Performance enhancement of gas turbines of Zawia Combined Cycle Power Plant (ZCCPP) using absorption chiller system

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الملخص:

تعاني محطات توليد الطاقة الكهربائية ذات الدورة المزدوجة والدورة الغازية التي تعمل في ظروف المناخ الحار من انخفاض في إنتاج الطاقة وهذا يؤثر سلبا على كفاءة المحطة وخاصة أثناء ارتفاع درجة الحرارة في أشهر الصيف ويقل إنتاج محطات توليد الطاقة ذات الدورة المزدوجة في أشهر الصيف الحارة أقل بنسبة تصل إلى 20٪ مقارنة بأيام الشتاء الباردة. نتيجة لذلك، تم تطوير عدد من تقنيات تبريد مداخل الهواء في التوربين الغازي على مر السنين للرفع من كفاءة المحطة. في نظام الدورة المزدوجة يتم الاستفادة من غازات العادم للتوربين الغازي لتوليد بخار عن طريق مبادل حراري، فإن ناتج الطاقة الكلي للدورة المزدوجة سينخفض بشكل كبير مع ارتفاع درجة الحرارة.

سيتم في هذا البحث دراسة تحسين كفاءة محطة توليد طاقة ذات دورة مزدوجة قائمة بذاتها (CCPP) في مدينة الزاوية، ليبيا باستخدام نظام تبريد امتصاص مقترح (AC) لتبريد الهواء الداخل التوربين الغازي، وسوف يتم مقارنة النتائج النظرية المتحصل عليها مع قراءات المحطة باستخدام برنامج محاكاة GTpro. من خلال مقارنة النتائج المتحصل عليها باستخدام نظام تبريد بالامتصاص (AC) مع النتائج بدون استخدام نظام تبريد بالامتصاص (AC)، تبين ان الطاقة المنتجة للتوربين الغازي للمحطة تزداد كلما انخفضت درجة حرارة دخول الهواء للتوربين الغازي

في المحطة وبالتالي زيادة كفاءة المحطة وبالتالي إمكانية تطبيق هذا النظام على محطات توليد الطاقة الكهربائية الغازية والمزدوجة في ليبيا على نطاق واسع.

Abstract

The Combined Cycle Power Plants (CCPP) and gas power plant operating in hot climate conditions suffer from a decrease in energy production, and this negatively affects the efficiency of the plant, especially during the high temperature in the summer months, and the production of CCPP in the hot summer months is less by up to 20% compared to cold winter days. As a result, a gas turbine inlet air cooling technology have been developed over the years to increase plant efficiency. In the gas turbine cycle system, the exhaust gases of the are used to generate steam through a heat exchanger. Because mass flux decreases with increasing ambient temperature, the total power output of the combined cycle will decrease dramatically with increasing temperature.

In this research, the efficiency improvement of Combined Cycle Power in Plant Zawia city (ZCCPP), Libya, will be studied by using a proposed absorption chiller system (AC) to cool the air entering the gas turbine, and the obtained theoretical results will be compared with the readings from power plant by using GTpro simulation software.

By comparing the results obtained using an absorption chiller system (AC) with the results without using an absorption chiller system (AC), it was found that the energy produced by the gas turbine of the plant increases with the decrease in the air entry temperature of the gas turbine, thus increasing the efficiency of the power plant and thus the possibility of applying this the system on gas and combined power plants in Libya on a large area.

Keywords: Absorption Chiller. HRSG, Gas turbine, fogging system, Steam Turbine, and combined cycle power plants.

Introduction

The Combined cycle power plant (CCPP) are being developed to improve their performance. Recently developed of Gas turbine power plant (GTPP) have over 42% net efficiency, and combined cycle power plants that use them have attained over 60% efficiency based on their Lower Heating Value (LHV) and are designed to work with constant airflow through the compressor[8]. When the ambient air temperature rises, its specific mass decreases, and thus the mass flow into the turbine decreases accordingly. This, in turn, will reduce the power output from gas turbines. The output power depends directly on the airflow flow in the cycle. For each degree Celsius increase in air temperature, 0.5 to 0.9% of the power generated by the gas turbines and 0.29 of the total power generated by the combined cycle are reduced[3].

