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Full Length Research Article

EFFECT OF PINCH POINT ON THE PERFORMANCE OF A COMBINED CYCLE GAS TURBINE UNDER KADUNA CLIMATIC CONDITIONS

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ABSTRACT
In this paper, an analysis was carried out to investigate the effect of pinch point on the performance of a combine cycle gas turbine engine, known as the GE MS9001E combined cycle gas turbine engine. The GE MS9001E is a heavy duty combine cycle gas turbine engine which is currently in use in the Olorunsogo power station in Oyo state, Nigeria. This simulation analysis was performed under the prevailing ambient temperature conditions of Kaduna state. The data for the 2017 ambient temperature conditions of Kaduna state was acquired from NIMET, and from these data the monthly mean ambient temperature values were calculated. These monthly mean temperature values will serve as the basis for the simulation analysis. The simulation comprises of two stages; the first stage involves simulating the performance of the gas turbine engine with GasTurb 11 software while the second stage involves simulating the performance of the steam turbine engine using Aspen HYSYS version 11 software. A detailed procedure was described in chapter three while the simulation results are presented in chapter four. From the results, it showed that at ISO conditions, the power output for GE MS9001E single cycle system is 126.1 MW while for a combine cycle system is 193.2 MW. This implies that the gas turbine produces about 126.1 MW which is about 65.3 % of the combined power output, while the steam turbine produces about 67.1 MW which is about 34.7 % of the combined power output. Varying pinch point values of 0, 5, 10, 15, 20, 25, 30 and 35 were used to carry out this analysis and the results clearly showed that as the pinch point values increases, the turbine power output will decrease and as the pinch point values decreases, the turbine power output will increase. These observations were the same for all the months in the year 2017. The relationship between the pinch point value and the turbine power output can be said to be inversely proportional to one another.

Keywords; Pinch Point, Gas Engine, GE MS9001E, Ambient Temperature

INTRODUCTION
Vital human needs can be achieved by rapid and efficient industrial growth, based on provision of electricity the combined cycle gas turbine (CCGT) power plant is used to generate utility scale electricity worldwide because it does so with less pollution and higher efficiency than other conventional fossil fired plants. (Ma. W et al.,) In simple terms, it consists of the gas turbine (GT) and the steam turbine (ST), connected via the heat recovery steam generator (HRSG) it operate the Brayton-Rankine thermodynamic cycle with the Brayton cycle as the topping cycle and the Rankine as the bottoming cycle (Abudu et al., 2021). Even though the ubiquitous CCGT is the most preferred conventional power generation technology, its performance is influence by specific environmental and operational factors For instance, the power output of the plant is affected by ambient temperature, relative humidity, etc. As ambient temperature increases, the air inducted into the engine become less dense resulting in a drop in the plants power output and vice versa. The same phenomenon also applies to the variation of relative humidity. Operating parameters such as the turbine entry temperature (TET), pressure ratio (PR), approach point (AP), pinch point (PP) etc. also influence the behaviour of the plant while in operation. For the CCGT, the pinch point is an important criterion of performance. (Adelaja, A.O., et al., 2018)
The pinch point is the maximum difference between the gas temperature leaving the GT exhaust into the evaporator section of the ST at the corresponding pressure. If the pinch point is lower, the total heat recovered in the HRSG increases and steam generation also becomes higher. However, high steam generation is achieved at the expense of increased heat exchange surface, higher cost and draft losses, as well as reduced effectiveness of the HRSG (Ibrahim et al., 2013). As such, therefore to achieve optimal performance of the CCGT at minimal cost, it is necessary to study the effect of pinch point variation as the plant interacts with the environment during operation elevated ambient temperatures. It is to this end that the study is undertaken (Kong, X., et al., 2018)
Gas turbine engines derive their power by burning fuel in a combustion chamber and using the fast-flowing combustion gases to drive a turbine in similar to high-pressure steam drives a steam turbine (Van et al., 2017). While natural gas is the fuel of choice for the GT, coal, oil, and natural gas are used for the ST, though a wide spectrum of fuels could be used alongside emission capture techniques. Furthermore, the GT is a continuous internal combustion engine, but the ST is an external combustion engine (ECE). It consists of a boiler, steam turbine, condenser, and a feed water pump in its simplest form (Van et al., 2017).
Van Erdeweghe et al. (2017) investigated the Influence of the pinch point temperature difference on the performance of the preheat-parallel configuration for a low-temperature geothermally-fed combined heat and power (CHP) system in their work, a low temperature geothermal source of 130°C, and a connection to a 75°C/50°C and a 75°C/35°C thermal networks. The main discussion were focused on three different configuration: The series configuration, the pre-parallel configuration and cascade configuration. paper focuses on the effect of the pinch point temperature difference on the plant performance. The pinch point temperature difference is directly related to the size and cost of the heat exchangers and significantly influences the preheating effect,

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which is the most distinctive feature of preheat-parallel configurations. In their work, the result of a detailed sensitivity analysis of the pinch point temperature differences was presented and furthermore, a comparism was carried out between the performance of the pre-heat parallel configuration with the convenient parallel and series CHP configuration. The paper also stated that with respect to the parallel configurations, the gain in net power generation stays approximately constant (75 ℃/35 ℃ thermal network) or decreases (75 ℃/50 ℃ thermal network) with imposed pinch point temperature difference. Similarly for the CHP with higher values of pinch point in series configurations, the gain in net power generation increases for a higher value of pinch point temperature difference. This, in conclusion, means that the impact of pinch point temperature difference is highest for the series configuration, followed by the preheat parallel configuration, and smallest for the parallel configuration.

