78
November	78
December	79

Results and Discussion

The power generated for the period under study is shown in Figure 1.

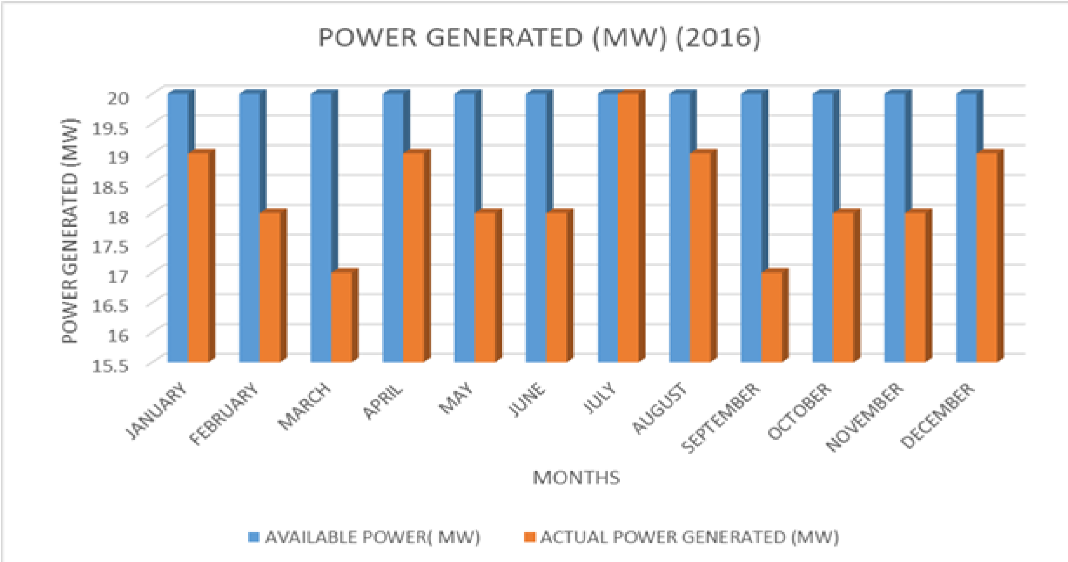

Figure 1: Power generated by Delta III GT9

The expected full load installed capacity of the plant under study is 25 MW of power for each month, then for the whole year (January to December) it is expected to generate a total of 300 MW of power. But the available capacity (the obtainable power) for each month is 20 MW (240 MW/year), and the actual generated capacity for each month ranges from 17 MW to 20 MW (Figure 1). The average actual power generated by the plant from the data obtained for the period under study is about 18 MW, and the total actual power generated is 220 MW against the 240 MW available powers. This shows that only 20 MW is lost, hence about 92% of the available power was actually available. The power lost was as a result of the plant being out of service for a period in the month of March, June and July due to gas shortage. Also, in the month of November a major inspection (MI) was carried out on the plant resulted to downtime. The plant capacity for the period under study is presented in Figure 2.