To generate more energy in hot weather, the temperature of the air circulating in the gas turbine must be reduced. Air intake cooling systems are one of the most economical means of improving the efficiency of gas turbines. As a result, many inlet air cooling technologies have been implemented, such as mechanical cooling, absorption cooling, inlet fogging system, evaporative cooling and wet compression[1]. In the case of evaporation cooling, the capital cost is very low because evaporation coolers only have blowers and small water pumps in a typical system, but the cooling effect is relatively low in comparison with other intake air cooling systems. The inlet vapour is similar to evaporative cooling, but water spray into the air into nozzles to increase moisture. With wet compression, water is sprayed at the compressor inlet and evaporated inside the compressor, significantly reducing the compressor's power. However, the possibility of corrosion and erosion is a limiting factor in the application of inlet fogging and wet compression[10].

The open ideal cycle gas turbine and T-S diagram of this cycle[1]. As shown on the Figure (1), the pressure lines of the compressor (1-2) rise as the ambient temperature rises. Because of the constant spacing of the pressure, the compressor work will increase. Instead, by increasing the ambient temperature, the compressor outlet pressure will decrease, resulting in reduced cycle efficiency[1]. In addition, due to the decrease in air density due to the increase in temperature, the heat rate will decrease and, consequently, the specific fuel consumption will increase. From the T-S chart, it is easy to conclude that on a hot summer day and at a constant maximum cycle temperature (the maximum temperature of the gas entering the turbine is determined by metallurgical considerations) the compression ratio will be reduced. This will reduce the work done by the turbine[4].

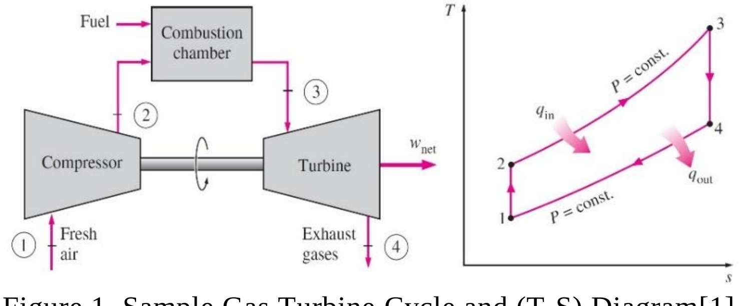

Figure 1. Sample Gas Turbine Cycle and (T-S) Diagram[1]

Figure 2 shows that, as the temperature of the air entering the compressor section of the gas turbine increases, the output power, thermal efficiency and air mass flow decrease, while the heat rate increases in comparison with ISO (15°C, 60% relative humidity) the temperature of the air entering the compressor is shown[4]. As shown in this figure, when the input air temperature changes from 15°C to 32°C, the output power decreases by approximately 10%.

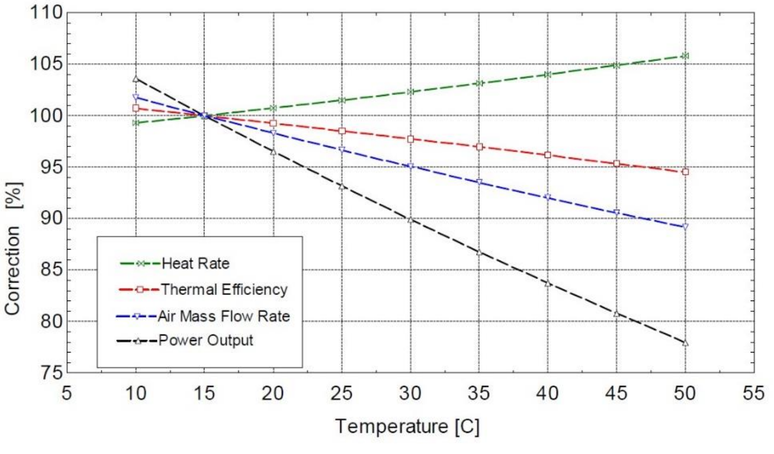

Figure 2. Compressor inlet air temperature (°C)

The power plant model in this study is an existing power plant located in the city of Zawia in Libya and has been connected to the General Electric Company of Libya (GECOL) since 1999. The power plant is situated to the west of the city of Tripoli, next to the Zawia oil refinery[2].Figure 3 shows 3D drawing of the Zawia Combined Cycle Power Plant (ZCCPP) [2], and the parameters used for the simulation project are also shown in Table 1. The plant includes three power blocks each one contains two Gas Turbine and one Steam Turbine; our steady will be on one block contains two gas turbines GT13E2 (GTs) and one steam turbine (STs). The main operational parameters for gas turbines (GT13E2) consume 9.263 kg/s of natural gas or light fuel and 468 kg/s of air at ambient temperature of 37 °C to produce 155 MW of electricity and emits 460.8 kg/s of exhaust gases at a temperature of 585.5 °C [2].