Nordin et al., (2017) a parametric study on the effect of pinch and approach points on heat recovery steam generator performance at a district cooling system. In their paper, the importance and the capability of heat recovery, steam generator (HRSG) in steam generation was discussed along with the roles of the pinch point and approach point in the influencing steam production, The paper also went further to discuss how the study of pinch point and approach point will be useful in understanding the effects of the variation on the performance of heat recovery steam generators (HRSG). The study examined the impact of pinch point on steam mass flow rate, exhaust heat temperature, and efficiency of heat recovery steam generators In total, the paper covered which includes the effect of pinch point and approach point on steam generation, the effect of pinch point and approach point on the exhaust heat temperature leaving heat recovery steam generators, the effect of pinch point and approach point on the efficiency of heat recovery steam generators and the effect of exhaust heat temperature of the gas turbine on the mass flow rate of steam. The initial scenario revealed that higher pinch and approach points resulted in decrease in steam generation. For the second scenario, the increase in pinch point and approach point resulted in higher exhaust heat temperature leaving the heat recovery steam generators. Meanwhile, for the third scenario, it was noted that there was only a minimal variation in the efficiency of the heat recovery steam generator when the pinch point and approach point were increased. The findings of the fourth scenario indicated that with higher gas turbine exhaust heat temperatures, there was an increase in steam being generated.

Kumar et al. (2013) investigated the performance evaluation of a gas-steam combined cycle having transpiration cooled gas turbine. In their paper, discussions were made on how to improved gas turbine performance through developments in high temperature materials and blade cooling methods has made a positive impact on the combined cycle performance. It also discussed how transpiration cooling technique has emerged as the most promising technique to improve the gas turbine cycle performance by allowing higher turbine inlet temperatures. The paper also focuses on enhancing the combine cycle performance by enabling higher inlet temperature use of transpiration cooling of gas turbine blades. A four-stage advanced gas turbine coupled with a dual-pressure steam bottoming cycle was considered for the performance of the combined cycle. Input parameters from the data log sheets were also considered for the study. The effects of varying higher inlet temperature on the performances of topping, bottoming and combined cycle were also presented and discussed in the paper. The results show that for the combined cycle using a transpiration-cooled gas turbine increasing the turbine inlet temperature from 1600K to 1800K leads to combine cycle efficiency increase by 2.37% and the combined specific work increases by 185.42 kJ/kg. The results indicate that at a TIT of 1800 K the achievable efficiency of combined cycle with transpiration cooled gas turbine is 59.97 %.

Abudu et al., 2021 worked on the impact of gas turbine flexibility improvements on combined cycle gas turbine performance. According to the paper, the improvement of gas turbines flexibility has been driven by more use of renewable sources of power due to environmental concerns. There are different approaches to improving gas turbine flexibility, and they have performance implications for the bottoming cycle in the combined cycle gas turbine (CCGT) operation. The CCGT configuration is favourable in generating more power output, due to the higher thermal efficiency that is key to the economic viability of electric utility companies. However, the flexibility benefits obtained in the gas turbine is often not translated to the overall CCGT operation. In this study, the flexibility improvements are the minimum environmental load (MEL) and ramp-up rates, that are facilitated by gas turbine compressor air extraction and injection, respectively. The bottoming cycle has been modelled in this study, based on the detailed cascade approach, also using the exhaust gas conditions of the topping cycle model from recent studies of gas turbine flexibility by the authors. At the design full load, the CCGT performance is verified and subsequent off-design cases from the gas turbine air extraction and injection simulations are replicated for the bottoming cycle. The MEL extension on the gas turbine that brings about a reduction in the engine power output results in a higher steam turbine power output due to higher exhaust gas temperature of the former. This curtails the extended MEL of the CCGT to 19% improvement, as opposed to 34% for the stand-alone gas turbine. For the CCGT ramp-up rate improvement with air injection, a 51% increase was attained. This is 3% point lower than the standalone gas turbine, arising from the lower steam turbine ramp-up rate. The study has shown that the flexibility improvements in the topping cycle also apply to the overall CCGT, despite constraints from the bottoming cycle.

Ibrahim et al., 2013 worked on study on effective parameter of the triple-pressure reheat combined cycle performance. According to their paper, the thermodynamic analyses of the triple-pressure reheat combined cycle gas turbines with duct burner are presented and discussed in this paper. The overall performance of a combined cycle gas turbine power plant is influenced by the ambient temperature, compression ratio, and turbine inlet temperature. These parameters affect the overall thermal efficiency, power output, and the heat-rate. In this study a thermodynamic model was developed on an existing actual combined cycle gas turbine. The code of the performance model for combined cycle gas turbine power plant was developed utilizing the THERMOFLEX software. The simulating results showed that the total power output and overall efficiency of a combined cycle gas turbine decrease with increase in ambient temperature which increase the consumption power in the air compressor of a gas turbine. The total power of a combined cycle gas turbine decreases with increase the compression rate, while the overall efficiency of a combined cycle gas turbine increases with increase in the compression ratio to 21, after that the overall efficiency will go down. Furthermore, the turbine inlet temperature increases the both total power and overall efficiency increase, so the turbine inlet temperature has a strong effect on the overall performance of

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combined cycle gas turbine power plant. Also, the simulation model gives a good result compared with MARAFIQ combined cycle gas turbine power plant. With these variables, the turbine inlet temperature causes the greatest overall performance variation.

