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# Exergy analysis of Gas Turbine Power Station under Different Operation Conditions

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Abstract

The present study aims to assess and investigate the Qayyarah Gas Station in Nineveh City, Iraq's gas turbine power generating system. The gas turbine unit produces a design power of up to a maximum of 125 megawatts under standard conditions, and the operating power of one unit of the station reaches 100 megawatts. The system is made up of a generator, air compressor, and gas turbine that are connected to a single shaft. Based on the direct Joule-Brayton cycle, it performs its duties. The concepts of conservation of mass, first law, and second law were taken into consideration while analysing the exergy of the aforementioned unit. The study's primary goal was to determine how various factors, such as operational load, relative humidity, ambient temperature, and pressure ratio, affect one another. To reproduce the company's data, two programs were employed; the first utilized Aspen HYSYS, while the second used Excel to design the simulation. For that year's simulation, average data from every month of the simulation was used to assess the gas unit's performance. The findings of the simulation showed that the combustion chamber is the main source of energy dissipation and that fuel in the form of chemicals may produce the most energy. According to the findings, the highest energy efficiency of the station was reached in the month of December at a temperature of (17C°), about (40.2%), while the maximum available energy efficiency (Exergy) was reached in the month of December at a temperature of (17C°), about (33.7%). The lower the external ambient temperature, the greater the station's utility.

## 1. Introduction

The globe faces several difficulties, chief among them the scarcity of energy and the rising demand for it brought on by the rise of the global economy and population growth. It forced nations to consider carefully how they would supply this energy. One of the factors behind the phenomena of global warming is energy. Energy is essential for human usage and plays a significant role in social and economic advancement. Studies have indicated a correlation between the expansion of the economy and the usage of electricity. This link suggests that increased electrical energy usage has an impact on economic expansion [1]. In contrast to conventional energy sources like nuclear power, hydropower, solar energy, wind energy, and others, renewable energy is clean energy that doesn't harm the environment. However, because of its limited supply and damage to the ozone layer, which impacts both human health and the planet's climate, it can't meet demand. Like other nations, Iraq experiences a deficit of electrical energy as a result of the recent rise in demand for it. This has led to a lack of electrical energy sources, which has impeded Iraq's progress in the majority of fields related to modern development [2]. The development of electrical energy consumption and satisfying the growing demand for it depend on boosting production efficiency and streamlining usage. This is seen as a good way to lessen the influence on the environment as it lowers emissions and the amount of fuel used in the thermal station, which tends to be replaced by clean energy to cut down on the usage of fossil fuels and lowers prices. However, because they can transform thermal energy into electrical energy in gas turbines, fossil fuels are regarded as one of the most significant sources of electrical energy generation [3]. The thermal energy found in the hot gases produced by burning is transformed into mechanical energy by gas turbines. The stored thermal energy is transformed into energy by the gas turbine, which raises air pressure and directs compressed air to the combustion chamber, where fuel and air are combined. Hot gasses are produced when they are ignited. The compressor and turbine shaft are run by the energy contained in the gases. The turbine's rotating action causes the air compressor's main shaft to revolve independently at the same time, utilizing mechanical energy [4]. Figure 1 shows the parts of a gas turbine.

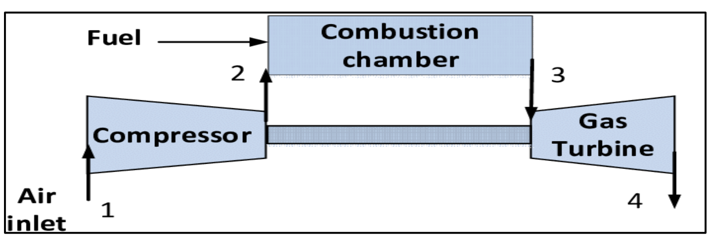



**Fig. 1** Gas Turbine unit [5]

The capacity of gas power plants to generate vast amounts of energy surpasses that of other forms of power plants that concentrate solely on producing electrical energy, which is just one of their numerous advantages. This is as a result of how much fuel they can efficiently turn into electricity. Gas turbines are distinguished from other types of turbines by their quick start-up times and high energy distribution, which frequently exceeds 60% or more. Gas turbines can effectively satisfy the necessary requirements in a short amount of time, which makes them highly sought after. Gas turbines' reliance on carbon as a fuel source also restricts the fields in which they may be used to produce electricity [6]. Because gas power plants are so efficient at producing energy, they are vital to the economy, especially when it comes to the creation of electricity. Gas turbines are devices that convert the thermal energy released during the combustion of natural gas into mechanical energy. This mechanical energy is then converted into electrical energy by electrical generators. Gas-fired power plants have the capacity to generate electricity at a high rate during times of demand, which makes them a potentially viable option for meeting significant energy needs. Additionally, these power plants significantly contribute to the stability of the electrical system as a whole [6]. The goal of engineering was to increase the gas power plants' part-load operational efficiency. The goal of gas turbine technological advancements was to improve efficiency and operational capabilities. Control and switching system functionality has improved, enabling plants to respond more quickly to variations in energy demand and preserve grid stability. Many tactics have been developed to lower power plant gas emissions. This entails employing cutting-edge combustion technology and putting in place gas processing systems to manage combustion byproducts. Water usage was to be decreased while plant operating efficiency was increased through the development of the cooling systems [6].