Figure. 3 3D drawing of the Zawia Combined Cycle Power Plant (ZCCPP)[2] .

The ISO Parameters of the Manufactory Company Alstom GT13E2 unit shown in Table 1 and the diagram of Zawia Combined Cycle Power Plant (ZCCPP) in figure 4.

TABLE 1. Parameters of the Manufactory Company Alstom

Parameters at ISO Day	Design specification	At Ambient temperature of 38 °C
Manufacturer	Alstom Co.	
Model (power)	GT13E2 (160.0 MW)	GT13E2 (140.0 MW)
Frequency	50 MHz	50 MHz
Overall thermal efficiency at generator terminal	38.6%	33.6%
Compressor pressure ratio	GT13E2 (14.5:1)	GT13E2(14.5:1)
Number of compressor stages	21	21
Number of turbine stages	5	5
Shaft speed	3000 (rpm)	3000(rpm)
Type of the shaft	Single one spool	Single one spool
Fuel type	Natural gas or light fuel	Natural gas or light fuel

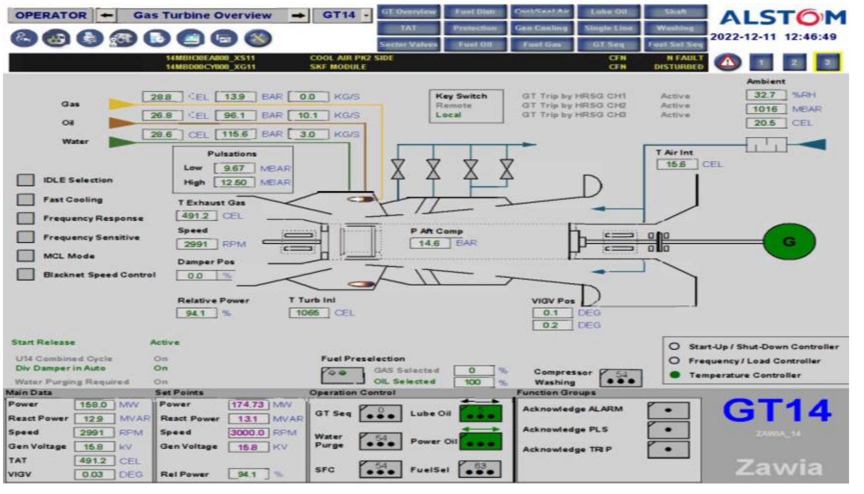

Figure. 4 Gas Turbine overview of control screen Zawia Combined Cycle power plant[2].

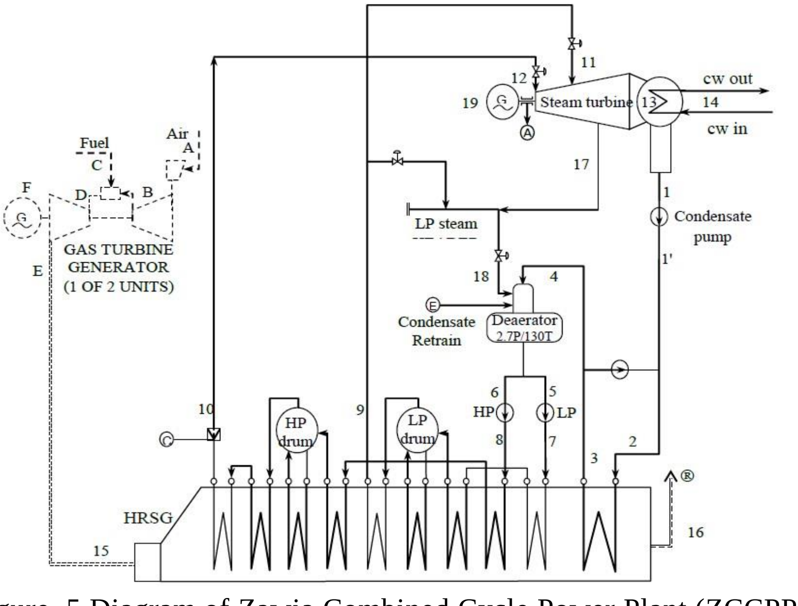

Figure. 5 Diagram of Zawia Combined Cycle Power Plant (ZCCPP) [10].