Ibrahim et al., 2013, worked on thermal impact of operating conditions on the performance of a combined cycle gas turbine. According to the paper, the combined cycle gas-turbine (CCGT) power plant is a highly developed technology which generates electrical power at high efficiencies. The first law of thermodynamics is used for energy analysis of the performance of the CCGT plant. The effects of varying the operating conditions (ambient temperature, compression ratio, turbine inlet temperature, isentropic compressor and turbine efficiencies, and mass flow rate of steam) on the performance of the CCGT (overall efficiency and total output power) were investigated. The programming of the performance model for CCGT was developed utilizing MATLAB software. The simulation results for CCGT show that the overall efficiency increases with increases in the compression ratio and turbine inlet temperature and with decreases in ambient temperature. The total power output increases with increases in the compression ratio, ambient temperature, and turbine inlet temperature. The peak overall efficiency was reached with a higher compression ratio and low ambient temperature. The overall efficiencies for CCGT were very high compared the thermal efficiency of GT plants. The overall thermal efficiency of the CCGT quoted was around 57%; hence, the compression ratios, ambient temperature, turbine inlet temperature, isentropic compressor and turbine efficiencies, and mass flow rate of steam have a strong influence on the overall performance of the CCGT cycle.

Valdés et al., 2001 discussed on the thermo-economic optimization of combined cycle gas turbine power plants using genetic algorithms. This paper shows a possible way to achieve a thermos-economic optimization of combined cycle gas turbine (CCGT) power plants. The optimization has been done using a genetic algorithm, which has been tuned applying it to a single pressure CCGT power plant. Once tuned, the optimization algorithm has been used to evaluate more complex plants, with two and three pressure levels in the heat recovery steam generator (HRSG). The variables considered for the optimization were the thermodynamic parameters that establish the configuration of the HRSG. Two different objective functions are proposed: one minimizes the cost of production per unit of output and the other maximizes the annual cash flow. The results obtained with both functions are compared in order to find the better optimization strategy. The results show that it is possible to find an optimum for every design parameter. This optimum depends on the selected optimization strategy.

Tyagi et al., 2010 worked on the effect of gas turbine exhaust temperature, stack temperature and ambient temperature on overall efficiency of combine cycle power plant. According to the paper, the gas turbine exhaust temperature, stack temperature and ambient temperature play a very important role during the predication of the performance of combine cycle power plant. This paper covers parametric analysis of effects of gas turbine exhaust temperature, stack temperature and ambient temperature on the overall efficiency of combine cycle power plant keeping the gas turbine efficiency as well as steam turbine efficiency constant. The results show that out of three variables i.e., turbine exhaust temperature, stack temperature and ambient temperature, the most dominating factor of increasing the overall efficiency of the combine cycle power plant is the stack temperature.

Ladislav et al., 2016 worked on pinch point analysis of heat exchangers for supercritical carbon dioxide with gaseous admixtures in CCS systems. According to the paper, Carbon dioxide (CO_2) captured in carbon dioxide capture and storage (CCS) processes is transported and stored in a supercritical state. Heat exchangers, especially recuperators, with CO_2 on both the hot and the cold side are often impacted by the occurrence of a pinch point, that is, area of closest approach between hot and cold temperature curves. CO_2 in CCS systems is not pure, and even small number of admixtures can have a significant effect on the location and impact of the pinch point, on heat transfer properties and exchanger sizing. This work investigates the effects of several admixtures on these parameters. It is found that these admixtures may have a slightly positive effect on recuperative heat exchangers. However, these admixtures also result in a significant size increase of CO_2 coolers.

Javadi et al., 2020 discussed on sensitivity analysis of combined cycle parameters on exergy, economic, and environmental of a power plant. In their paper, a typical combined cycle power generation unit in Iran is simulated by a mathematical method in order to perform sensitivity analysis on environmental emission and electricity price. The results of this study demonstrate that the efficiency of the power plant depends on both gas turbine design parameters such as gas turbine inlet temperature, compressor pressure ratio and steam cycle design parameters such as HRSG pinch point temperature, condenser pressure. The results demonstrate that an increase in TIT and compressor pressure ratio have a significant effect on exergy efficiency and destruction.