Using software techniques to simulate a power plant from data taken from the operating department for the year 2023, this research aims to theoretically analyze the exergy and study the effect of relative humidity, pressure ratio, heat load and external ambient temperature on the equipment of the Qayyarah gas station.

There are previous studies on energy analysis in general, especially exergy analysis. We will mention some of them in this table:

**Table 1.** Previous studies on exergy analysis and improvements in electric power generation plants [6]

| No. | Researcher and Location | Parameter | Type of study | Conclusion |
|---|---|---|---|---|
| 1. | Feron P, (2010) Norway | Improving the performance of power generation plants | Analytical study | Improving the overall efficiency of combustion gas turbine plants from (41%) to (46%) |
| 2. | Kumar Shukla A, et al. (2018) India | Improving the performance of simple gas turbine cycle | Analytical study | The thermal efficiency of the gas turbine cycle has been enhanced by an increase of (2%), resulting in an overall efficiency of (18%) |

| | | | | |
|---|---|---|---|---|
| 3. | Javadi M, et al. (2020) UAE | Improvements in cogeneration plants | Sensitivity analysis | Improvements in the performance of combined power plants have been achieved through the use of energy analysis and economic analysis techniques. System modification resulted in a maximum efficiency improvement of 9.9% |
| 4. | Almajali M, Quran O (2021) | Optimize the main cycle parameters for each system at intervals | Parametric study | Enhancing the thermal efficiency of the cogeneration plant was achieved by implementing two main strategies: raising the gas turbine inlet temperature and increasing the pressure ratio of the gas turbine. Efficiency has been enhanced to 60% |
| 5. | Chen H, et al. (2022) China | Improving the overall efficiency of the station | Analytical study | A new waste heat recovery system has been developed by integrating a cement mill and a coal power plant, resulting in significant improvements. The coal power plant achieved an increase of (16.14) megawatts in its total energy production |

**Nomenclature:**

| | | | |
|---|---|---|---|
| **B.W.R** | Brick work ratio | **PE** | Potential energy , J |
| **CO** | carbon dioxide | **Rp** | Pressure ratio |
| **CP** | Specific heat , J/kg.K | **RH** | Relative humidity |
| **Ex** | Exergy , W | **S** | Entropy ,KJ/k |
| **H** | Enthalpy , J/kg | **T** | Temperature , K |
| **G** | Acceleration , 9.81 m/s2 | **W** | Work |
| **JBC** | Joule-Brighton cycle | **V** | Velocity , m/s |
| **KE** | Kinetic energy , J | **Z** | Elevation, m |
| **LHV** | Lower heating value , J | **ηI** | Energy efficiency |
| **ṁ** | Mass flow rate , kg/s | **ηII** | Exergy efficiency |
| **P** | Pressure , Pa | **a** | Ambient |

| | | | |
|---|---|---|---|
| **c** | Compressor | **PT** | Potential |
| **CH** | Chemical | **T** | Turbine |
| **cc** | Combustion champe | **T2** temperature | Compressor inlet |
| **i** | Inlet | **T3** temperature | Turbine inlet |
| **o** | Out let | **T4** temperature | Turbine outlet |
| **dec** | Destructs | | |
| **KN** | Kinetic | | |
| **PH** | Physical | | |

### The purpose of the research

- Conducting an analysis of the energy and exergy of the power generation station (Gas Station in Qayyarah) using the simulation program (Aspen HYSYS) under the ideal conditions of the station according to the principles of thermodynamics (the first and second laws).
- Determining the exact location and amount of energy wasted through the components of the unit efficiently and cost-effectively.
- Evaluating the impact of external variables on the thermal efficiency of the station, the total energy efficiency, the energy availability rate, the energy loss rate, the particular fuel consumption, and the work output ratio.
- Evaluating the economic cost of operating the station with the used fuel (natural gas) and other maintenance procedures.

## 2. Plant description

The Qayyarah gas station is a vital station located in the northern region of Iraq. It was designed by Turkish companies and developed by General Electric (GE). The plant has a single-shaft turbine model (9001E), six Calic Energy Corporation generators, and an engine speed specification (3,000 rpm). The unit aims to operate at a capacity of 12,500 megawatts, and the design power is approximately 100,000 megawatts when operating under load. Designed to operate on three different types of fuel: natural gas, light fuel, and crude oil [7]. Figure 2 provides an overview of the Qayyarah Gas Power Station from Brighton. The ambient air in this gas plant is filtered before it reaches the gas turbine compressor. The compressed air is then brought to the same temperature as the intake by combustion equipment inside the combustion chamber. Combustion occurs, causing the turbine to rotate. Exhaust gases are produced during the combustion process at high temperatures. [6].