There are many techniques of cooling air intake in Gas Turbines and the most common are:

- evaporative cooling or water spraying to the inlet air (fogging).
- The chiller water Cooling system using thermal energy storage or ice harvesting.
- Mechanical chiller to be used Cooling of intake or absorption chiller.

According to the technical study for the different possible methods for the environmental condition of Zawia City (41°C), from my paper that I published about Zawia Combined Cycle Power Plant (ZCCPP)[7] , Benefits from evaporative cooling include:

- Up to 10% increase in output power.
- Low service costs (2-4% of initial install cost).
- Reduced NOx emissions (0.7 to 1.2 per cent for every degree Celsius of air cooling)[5].
- Low water consumption (0.7-1.1 m3 for every additional MW electricity generation).
- Low energy consumption to operate the pumps (less than 0.4% of additional electricity generation)[11].

The study showed that evaporative cooling (fog and media) is better than other options for gas power plants located in desert areas, given that the humidity is low, and therefore a fogging cooling system can be used. However, in the case of Zawia power plant (ZCCPP) , this is not possible due to the high humidity in the summer, given that the station is close to the sea[7].

Methodology

In this study, waste heat is employed to drive the Absorption Chiller (AC) to lower the ambient temperature of the gas turbine air compressor inlet are shown in figure 6. The thermal exhaust from the gas turbine can be used for productive purposes. At this phase, the two power plants will be linked so that the absorption chillers are powered by the exhaust heat energy of the gas turbine as it exits the Heat Recovery Steam Generators (HRSG) [9].

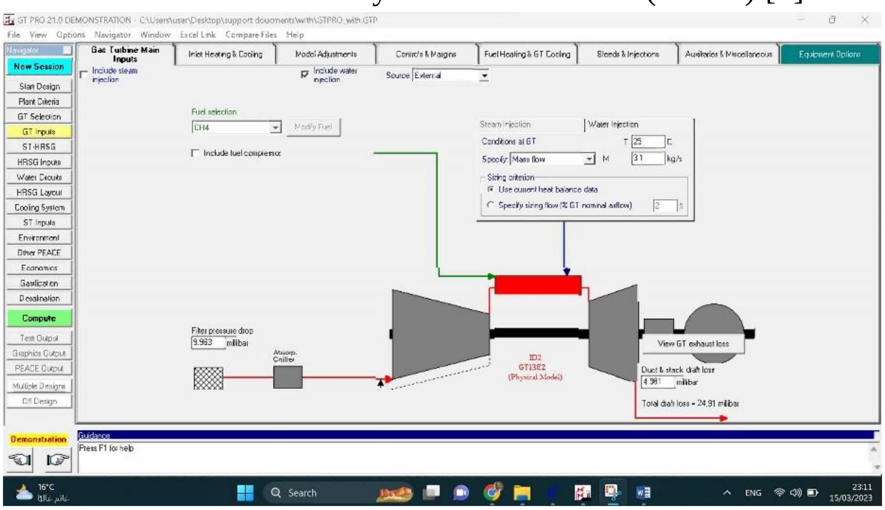

Figure. 6 Simulation model of the gas turbine with AC (GTpro Model)