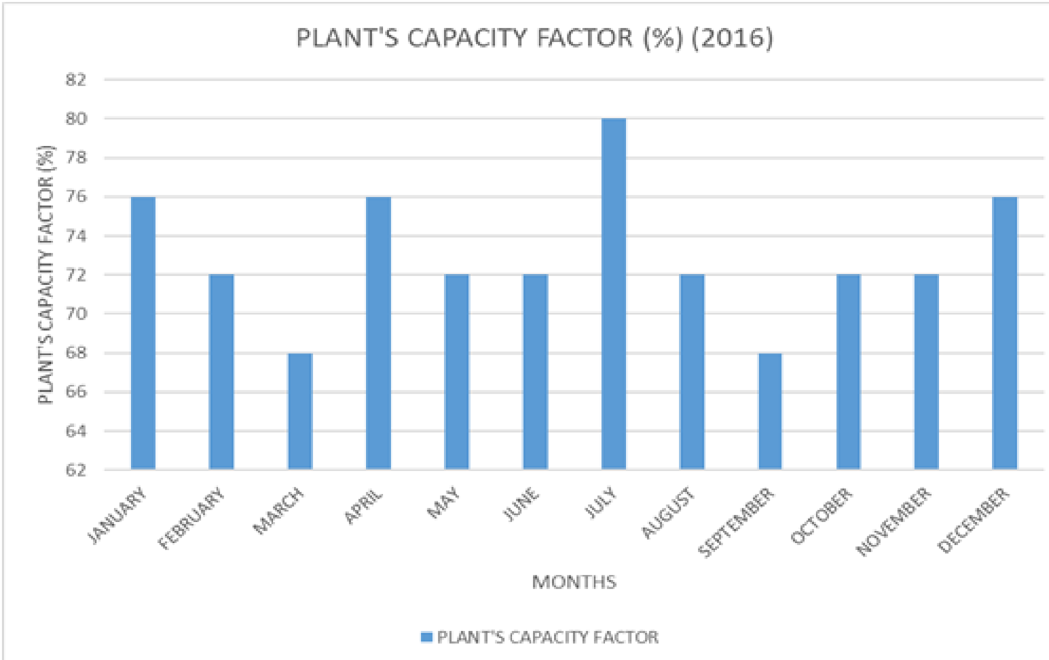

Figure 2: Plant's Capacity Factor

The average capacity factor of Delta III GT9 from the data obtained from the period under study is 73% with a minimum value of 68% in the month of March and September, and a maximum value of 80% in July against the best industrial practice (between 40% to 80%). The values of the plant's capacity factor signify that the average power generated is acceptable. The thermal efficiency of the plant for the period under study is shown in Figure 3.

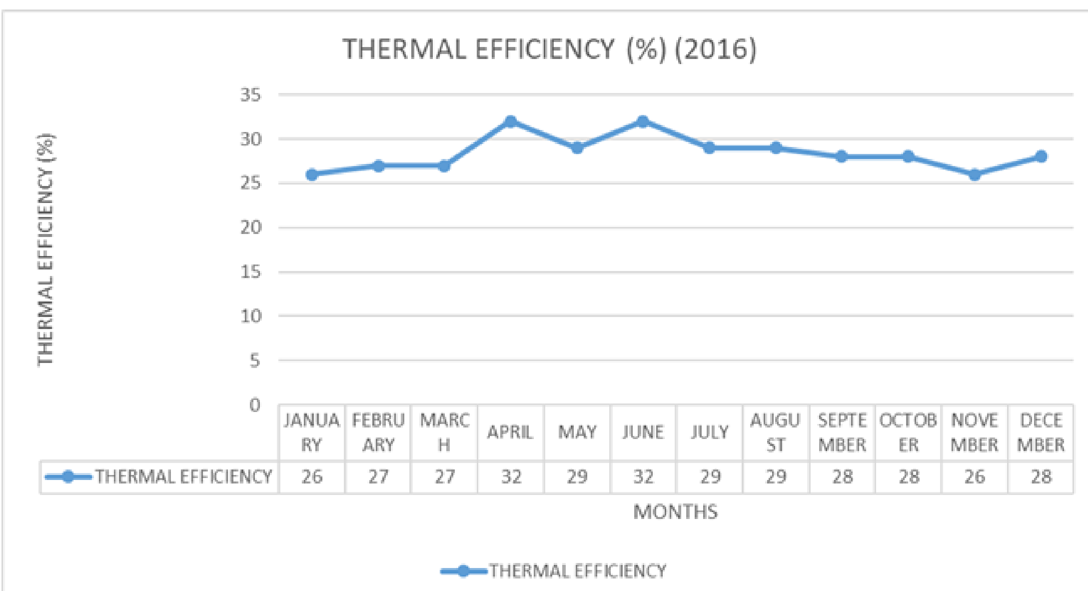

Figure 3: Thermal efficiency of Delta III GT9

The thermal efficiency of a gas turbine is about 20% to 35%. From figure 4.3, the thermal efficiency of the plant for each month is above the 20%, and the average efficiency is 28%. That is to say, the plant is quite efficient. The maximum thermal efficiency is 32% in the month of April and June, while the minimum thermal efficiency is 26% in the month of January and November. The maximum efficiency corresponds to the minimum amount of fuel consumed and the minimum efficiency corresponds to the maximum amount of fuel consumed. The plant fuel rate under the period under study is presented in Figure 4.