MATERIALS AND METHODS

Materials

To analyse the effect of pinch point on the performance of a Combined Cycle Gas Turbine, several materials were needed for the successful completion of the project. The materials include;

i. Technical specification of GE Frame 9E Combined Cycle Gas Turbine (CCGT).
ii. Technical specification of Gas Turbine (GT).
iii. Technical specification of Steam Turbine (ST).
iv. Technical specification of Heat Recovery Steam Generator (HRSG).
v. Overall Technical specification of the equipment used (CCGT).
vi. GasTurb11 software for analysing gas turbine design point parameters.
vii. Aspen HYSYS software version 11.0 used for analysing the effect of pinch point on the steam turbine.
viii. Temperature readings acquired from NIMET from 2012 to 2017.
ix. Microsoft Excel 2016 edition.
x. Microsoft Word 2016 edition.

Equipment

The equipment used is listed as follows;

i. The HP Pavillion power features on intel core i7 processor operating at 2.8 GHz, 8.0 DB of Ram, a 1Tb of hard drive, a 64-bit operating system graphics card.
ii. A gas turbine supplied by General Electric and a steam boiler supplied by John Cockerill Group.
iii. 4G Mobile broadband is used for internet connectivity.
iv. 3.5 kVA/48 V Static UPS/Inverter, used for uninterrupted power supply.

Method

The effect of pinch point on the performance of a Combined Cycle

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Gas Turbine was carried out using an HP laptop with installed GasTurb 11 software and Aspen HYSYS version 11.0 software as the main simulation software. The methods used to achieve the various objectives were grouped into two stages.

The GE MS9001E Gas Turbine Performance Analysis
As described in the Gas Turbine MS9001E Operating Training Manual, the MS9001E is a simple cycle, single-spool gas turbine. Some of the input parameters are presented in Table 4.2. The Burner Exit Temperature will be acquired through iteration calculation, as shown in the subsequent procedure to perform a performance analysis of the GE MS9001E gas turbine, the following expunge steps and procedures were adopted.

The Steam Turbine Analysis with ASPEN HYSYS 11 Software
Using the exhaust temperature of the gas turbine engine, the exit temperature of the heat recovery steam generator was acquired by subtracting pinch point values. This procedure is illustrated and expressed in tabular form in Chapter 4. A basic steam turbine cycle will be built with Aspen HYSYS 11 software, and the effect of the pinch point on the steam turbine will be evaluated as follows.

RESULTS AND DISCUSSION
Meteorological data were acquired from NIMET, and the monthly average temperature was determined. This was done by finding the monthly average between the minimum and maximum temperatures.

The graphical representation of the monthly average temperature is given below in figure 4.1

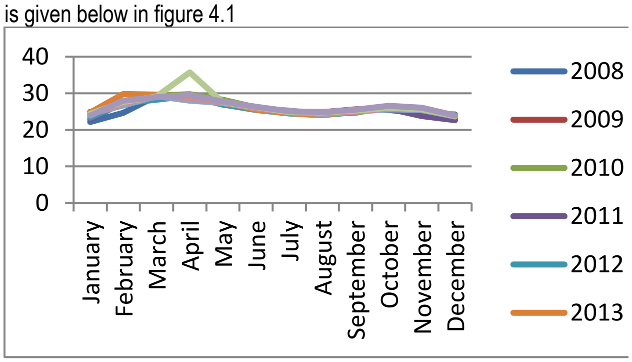

Figure 1. Graphical representation of the monthly average temperature in Kaduna

The most recent result, which was in 2017, will be used for the GE MS9001E gas turbine performance analysis
After iteration, the Burner Exit Temperature was determined to be 1466.04 K. This value was used as a constant input parameter in the performance analysis of GE MS900IE gas turbine.

Simulation Result for the GE MS9001E Gas Turbine Engine
The various stations on the selected engine module are shown in plate 4.1 below. These stations enable us to read the simulation summary result, which will be further presented later. These stations are automatically generated in the GasTurb 11 software.

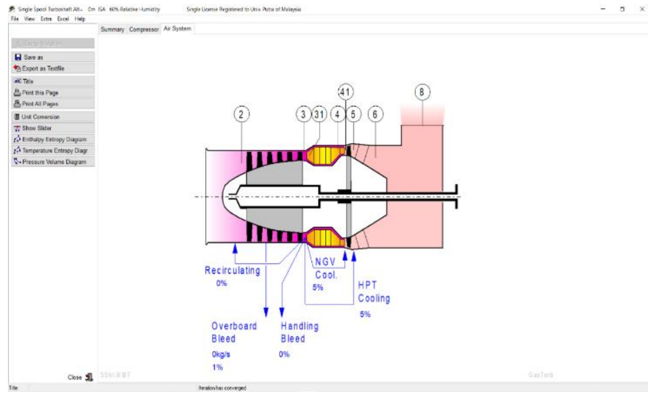

Plate 1; The stations on the turboshaft single spool power generation

From the above plate;
Station 2 – compressor inlet
Station 3 – compressor outlet
Station 31 – combustion chamber inlet
Station 4 – combustion chamber outlet
Station 41 – turbine inlet
Station 5 – turbine outlet
Station 8 – exhaust

The graphical representation of the relationship between the pinch point values and the steam turbine power output for January is presented in Figure 2 below.