Based on the simulated model, the exhaust stream leaves the HRSG unit for (GT13E2) at a temperature of 108.29°C, enters the counter current heat exchanger with a heat transfer area of 742.48 kW/K, and uses 2.9% of the thermal energy left over to feed a single-effect absorption cooler to produce 2329 RT of chilled water at a temperature of 7°C for the HRSG (GT13E2) unit, the exhaust flow temperature is 106.39°C, and the exhaust flow temperature is 108.29°C, enters the counter-current heat exchanger with a heat transfer area of 742.48 kW/K, where 2.9% of the remaining thermal energy is used to feed a single-effect absorption cooler to produce 2329RT of refrigerated water at a temperature of 7°C for the HRSG (GT13E2) unit, and where 3.31% of the remaining exhaust heat energy is used to power the second absorption coolers with a refrigeration capacity of 2329RT With a mass flow rate of 328 kg/s, the absorption chiller generator receives heat energy from the counter-current heat exchanger of the absorption chiller at temperatures of 108.29 and 106.39°C. At a temperature of 78°C, the water was then pumped back to the heat exchanger. are shown in figure 7 The water stream is chilled to the necessary temperatures as it travels from the absorption chiller's evaporator, which is located at 7°C, to the gas turbine's inlet heat exchanger as depicted in the Figure 8. Afterwards, it is pumped into the evaporator with a mass flow of 328 kg/sec at a temperature of 12°C. Moreover, the absorption chillers are cooled by a stream of 24°C seawater.

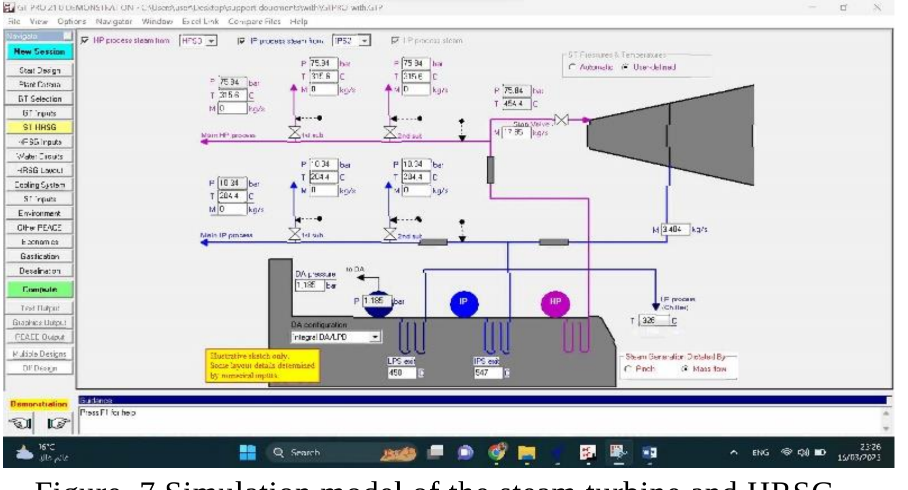

Figure. 7 Simulation model of the steam turbine and HRSG

The chillers that cool the condenser have an inlet temperature of 40.7°C and an exit temperature of 33°C. Under ISO conditions, which were as follows: ambient temperature of 15 °C, humidity of 60%, atmospheric pressure of 1.013 bar, and full load seawater temperature of 25 °C, the first simulation was performed. The half load condition was explored by varying the output between 25% and 100% while keeping a balanced load distribution across the gas turbines.

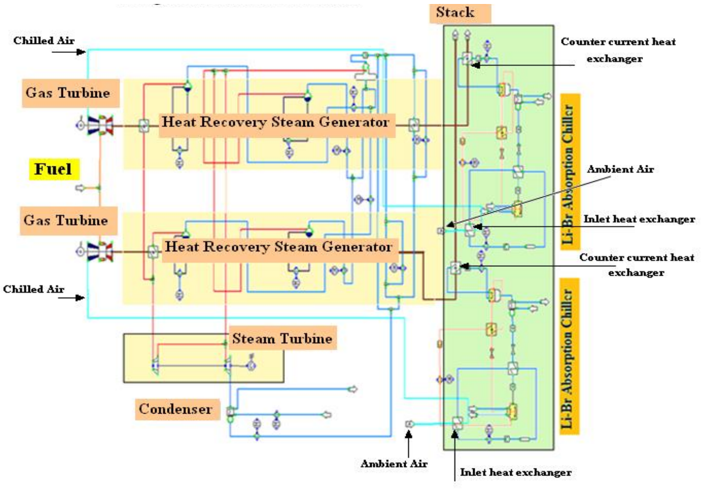

Figure. 8 Zawia Power Plant retrofitted with Absorption Chillers (AC).