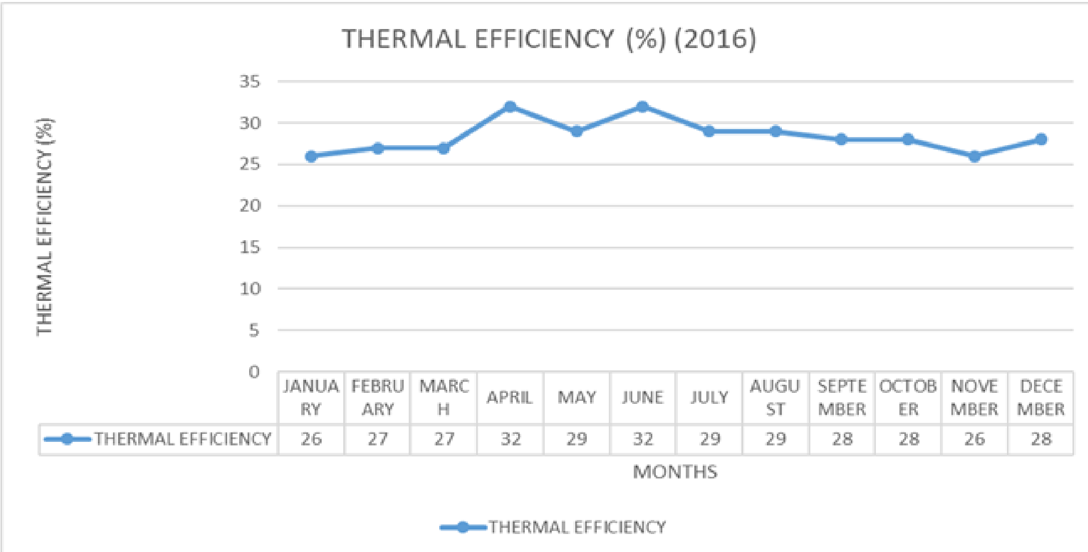

Figure 4: Plant Fuel Rate

It can be seen that the best value of the plant fuel rate is for the month of June which only took 7.3% of the total plant fuel against the other months which fall between the ranges of 7.3% to 9.0%. The maximum value (9.0%) occurs in the month of January. The plant heat rate for the period under review is shown in Figure 5.