The gas turbine unit's technical specifications are comprehensive in Table 1 [6] [7] They include the type of turbine designed, the design and operating capacity, the number of turbine and compressor stages, the approximate amount of pressure ratio and shaft rotation speed.

**Fig. 2.** Qayyarah gas power station [6]

**Table 2.** Gas turbine technical specifications [6, 7]

| Turbine type | Aeroderivative |
|---|---|
| Model | 9001E |
| Nominal power | 100 MW |
| Stage number of turbine | 14 |
| Stage number of compressor | 14 |
| Compressor ratio | 10 |
| Shaft speed | 3000 rpm |

## 3. Performance analysis techniques

Prior to being acquired by Aspen Tech and rebranded as Aspen HYSYS, Hyprotech developed the HYSYS software. Oil, natural gas, petrochemical, gas, and thermal facilities are all simulated using the HYSYS program as it includes all the industrial components required for most businesses. A thorough database with the majority of the materials used in the aforementioned areas is also provided by the program, and users have the option to add more materials or compounds. Reactors, distillation towers, absorption columns, heat exchangers, and a plethora of other industrial equipment are among the numerous that use it in their design [8]. Large design firms like Enppi and others to create comprehensive designs for gas plants, petrochemical plants, and petroleum refining facilities use the HYSYS program. In the Arab world as well as other parts of the world, this software is utilized in design in conjunction with other auxiliary programs. Furthermore, the program uses the values of the various parameters to calculate the necessary values. The system also determines the ideal pressure, temperature, heat quantity, and production rate parameters to optimize facility revenues and minimize costs [9]. It is also possible to replicate DCS control units using the HYSAS application. The program is also used to look at how operating conditions are changing. Unlike other approaches, we simulate the unit whose operational parameters we want to change first using the HYSAS program. Then, we gradually change the settings and evaluate the effect of this alteration on production rates. The ideal combination of temperature, pressure, heat output, and production rate will allow the facility to maximize profits while minimizing expenditures [10]. The flexible and reliable process simulation offered by the HYSAS program is built on the fundamental concepts of innovation and integration. A few of the many significant advantages it provides HYSAS users with are the most recent chemical process technologies, unified functions in a single software environment, seamless connection to the chemical engineering computing environment with tool links like MS Excel and Word and interfaces like (COM, DCOM), and HYSAS combining a state-of-the-art graphical user interface. Furthermore, the application may be customized to enable particular thermodynamics, unit operations, calculations, and reporting. Simulations are performed for both dynamic and stable systems [11]. A simple model for simulating gas turbines is created, as shown in **Fig.3.** Three fundamental parts make up the model: a turbine, a combustion chamber, and a compressor. Throughout the year, the conditions under which air enters the compressor vary.

In our current research, we have shown the importance of using and using the Aspen HYSYS program, through which we obtained results and values under ideal conditions for the performance and efficiency of the gas station, where an integrated station was designed and an exact copy of the actual station operating at the present time, and we reached an evaluation that is close to the actual values using theoretical calculations conducted on The station that we set up on the Excel program to facilitate time and at a lower cost and to achieve ideal results that are close to the theoretical results with a small percentage of error.

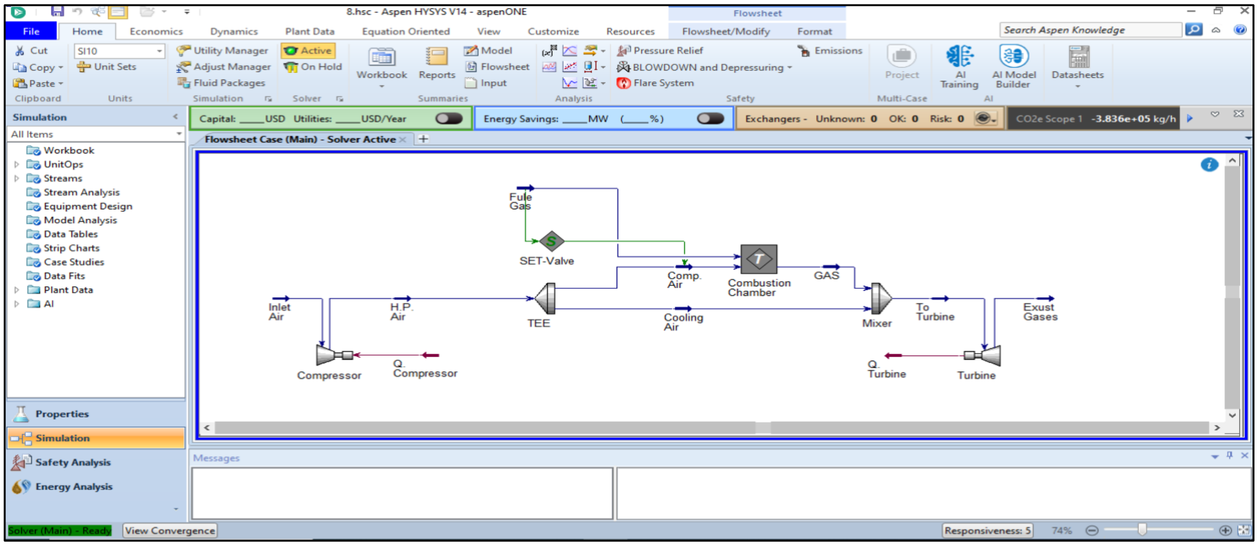



**Fig. 3.** An Aspen HYSYS gas turbine model's flowchart

## Assumptions

In order to provide a coherent and precise framework for the study of this system, a number of fundamental presumptions are established. These presumptions are:

1. <u>Steady-State Flow:</u> Throughout our investigation, it assumed that the GPP is operating in an equilibrium state with constant circumstances.
2. <u>Ideal Gas Assumption:</u> In thermodynamic studies, it is usual practice to assume the air and combustion products within the GPP as ideal gasses.
3. <u>Molar Fraction of Air and Combustion Products:</u> The molar fractions of air and combustion products are broken out in Tables 3 and 4, respectively.
4. <u>Dead State Conditions:</u> We take into account the conditions at a dead state with a temperature of (298.15 k) and a pressure of (101.325 kpa).
5. <u>Insignificant Heat transmission:</u> To ensure that outside influences on our study kept to a minimum, we assume that heat transmission between the plant's equipment and the surrounding environment is insignificant.

**Table 3.** Air Molar Fraction [12]

| Air elements | Molar fraction (%) |
|---|---|
| $N_2$ | 79.00 |
| $O_2$ | 21.00 |
| Others | 0.00 |

**Table 4.** Molar percentage of products of combustion [12]

| Combustion gasses | Molar fraction (%) |
|---|---|
| $N_2$ | 76.60 |
| $O_2$ | 14.08 |
| $H_2O$ | 6.07 |
| $CO_2$ | 3.24 |
| Others | 0.00 |

### 3.1 Exergy analysis

The term "exergy" refers to the greatest amount of beneficial work that a system may produce under given environmental circumstances [13]. The reason for its extensive usage in thermodynamic research is that it makes it possible to identify possible improvements in efficiency. Physical, chemical, kinetic, and prospective exergies are the four categories that comprise an exergy. We do not include potential or kinetic exergies in our analysis; instead, we concentrate on chemical and physical exergies. We provide the Exergy performance analysis equations in the following parts. The greatest amount of work that may be extracted from a system in its original condition is known as physical exergy [14], Conversely, chemical exergy is associated with changes in the system's chemical composition that deviate from equilibrium circumstances. The following equations may apply on a thermodynamic system and may derive on the second law of thermodynamics too:

$$\dot{E}_X = \dot{E}x_{CH} + \dot{E}x_{PH} + \dot{E}x_{KN} + \dot{E}x_{PT} \quad (1)$$

$\dot{E}x_{CH}$ Chemical available energy

$\dot{E}x_{PH}$ Physical available energy

$\dot{E}x_{KN}$ Kinetic available energy

$\dot{E}x_{PT}$ Potential available energy

The open cycle (JBC) calculates the quantity of energy to each component of the system as follows [15]

$$ex = (h_i - h_o) - T_a \times (s_i - s_o) + \frac{V^2}{2} + gz + ex_{CH} \quad (2)$$

The following rule uses to calculate the available power rate [16]

$$\dot{E}_X = \dot{m} \times ex \quad (3)$$

$ex_{PH}$, the result of temperature changes for air, fuel, and combustion gases entering and exiting a system in respect to the external environment, can be defined using the following formula [17]

$$ex_{PH} = (h_i - h_o) - T_a \times (s_i - s_o) \tag{4}$$

To use specific entropy of an ideal gas and calculate the amount of ΔS between two states' entrance and exit in each step [18]

$$\Delta S = S_{i+1} - S_o \tag{5}$$

$$\Delta S = C_{P,i} \times ln\left(\frac{T_{i+1}}{T_o}\right) - R \times ln\left(\frac{P_{i+1}}{P_o}\right) \tag{6}$$

The ηII for each component may be written as [19]

For Compressor **ηII AC :**

$$\eta\text{II. AC.} = \frac{Ex_2 - Ex_1}{w} \times 100\% \tag{7}$$

For Combustion Chamber **ηII C.C :**

$$\eta\text{II C. C.} = \frac{Ex_{fule\ gas}}{Ex_{fule} + Ex_{air}} \times 100\% \tag{8}$$

For Gas Turbine **ηII GT :**

$$\eta\text{II GT} = \left(1 - \frac{\dot{Ex}_{des,GT}}{Ex_3 - Ex_4}\right) \times 100\% \tag{9}$$

ηII cycle is calculated from [20]

$$\eta\text{II cycle} = \frac{W_{net}}{Ex_f} \times 100\% \tag{10}$$

And $\dot{W}_{net,load}$ is calculated from [21],[22]

$$\dot{W}_{net,load} = \left(\dot{W}_{GT} - \dot{W}_{AC}\right) \times \left(\eta_{generator} \times \eta_{mechanical}\right) \tag{11}$$

And $\dot{Ex}_{des}$ is determined from [23]

$$\dot{Ex}_{des} = T_a \times \sigma_{CV} \tag{12}$$

We must account for any measurement discrepancies when we dive into exergy estimates using real operating data from the Qayyarah GPP. Calculations of thermodynamic efficiency may be impacted by factors that cause mistakes in the recorded data, such as friction in measurement equipment, oscillations, or calibration errors. "Uncertainties" refers to these measurement uncertainties [24].