RESULTS

The purpose of this study is to look into how well plants perform when the ambient temperature varies due to the weather. The Zawia power plant's planning department provided the meteorological information that was used to calculate the maximum and minimum ambient temperature values that were taken into consideration.

The GTpro Model, which was utilized to generate the necessary variation and interchange the input values and results between the GTpro process simulator and MS Excel spreadsheet and simulation was for one block (two gas turbine and one steam turbine) of the power plant, was used to conduct the sensitivity studies. Figures 9 through 15 show how this simulation's results came out. As anticipated, as ambient temperature rises, both power output and efficiency drop, with the sensitivity being highest for power production under high load but lowest for efficiency under low load. Compared to the low load situation, the fuel flow rate considerably reduces during high load as the ambient temperature rises. The CO2 emission rate, which is maximum for the low load, high ambient temperature situation, reflects this depicts the impact of ambient temperature on the performance of the plant's output power at various loads prior to improvement. When the block in ZCCPP was operating at full capacity and at an ambient temperature that was 37°C above the ISO condition, power output was reduced by 12.17 percent, and plant efficiency was reduced by 1.97%. At 50% part load and 37°C ambient temperature, the block in ZCCPP's power production reduced, and its plant efficiency decreased by 2.80%.

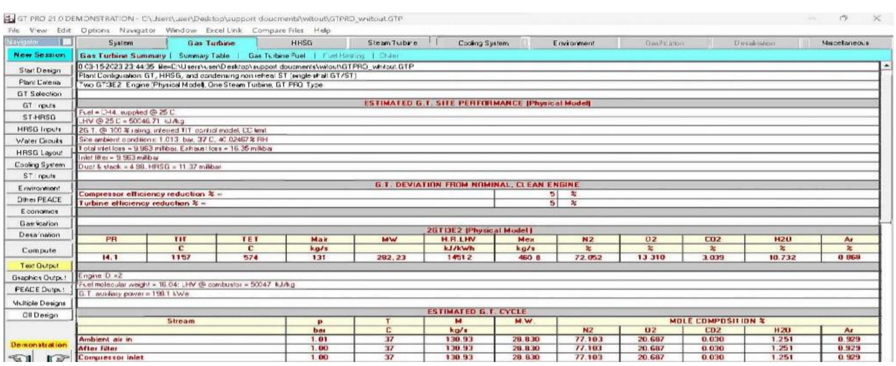

Figure. 9 Simulation model of the gas turbine output data Summary without AC

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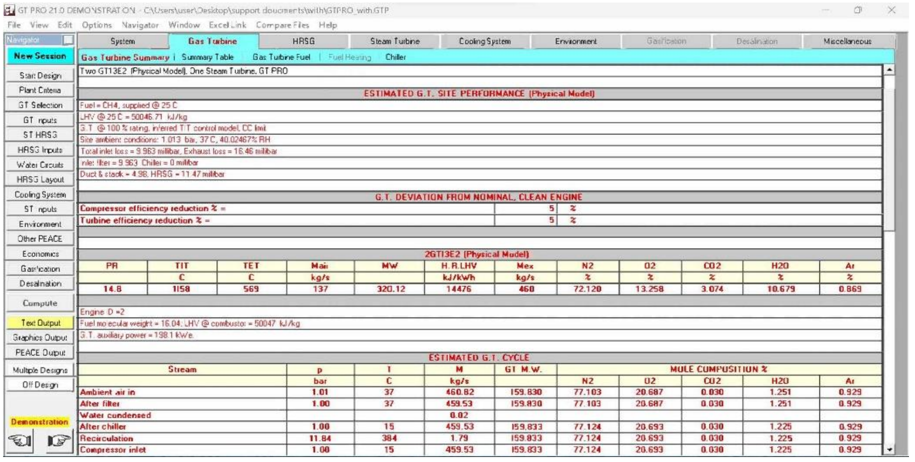