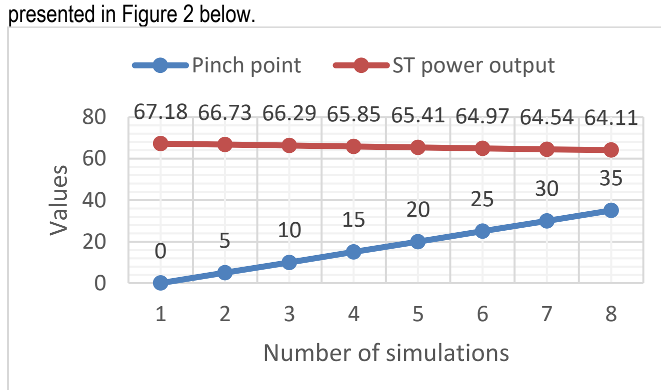

Figure 2 Pinch point values and turbine power output relationship for January

The graphical representation of the relationship between the pinch point values and the steam turbine power output for February is presented in Figure 3 below.

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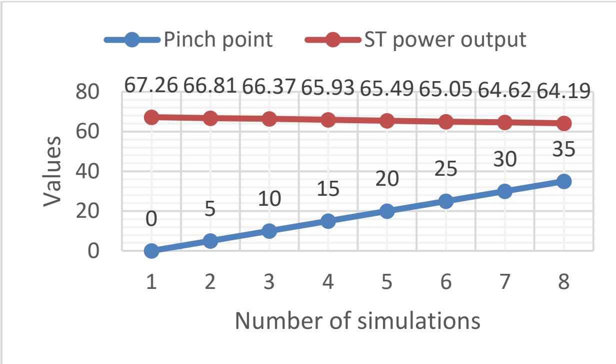

Figure 3 Pinch point values and turbine power output relationship for February

The graphical representation of the relationship between the pinch point values and the steam turbine power output for March is presented in figure 4 below

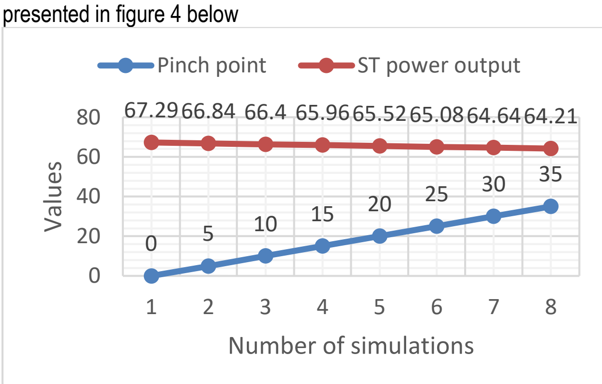

Figure 4 Pinch point values and turbine power output relationship for March

The graphical representation of the relationship between the pinch point values and the steam turbine power output for April is presented in Figure 5 below

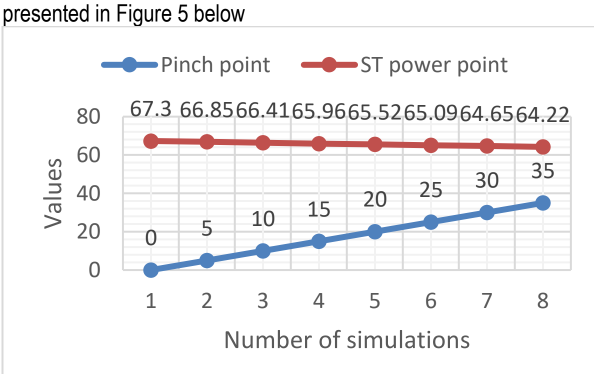

Figure 5 Pinch point values and turbine power output relationship for April

The graphical representation of the relationship between the pinch point values and the steam turbine power output for May is presented in Figure 6 below.

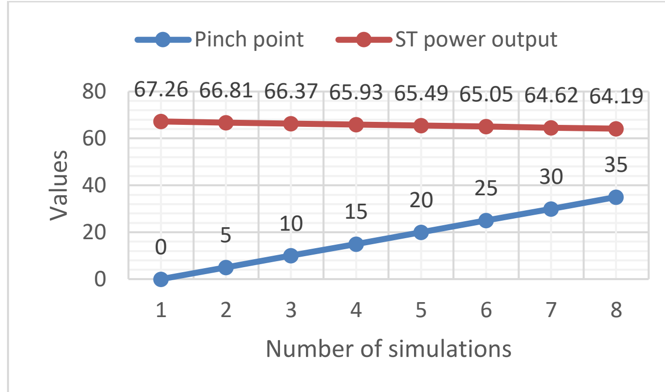

Figure 6 Pinch point values and turbine power output relationship for May

The graphical representation of the relationship between the pinch point values and the steam turbine power output for June is presented in figure 7 below.

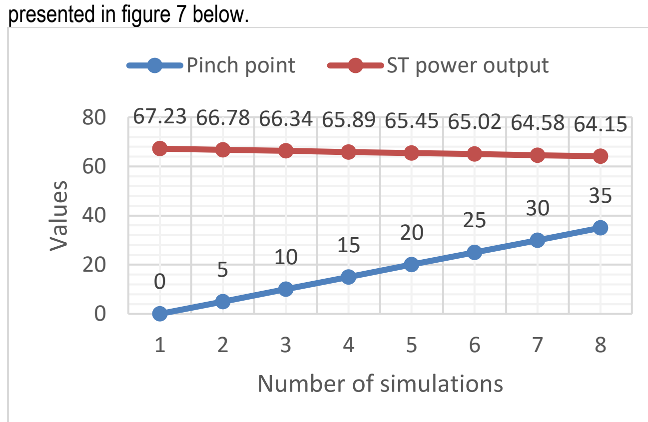

Figure 7 Pinch point values and turbine power output relationship for June

The graphical representation of the relationship between the pinch point values and the steam turbine power output for July is presented in figure 8 below.