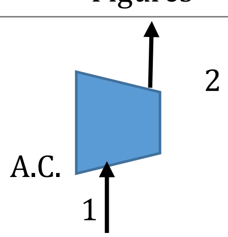
**Table 5.** Findings from the Uncertainty Analysis of the GPP

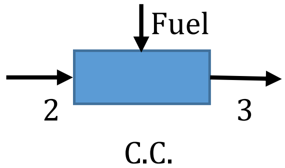
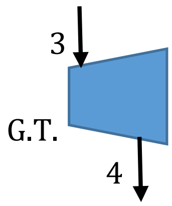
| Quantity | Total uncertainty |
|---|---|
| Temperature | ±0.10 K |
| Pressure | ±0.05 bar |
| Volumetric Flow Rate | ±0.20 $m^3$ /s |
| Specific exergy | ±0.182 kJ/kg |
| Exergy rate | ±0.012 kW |
| Exergy efficiency | ±0.148 |

### 3.2 Exergy balance

An essential indicator for evaluating how well a system uses energy as an energy efficiency. It measures the ratio of usable work that a system can produce to the total amount of energy input while taking into account the energy's quality and work-performing potential. A system may decrease energy waste and increase overall efficiency by increasing its energy efficiency. When assessing an energy system's sustainability and financial feasibility, energy efficiency is crucial. Exergy destruction specifies using the product calculations for Exergy flow rate at each component. Energy flow diminishes after each step. The formulas used to determine energy destruction and efficiency at various GPP components are given in  table 5 [25].

**Table 6.** Energy efficiency and destruction for various GPP components [26]

| Component | Figures | Exergy destruction rate | Exergy efficiency |
|---|---|---|---|
| Compressor |   | $\dot{E}x_{D,AC.} = \dot{E}x_1 - \dot{E}x_2 + \dot{W}_{AC}$ | $\eta_{X,AC.} = \frac{\dot{E}x_2 - \dot{E}x_1}{\dot{W}_{AC}}$ |

| | | | |
|---|---|---|---|
| Combustion chamber |  | $\dot{E}x_{D,C.C.} = \dot{E}x_2 + \dot{E}x_f - \dot{E}x_3$ | $\eta_{X,C.C.} = \dfrac{\dot{E}x_3}{\dot{E}x_2 + \dot{E}x_f}$ |
| Gas turbine |  | $\dot{E}x_{D,GT.} = \dot{E}x_3 - \dot{E}x_4 - \dot{W}_{GT}$ | $\eta_{X,GT.} = \dfrac{\dot{W}_{GT}}{\dot{E}x_3 - \dot{E}x_4}$ |

**4. Results and discussion**

Gas turbine performance data at the Qayyarah fuel station was simulated using both methods over a twelve-month period in 2023. The system includes variations in exergy analysis results based on factors such as ambient temperature, pressure ratio, relative humidity and heat load. . First, we studied the impact of these factors on energy production behavior:

**4.1 The effect of external variables (external temperature, relative humidity, operating load) and compression ratio on exergy efficiency**

The energy efficiency available for a full year (12 readings) of data collected from the gas station for the year (2023) was calculated, and the results indicate that the external environment's temperature has an impact on the gas turbine station's device. This means that variations in the external environment's temperature have an impact on the second law's efficiency. The results showed that the second law's efficiency ranged from (33.76%) in the eighth month at (43C$^o$) to (21.41%) in the fourth month at (21 C$^o$). This indicates that at high temperatures, the second law performed most efficiently. The second law's effectiveness is enhanced by the temperature of the surrounding environment; nevertheless, it is less effective when the ambient air temperature falls below the design temperature of (15 C$^o$). The efficiency achieved (27.45%) and (29.19%) at temperatures of (9 C$^o$) and (10 C$^o$), as shown by the findings in the first two months of the year, and this is compatible with the majority of researchers' study [27],[28], as shown in Figure 4.