Figure. 10 data output Gas Turbine Summary from GTpro Model simulation with AC

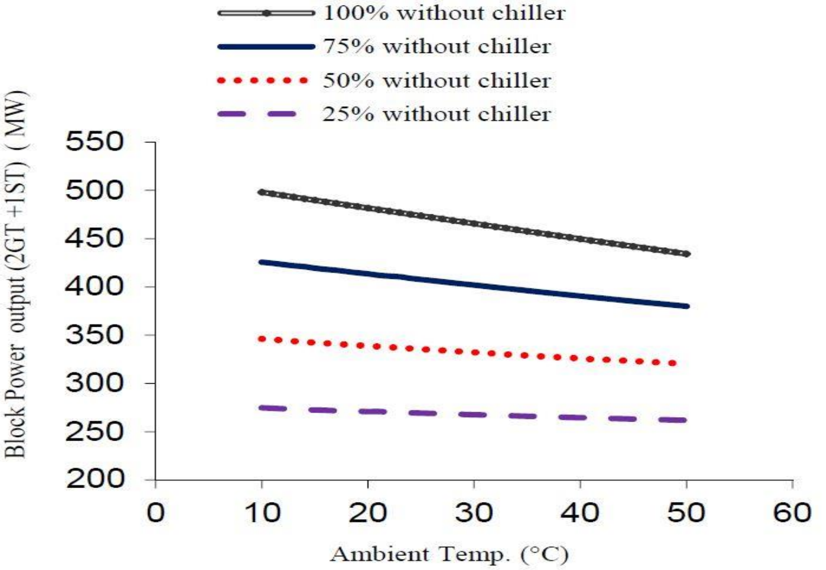

Figure 11. Power Output variations with Ambient Temperature without AC

According to Figure 12, the block in ZCCPP with absorption chillers performed significantly better than the plant without absorption chillers. Under full load and running with an ambient temperature of between 15°C and 37°C , the absorption chiller enhanced plant efficiency by 0.16%, and just slightly lowered power output. The efficiency dropped by 0.18% when the plant was running at 50% portion load.

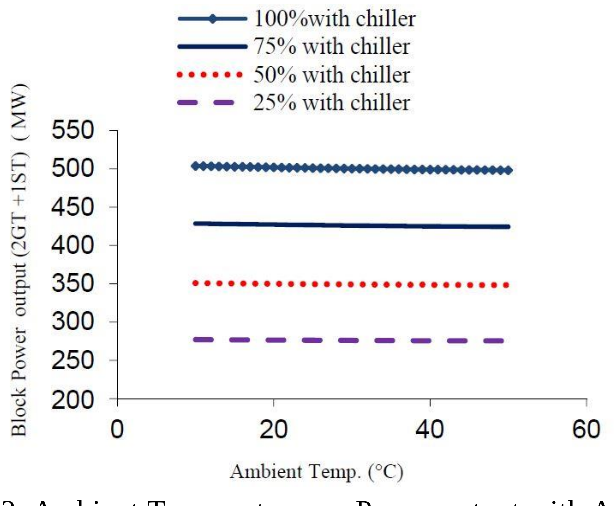

Figure 12. Ambient Temperature vs. Power output with AC and at different

Figures 13 and 14 display the block power plant's efficiency for all loads, with and without AC, and at various outside temperatures. Without absorption chillers and under ISO conditions, the plant's efficiency decreased by 0.27% for every 5°C rise in ambient temperature, while it increased by 0.04% when equipped with absorption chillers.

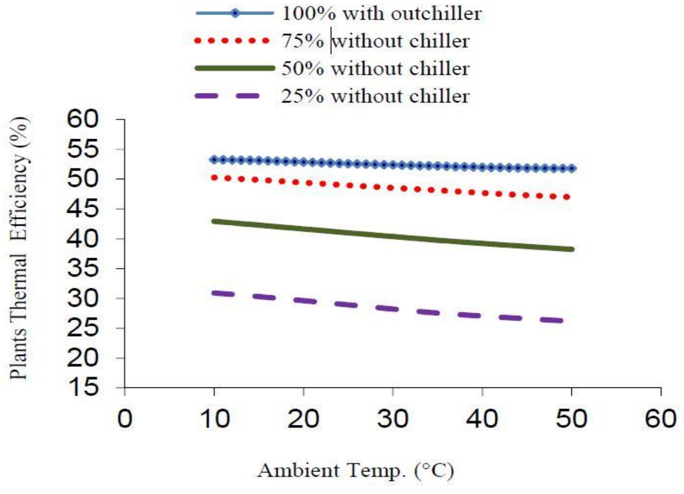

Figure 13. Plant thermal efficiency vs. Ambient Temperature and at different loads without AC