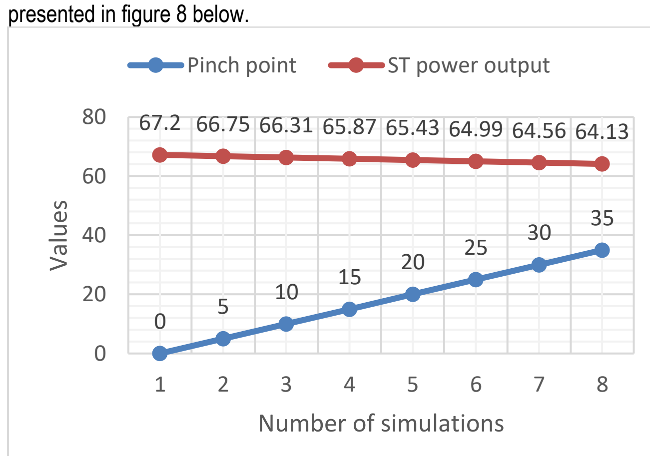

Figure 8 Pinch point values and turbine power output relationship for July

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The graphical representation of the relationship between the pinch point values and the steam turbine power output for August is presented in figure 9 below.

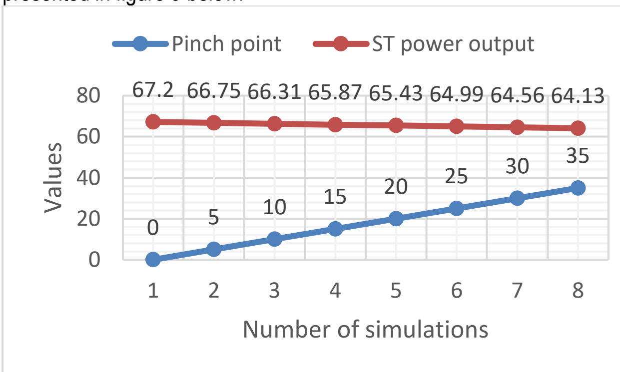

Figure 9 Pinch point values and turbine power output relationship for August

The graphical representation of the relationship between the pinch point values and the steam turbine power output for September is presented in figure 10 below.

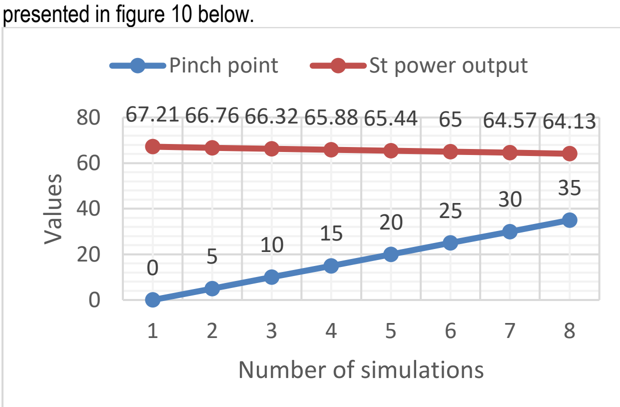

Figure 10 Pinch point values and turbine power output relationship for September

The graphical representation of the relationship between the pinch point values and the steam turbine power output for October is presented in figure 11 below.

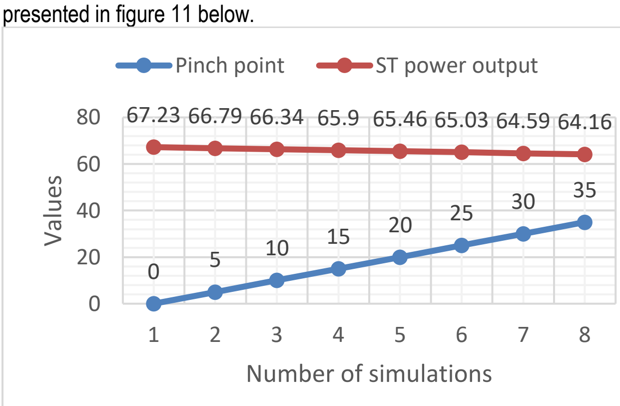

Figure 11 Pinch point values and turbine power output relationship for October

The graphical representation of the relationship between the pinch point values and the steam turbine power output for November is presented in figure 12below.