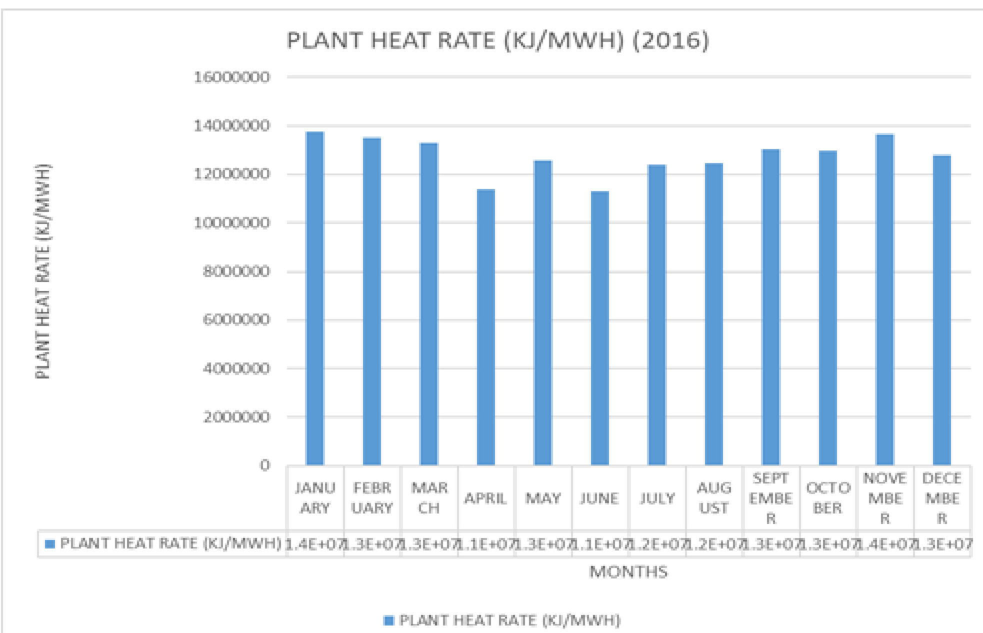

Figure 5: Plant Heat Rate

The reliability of Delta III GT9 for the period under study is presented in Figure 6.

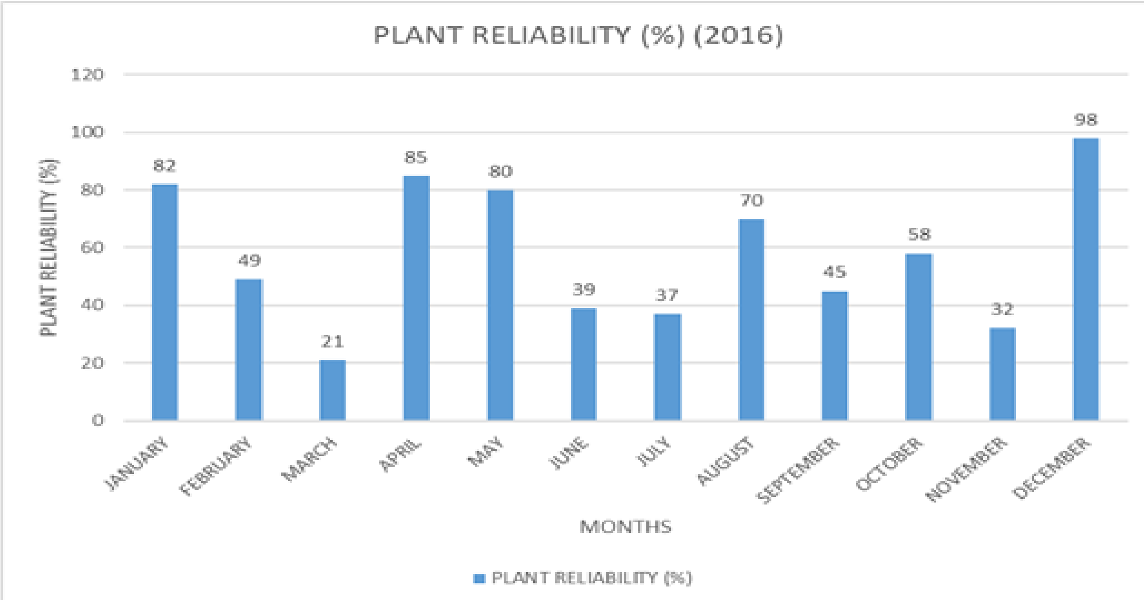

Figure 6: Reliability of Delta III GT9

The average reliability of the plant from the operational data obtained from for the period under study is 58%. The decreased in reliability of the plant in the month of March, June, July and November was as a result of major inspection (MI) that was carried out on the plant; also the plant was out of service for a period due to gas shortage. Generally, the behavior of the gas power plant depends majorly on the capacity factor. High capacity factor is desired for economic operation of the plant. Gas turbines are designed for standard air conditions. However, the operating periods at off-design conditions are much greater than that at design conditions. A difference between the actual power generated by a gas turbine and the design rated power tagged on the gas turbine is observed whenever a gas turbine operates at site ambient conditions that vary from the stipulated International Standard Organization (ISO). A detail study and extensive logging of operational data has shown the existence of a direct relationship between the ambient temperature and the de-rating of gas turbine power output. For every 1^{o}C rise in ambient temperature above ISO condition, the gas turbine losses 1% in terms of thermally efficiency and 1.47 MW of its gross power output.