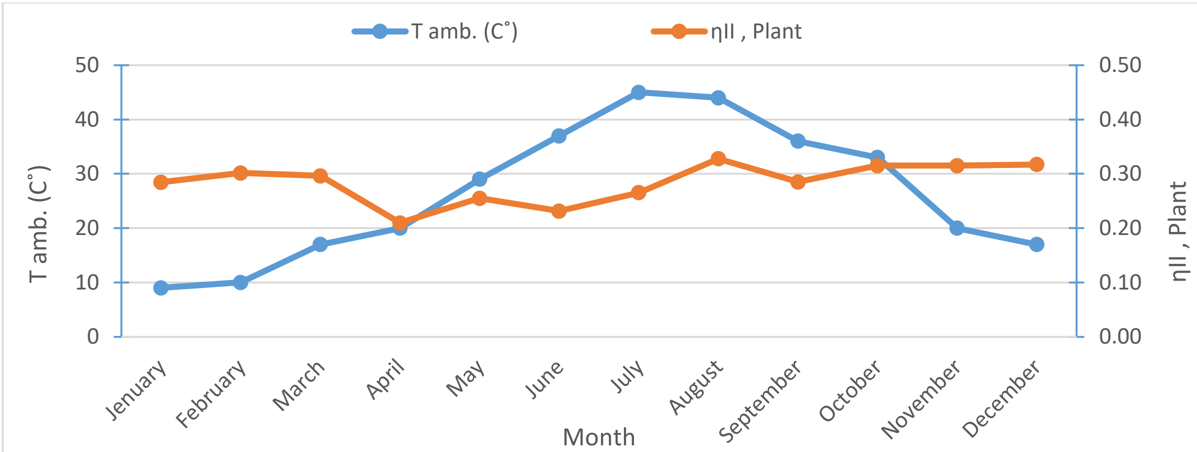



**Fig. 4.** The effect of external ambient temperature on the efficiency of available energy (2023)

The findings indicated the influence of the compression ratio for a year on the efficiency of available energy. It was observed that the greatest possible energy efficiency in the eighth month reached (33.76%) at a compression ratio of (8.88), while the highest compression ratio in the third month reached (9.37) at an efficiency of (30.99%). The lowest compression ratio in the fourth month was (6.9) at an efficiency of (21.41%). This is consistent with most researches, since they proved that when the compression ratio rises, the available energy efficiency improves [29],[30],[31], as shown in Figure 5.

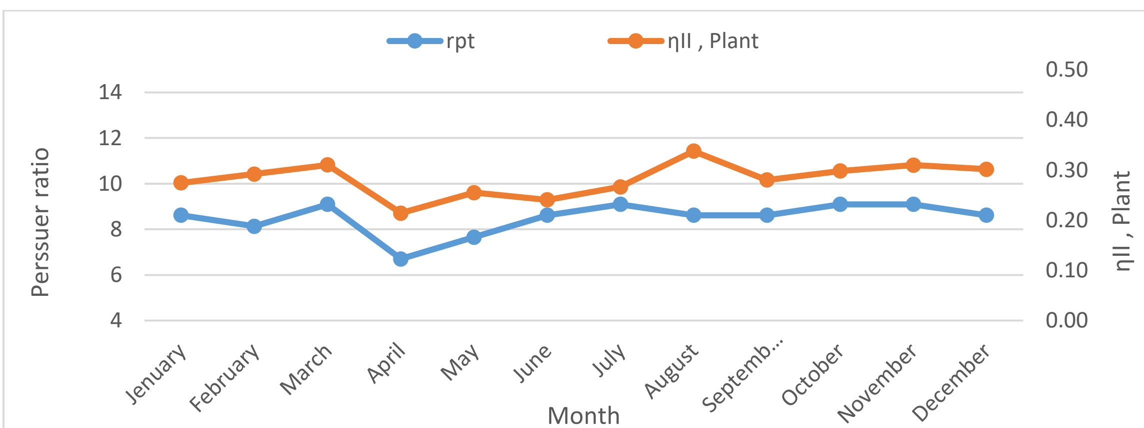



**Fig. 5.** The effect of compression ratio on available energy efficiency (2023)

Relative humidity has an influence on the efficiency of available energy, as the highest available energy efficiency was obtained in the eighth month at a relative humidity of (18%), while the lowest available energy efficiency was reached in the fourth month at a relative humidity of (68%). The attainable energy efficiency was attained at the lowest amount of relative humidity. In the seventh month (10%) at an efficiency of (26.62%). This demonstrates that as the relative humidity lowers, the efficiency of the available energy improves. As shown in Figure 6