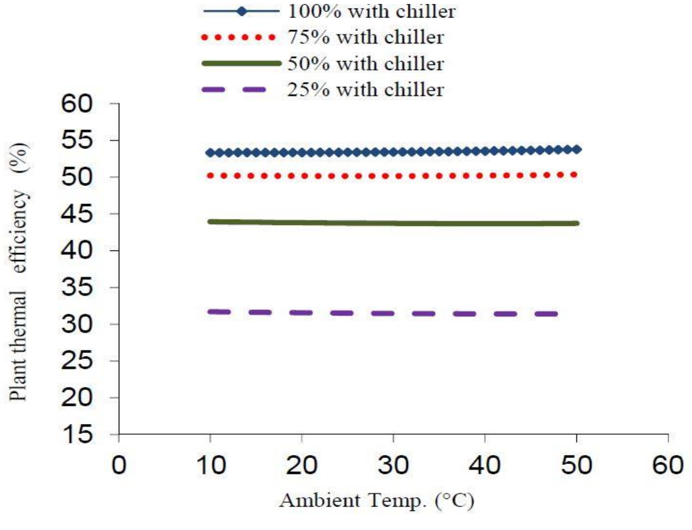

Figure 14. Ambient Temperature vs. Plant thermal efficiency at different loads with AC

TABLE 2. Fuel consumption Comparison between withAC and without AC

Temp (˚C)	ZCCPP Fuel consumption (kg/s) without AC and different loads				ZCCPP Fuel consumption (kg/s) with AC and different loads			
Loads %	25%	50 %	75 %	100 %	25 %	50 %	75 %	100 %
ISO	9.6	13.5	17.6	21.8	9.7	13.7	18.2	22.7
25˚C	9.6	13.2	17	20.8	9.7	13.7	18.1	22.6
35˚C	9.6	13	16.3	19.7	9.7	13.6	18	22.4
45˚C	9.5	12.7	15.7	18.7	9.6	13.6	17.9	22.3
50˚C	9.5	12.6	15.3	18.1	9.6	13.6	17.8	22.2

Figure 15 shows how the HRSG behaves when recovering the energy present in the gas turbine exhaust. In the design case full load, it is the most effective and is not susceptible to fluctuations in the outside temperature. At low load, however, the temperature has a significant impact on performance.

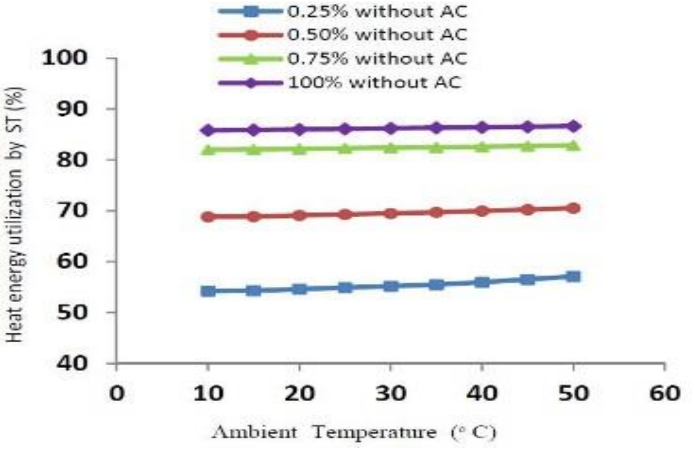

Figure 15. Ambient Temperature vsheat energy utilization by ST without AC

CONCLUSION

All of the results show that adding inlet air cooling to an existing combined gas steam turbine power plant that is currently in operation in Zawia, Libya, will have positive consequences. According to the simulation, the planned plant would operate reliably and effectively under a variety of loads. The facility gains a lot from installing absorption chillers in numerous ways. First of all, it makes use of waste heat energy that would typically be released into the atmosphere. Second, it reduces the impact of changes in the outside temperature. Thirdly, it boosts power output and raises total plant efficiency. Ultimately, it lengthens the lifespan of the gas turbine and lowers maintenance expenses.

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