The power output of gas turbine is a function of the inlet temperature of the turbine. The turbine inlet temperature plays a vital role on the performance of the single cycle plant. The gas turbine performance is affected by the component efficiencies and the turbine working temperature. The effect of temperature is very predominant; for every 56^{o}C increase in temperature, the work output increases approximately 10% and gives about 1.5% increase in efficiency. The overall efficiency of the gas turbine cycle depends primarily upon the pressure ratio of the compressor. A summary of all the key performance parameters are shown in the Table 8.

Table 8: Summary of the Values of the Key Performance Parameters

Month	Power Generated (MW)	Capacity Factor (%)	Plant Fuel Rate		Plant Heat Rate		Efficiency (%)
			Kg/KWH	% Total	KJ/MWH	% Total	
Jan.	19	76	0.262	9.0	13,761,973	9.0	26
Feb.	18	72	0.256	8.8	13,498,100	8.8	27
March	17	68	0.253	8.6	13,286,909	8.7	27
April	19	76	0.217	7.4	11,392,655	7.4	32
May	18	72	0.239	8.2	12,566,088	8.2	29
June	18	72	0.215	7.3	11,315,615	7.4	32
July	20	80	0.236	8.1	12,392,834	8.1	29
August	19	76	0.237	8.1	12,463,830	8.1	29
Sept.	18	72	0.248	8.5	13,057,846	8.5	28
Oct.	17	68	0.247	8.5	12,989,730	8.5	28
Nov.	18	72	0.260	8.9	13,661,713	9.0	26
Dec.	18	72	0.243	8.3	12,773,834	8.3	28
Total	19	76	2.913	100	153,161,127	100	

Conclusion

In this study, the performance of Delta III GT9 gas turbine power plant was evaluated and analyzed. Emphasis has been on the key performance parameters (such as power generated, capacity factor, plant fuel rate, plant heat rate and the thermal efficiency of the plant). The study shows that 92% of the expected capacity was available in the period. The thermal efficiencies of the plant in the period ranged from 26% to 32% as against the standard value of 20% to 35%. The plant's capacity factor ranged from 68% to 80% against best industrial practice of 40% to 80%. The plant fuel rate ranged from 7.3% to 9.0%, and also the plant heat rate ranged from 7.4% to 9.0%. The average reliability of the plant for the period is 58%. Only 20 MW of energy (power) was lost out of the expected power of 240 MW for the period under study. The study revealed that the above performance parameters analyzed for Delta III GT9 plant are within the range of best industrial practice. Besides, the efficiencies achieved for the period under study are within the best international value for a single cycle gas turbine plant.

Recommendation

The performance and reliability of Delta III GT9 power plant can be greatly improved. The few ways in which the performance of the plant can be improved are as follow:

i. Increase the turbine inlet temperature, provided the turbine materials can withstand the high temperature or the parts can be replaced with those that can withstand the temperature. For every 56 ^{o}C increase in temperature, the work output increases approximately 10% and gives about 1.5% increase in efficiency.

ii. Install of a heat recovery steam generator (HRSG) to recover energy from the turbine's exhaust. A heat recovery steam generator helps in generating steam by capturing the heat from the exhaust system. High pressure steam from the HRSG can be used to generate additional power with steam turbines, a configuration called combined cycle.

iii. Proper maintenance and cleaning of compressor inlet filters. Dirty and poorly maintained filters would cause monumental loss of efficiency due to damage and clogging of the compressor blades. Pressure drop is a consequence of dirty filters. Regular checkup and cleaning of the components can improve the performance and reliability of the plant.

iv. Planned maintenance such as Preventive, Running, Condition Monitoring should be carried out on the plant to keep it running smoothly and thus improve the reliability of the plant.