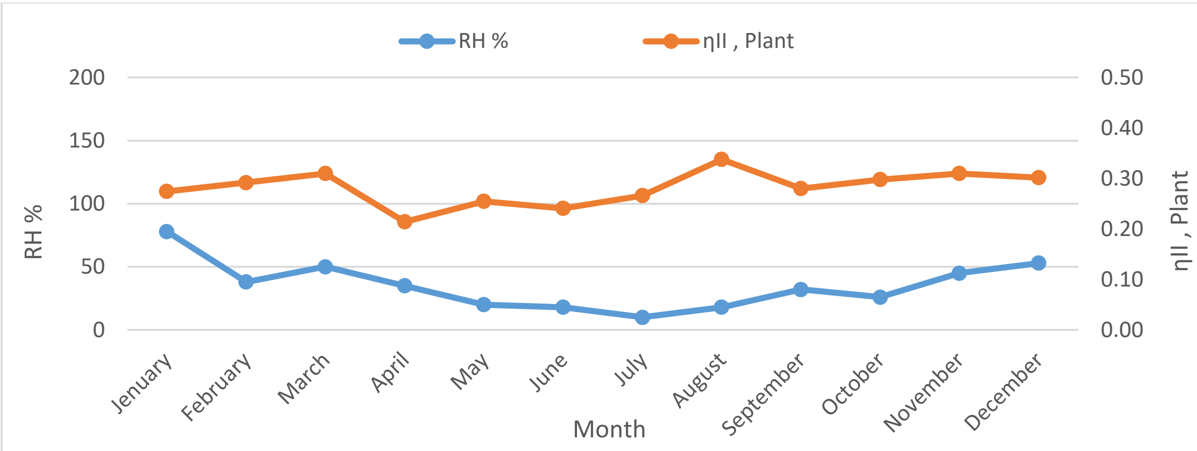



**Fig. 6.** The effect of relative humidity on the efficiency of available energy (2023)

The maximum efficiency of the available energy was reached in the eighth month at a load of (73MW) (33.76%), while the efficiency reached the maximum load of (87MW) in the sixth month (24%), which is consistent with the researcher's findings. The results also indicated that the operating load affects the efficiency of the available energy. It shown that the available energy efficiency decreased with increasing operating load [32], as shown in Figure 7.

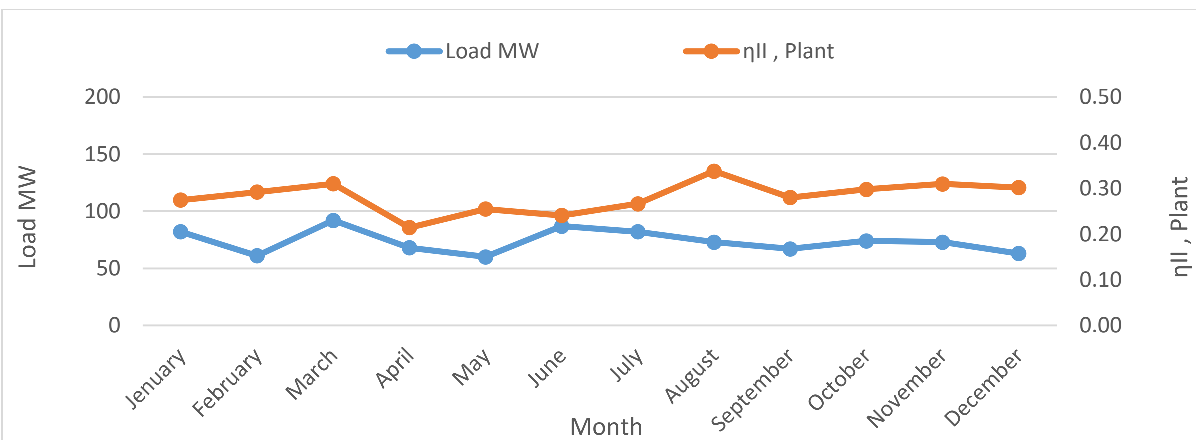



**Fig. 7.** The effect of operating load on the efficiency of available energy (2023)

### 4.2 Amount of destructive exergy

According to the available energy results, fuel has the largest rate of energy available due to the massive amount of chemical available energy it contains, which is equivalent to approximately ($Ex_f$=302.14 MW). This is followed by the gases exiting the combustion chamber, which have an amount of ($EX_3$=259.11MW), and compressed air, which has an amount of ($EX_2$=92.29MW). The quantity of gases emitted into the atmosphere is equal to ($EX_4$=66.48MW).