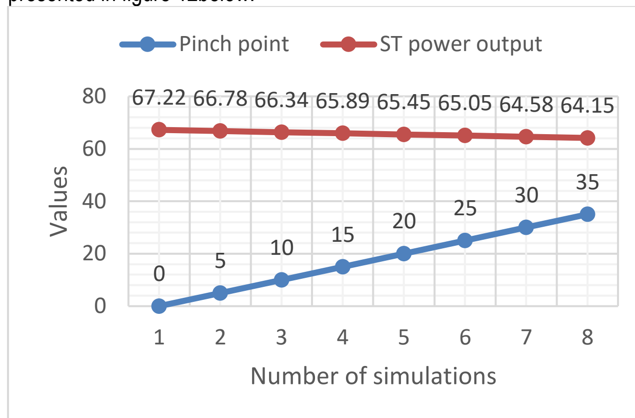

Figure 12: Pinch point values and turbine power output relationship for November

The graphical representation of the relationship between the pinch point values and the steam turbine power output for December is presented in Figure 13 below

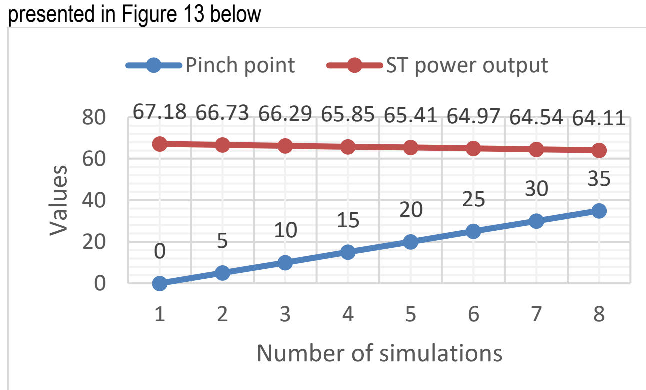

Figure 13: Pinch point values and turbine power output relationship for December

Discussion on the Effect of Pinch Point on Combined Cycle Gas Turbine

According to the GE Power Systems Gas Turbine and Combined Cycle Products manual, it showed that at ISO conditions.(smil, V. 2016) the power output for the MS900IE is 126.1MW in a simple cycle configuration and 193.2MW in a combined circle configuration. This implies that the gas turbine produces about 126.1 MW, accounting to for about 65.3% of the combined power output, while the steam turbine produces 67.1MW or 34.7% of the combined total, providing a clear understanding of idea of how the combined cycle gas turbine will perform when operating in Kaduna State. The results of the simulations were presented in tabular, graphical, and pictorial views from January to December.

This analysis was conducted using varying pinch point values. The result clearly showed that an increase in pinch point leads to a decrease in pinch point results in higher turbine power output. This observations remained consistent across all month of the year 2017. The relationship between the pinch point value and turbine power output is inversely proportional.

For January, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.18 MW. As the pinch point values

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rise by a multiple of five, the corresponding value for turbine power output was seen to decrease, and at a pinch point value of 35, the turbine power output was simulated to be 64.11. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward.

For February, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.26 MW. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward. As seen in figure 4.2 the orange line representing the turbine power output exhibit a downward slope, indicating decrease in power generation.

For March, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.29 MW. As the pinch point values rise by a multiple of five, the corresponding value for turbine power output was seen to decrease and at a pinch point value of 35, the turbine power output was simulated to be 64.21. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line, which represents the turbine power output, as shown in Figure 4.4.

For April, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.30 MWThe graphical representation of the values clearly shows that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line, which represents the turbine power output, as shown in Figure 4.5.

For May, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.26 MW. As the pinch point values increase in multiple of five, the corresponding turbine power output was observed to decrease. At pinch point value of 35 simulated turbine power output was 64.19.The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line which represents the turbine power output as shown in figure 4.6.

In June, when the pinch point value was 0, the simulated turbine power output was 67.23 MW. As the pinch point value increased in increments of five, the turbine power output consistently decreased, reaching 64.15 MW at a pinch point value of 35. The graph in Figure 4.7 clearly illustrates this inverse relationship: as the blue line (representing pinch point values) slopes upward, the orange line (representing turbine power output) slopes downward.

In July, the simulated turbine power output was 67.20 MW at a pinch point value of 0. As the pinch point increased in steps of five, the turbine power output gradually declined, reaching 64.13 MW at a pinch point value of 35. The graph in Figure 4.8 clearly demonstrates this inverse trend: while the blue line (indicating pinch point values) slopes upward, the orange line (indicating turbine power output) slopes downward.

For August, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.20 MW. As the pinch point values rises by a multiple of five, the corresponding value for turbine power output was seen to decrease and at pinch point value of 35, the turbine power output was simulated to be 64.13. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line which represents the turbine power output as shown in figure 4.9.

For September, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.21 MW. As the pinch point values rises by a multiple of five, the corresponding value for turbine power output was seen to decrease and at pinch point value of 35, the turbine power output was simulated to be 64.13. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line which represents the turbine power output as shown in figure 4.10.

For October, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.23 MW. As the pinch point values rises by a multiple of five, the corresponding value for turbine power output was seen to decrease and at pinch point value of 35, the turbine power output was simulated to be 64.16. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line which represents the turbine power output as shown in figure 4.11.

For November, it is seen that at 0 pinch point value, the turbine power output was simulated to be 67.22 MW. As the pinch point values rises by a multiple of five, the corresponding value for turbine power output was seen to decrease and at pinch point value of 35, the turbine power output was simulated to be 64.15. The graphical representation of the values clearly showed that as the blue line representing the pinch point values slopes upward, there is a downward slope on the orange line which represents the turbine power output as shown in figure 4.12.