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References

[1] S.I. Ukwamba1, E.K. Orhorhoro, A.A. Omonoji, "**Performance Evaluation of a Simple Gas Turbine Power Plant Using Vapour Absorption Chiller", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 15(2), pp.13-18, 2018**

[2] I. Al-Tobi, "Performance Enhancement of Gas Turbines by inlet Air Cooling", *International Conference on Communication, Computer and Power (ICCCP'09) Muscat*, 15(18), pp.165 – 170, 2009

[3] B. Firdaus, Y. Takanobu, N. Kimio, N. Soe "Effect of ambient temperature on the performance of micro gas turbine with cogeneration system in cold region",. *Applied Thermal Engineering*, 31, pp.1058– 1067, 2011

[4] EK. Orhorhoro, EN. Achimnole, MO. Onogbotsere1 and O. Oghoghorie, "Simulation of Gas Turbine Power Plant using High Pressure Fogging Air Intake Cooling System", European Journal of Advances in Engineering and Technology, 4(9):, pp.691-696, 2017

[5] AE. Nasser and MA. EL-Kalay, "A Heat-Recovery Cooling System to Conserve Energy in Gas – Turbine Power Stations in the Arabian Gulf", *Applied Energy*, 38 (2), pp.133-142, 1991

[6] YS. Kim, JJ. Lee, TS. Kim, and JL. Sohn, "Effects of Syngas Type on the Operation and Performance of a Gas Tur-bine in Integrated Gasification Combined Cycle", *Energy Convers Manage*, 52 (22), pp.62–71, 2011

[7] AG. Kaviri, MN. Jaafar, TM. Lazim, "Modeling and Multi-Objective Exergy Based Optimization of a Combined Cycle Power Plant Using a Genetic Algorithm", *Energy conversion management*, 58, pp.94-103, 2012

[8] T. Johnke and M. Mast, Gas Turbine Power Boosters to enhance power output. Siemens Power for generation, Siemens Power

[9] EK. Orhorhoro, and OW. Orhorhoro, " Simulation of Air inlet Cooling system of a Gas Turbine Power Plant", ELK Asia Pacific Journal of Applied Thermal Engineering, 1(2), 2016

[10] FG. Mahmood and DD. Mahdi, "A New Approach for Enhancing performance of a gas turbine (case study: Khangiran Refinery)", Applied energy, 86, pp.2750-2759., 2009

[11] E. Kakaras, "Inlet Air cooling Methods for Gas Turbine Based Power Plant", *ASME*, 128, pp. 312-317 , 2006

[12] B. Dawaud, "Thermodynamic Assessment of power requirement and impact of different Gas Turbine Air cooling technologies at two locations in Oman", Applied Thermal Engineering, 25, pp. 1579 – 1598, 2005

[13] W. Zhang, L. Chen, F. Sun, "Performance Optimization for an open cycle gas turbine power plant with a refrigeration cycle for compressor inlet air cooling. Part 2: power and efficiency optimization", Proceedings of the Institution of Mechanical Engineers, Part A. Journal of Power and Energy, 223 (5), pp.515-522 , 2009

[14] JN. Lamfon, "*Modeling and Simulation of Combined Gas Turbine Engine and heat Pipe System for Waste Heat Recovery and Utilization*", Energy Convers, 39, pp. 81-86, 1998

[15] B. Mohanty, G. Paloso, "Enhancing gas turbine performance by intake air cooling using an absorption chiller", *Heat Recovery Systems and CHP*, 15, pp. 41-50 , 1995

[16] M. Ameri,, "The Study of Capacity Enhancement of The Chabahar Gas Turbine Installation Using an Absorption Chiller", Applied thermal Engineering, 24, pp. 59-