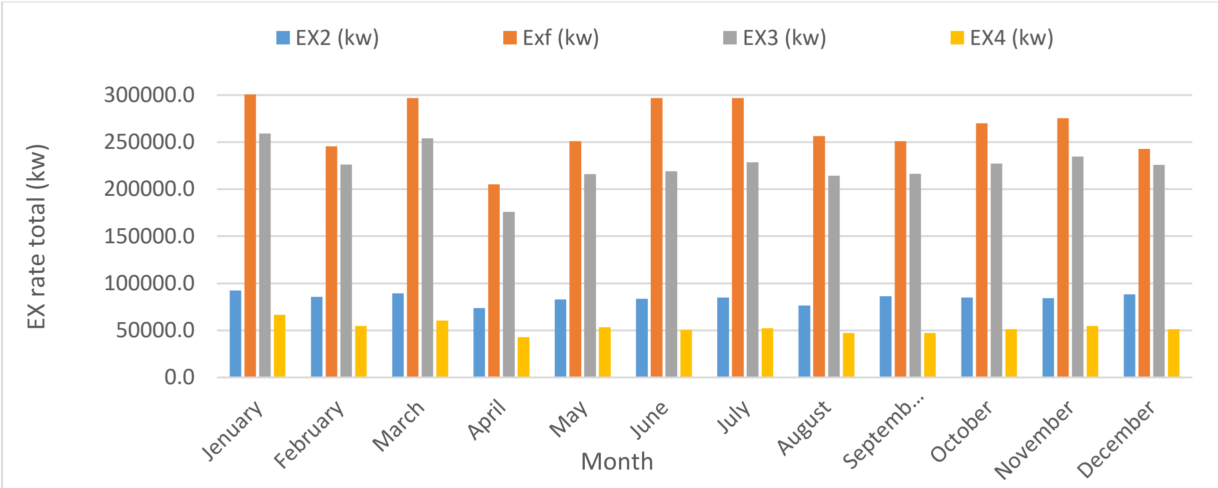



**Fig. 8** Unit component exergy simulation over a year (2023).

The combustion chamber occupied first place in terms of the rate of available energy destroyed due to the irreversible processes that occur there. The combustion chamber reached (EX,des,C.C.=135.32MW) as a result of the significant temperature difference between the environment and the combustion chamber. The majority of what the researchers demonstrated [33],[34], and [35] is compatible with this, although the study revealed Exhaust gas is where the available energy is destroyed, followed by the combustion chamber [36]. Nevertheless, the researcher [37] confirmed that the stages are the primary source of the destruction of the available energy, which is then followed by the compressor (EX,des,AC=21.34MW), the gas turbine (EX,des,GT=-3.945MW), and so on. The temperature of the gases from the gas turbine is higher than the temperature of the air exiting the compressor. It is observed that the available energy destroyed in the compressor is higher than in the turbine because of the losses brought about by the compressor's air flow slipping in its blades, which results in larger losses than in the turbine and causes expulsion when it occurs in the turbine's blades. The differential in pressure between the high input and low outlet allows gases to pass between the turbine blades and exit to the outside. It is for this reason that the air compressor has more stages than the gas turbine does.

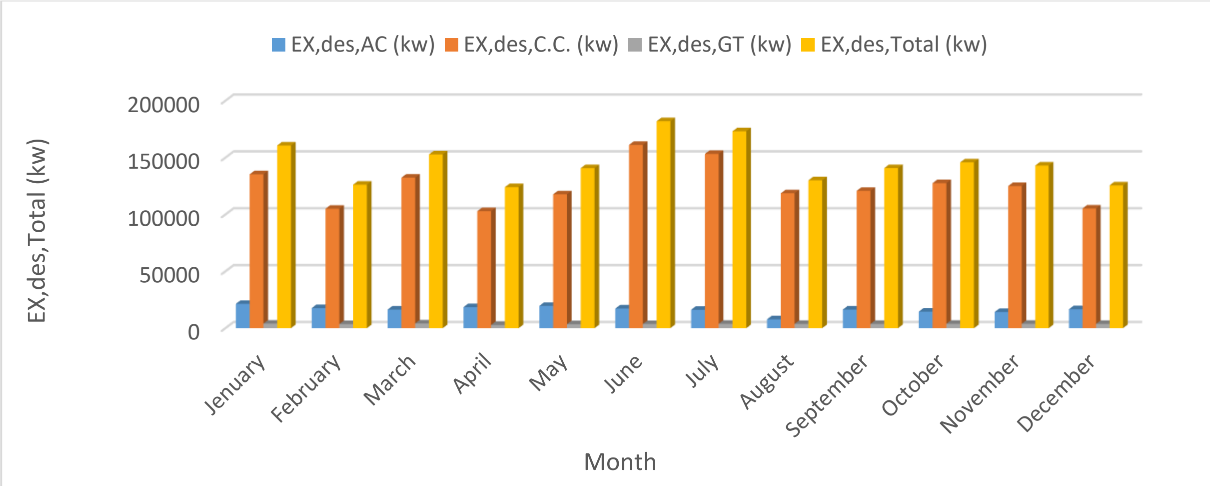



**Fig. 9.** Destructive available energy for station components (2023)

## 5. Conclusion

The study shows the effect of external variables (external temperature, humidity percentage, operating load) and compression ratio on the system's performance, in addition to the specific fuel consumption rate. In addition, it analyzed the power and energy available to the power generation station (Qayyarah Gas Station) to ascertain the resulting losses in Actual working conditions and explaining the importance of energy analysis and the energy available for the gas station to reach the highest efficiency and performance with the lowest percentage of costs and lowest losses. The following conclusions were drawn from the results of system operation:

1. The temperature of the external environment affects the system's equipment. The higher the temperature, as in the summer, affects the station's equipment. Conversely, in the winter, the lower the temperature of the external environment, the better for the organization.

2. The best tool for the system is when the compression ratio is high, as the mass flow rate of the air increases, and this in turn increases the tool of the system.

3. The combustion chamber achieved maximum power distortion due to the irreversible operations followed by the gas turbine and compressor respectively.

4. The economic price of electric energy production is affected by fuel consumption, which rises in response to external temperature changes. The quality of fuel used must be improved to reduce gas emissions and environmental pollution.

## Acknowledgment

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