In December, the simulated turbine power output was 67.18 MW at a pinch point value of 0. As the pinch point increased in increments of five, the turbine power output progressively decreased, reaching 64.11 MW at a pinch point value of 35. This inverse relationship is clearly illustrated in Figure 4.13, where the blue line (representing pinch point values) slopes upward, while the orange line (representing turbine power output) slopes downward.

A statistical analysis and a generalized graph representing the relationship between pinch point values and steam turbine power output across all months.

Statistical Summary

The data from January to December show a consistent pattern:

- **Pinch Point Values (K)**: 0, 5, 10, 15, 20, 25, 30, 35
- **Steam Turbine Power Output (MW)**: Decreasing linearly with increasing pinch point

Extracting the **average power output** for each pinch point across all 12 months:

Pinch Point (K)	Avg Power Output (MW)
0	67.233
5	66.786
10	66.338
15	65.891
20	65.446
25	65.002
30	64.581
35	64.151

This data clearly shows a **negative linear trend**.

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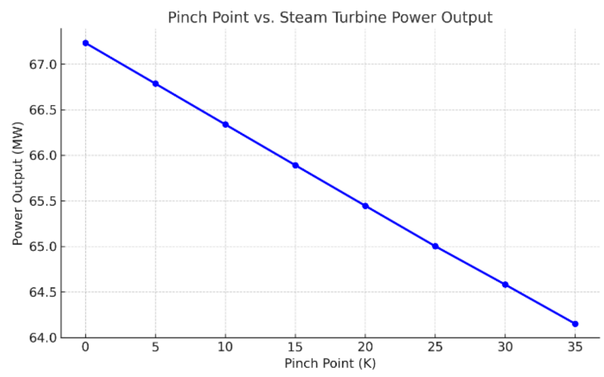
Graphical Representation

A generalized plot



Regression Model

To formalize this relationship:

Linear regression:

Let P be power output and x the pinch point.

Using the average data:

$P(x)=-0.088x+67.23P(x) = -0.088x + 67.23$

Where:

-0.088 MW/K is the **slope**, indicating that for every 1 K increase in pinch point, the steam turbine output drops by ~0.088 MW.

67.23 MW is the intercept at 0 K pinch point.

General Discussion

Pinch Point Values and Turbine Power Output Analysis

The statistical evaluation of simulation results from a combined cycle gas turbine (CCGT) system reveals a strong and consistent inverse linear relationship between pinch point values and steam turbine power output. Across all twelve months of analysis, it was observed that as pinch point values increased from 0 K to 35 K, the corresponding turbine power output steadily declined. This indicates that higher pinch point values result in reduced thermal energy extraction from the heat recovery steam generator (HRSG), ultimately lowering the amount of energy converted to mechanical work by the steam turbine. The consistency of this trend throughout the year confirms its reliability and robustness, regardless of seasonal or ambient temperature variations.

A linear regression model further substantiates this observation, with the derived equation

$P(x)=-0.088x+67.23P(x) = -0.088x + 67.23$,

where P(x)P(x) denotes power output in megawatts and xx is the pinch point in Kelvin. This equation shows that for every 1 K increase in pinch point, turbine output decreases by approximately 0.088 MW, highlighting the sensitivity of system performance to pinch point settings. Consequently, optimizing the pinch point is a crucial aspect of CCGT system design. While lower pinch point values enhance efficiency by maximizing energy recovery, they also require larger heat exchanger surfaces and increased capital investment. Therefore, engineers must carefully balance thermodynamic performance with practical engineering and economic constraints. In essence, effective pinch point optimization plays a pivotal role in achieving efficient and cost-effective power generation in combined cycle systems.

Conclusion and Recommendations

The effect of pinch point on a combined cycle gas turbine was analysed, and the following conclusions were drawn as follows;

The temperature variation for Kaduna was obtained from NIMET for the year 2017. These values were studied, and it was seen that the highest temperature occurred in March and was recorded to be 37 ℃, while the lowest temperature occurred in January, which was recorded to be 15.1 ℃.

The monthly mean temperature values were determined and these values were used to carry out a performance analysis on the MS9001E gas turbine using GasTurb 11 software. After each performance analysis, the exhaust temperature value was recorded. These exhaust temperature values coupled with the pinch point values were used to determine the HRSG exit temperature. Eight pinch point values were used starting from 0, 5, 10, 15, 20, 25, 30 and 35.

Eight HRSG exit temperature values were determined and used as the starting point in analysing the steam turbine performance using Aspen HYSYS version 11 software. Eight performance analysis were carried out for each month of 2017 and the results clearly showed how the varying pinch point values were affecting the steam turbine output performance.

Since the pinch point values affects the output performance of the steam turbine engine, this automatically means that the overall output performance of the combined cycle gas turbine will be affected since the steam turbine engine contributes up to 34.7 % of the output performance of the combined cycle gas turbine.

From the analytical research carried out, it can be recommended that in order to achieve a higher output performance and thermal efficiency, the pinch point value of any GE MS9001E combine cycle gas turbine must be kept as low as possible, because a higher pinch point value reduces the performance of the combine cycle gas turbine.

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