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Energetic, Exegetic and Economic Analysis for Power Plant

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التحليل النشط والتفسيري والاقتصادي لمحطة توليد الطاقة

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Abstract:
Thermodynamics plays a fundamental role in understanding and optimizing the performance of gas turbine power plants. As well known that the gas turbine power plants are sensitive to inlet air temperature, as it directly influences their efficiency and power output. Inlet cooling systems, therefore, emerge as critical components in enhancing gas turbine performance, particularly in regions with high ambient temperatures. This research study the significance of adding an absorption chiller system to the West Tripoli gas turbine power plant, a crucial energy infrastructure asset in Libya. The research explores the process of adding an absorption chiller into the plant's operation, leveraging its ability to utilize waste heat from the gas turbines to operate the absorption chiller. The work performed in this paper is modeling and improving the performance of a single gas turbine unit used in the West Tripoli power plant using the IPSEpro software. Furthermore, an absorption chiller was modeled for stabilizing the gas turbine inlet conditions. The result indicates that by stabilizing the inlet air temperature, the absorption chiller effectively enhances the gas turbine performance such as, efficiency, leading to a notable increase in power output. This improvement translates into significant economic benefits for the power plant and contributes to the overall stability of Libya's electricity supply.

Keywords: Absorption Chiller, Gas Turbine, Combined Cycle Power Plant.

الملخص
تلعب الديناميكا الحرارية دورا أساسيا في فهم وتحسين أداء محطات توليد الطاقة التوربينة الغازية. من المعروف جيدا أن محطات توليد الطاقة التوربينة الغازية حساسة لدرجة حرارة هواء المدخل، لأنها تؤثر بشكل مباشر على كفاءتها وإنتاج الطاقة. لذلك، تظهر أنظمة تبريد المدخل كمكونات حاسمة في تعزيز أداء التوربينات الغازية، خاصة في المناطق ذات درجات الحرارة المحيطة المرتفعة. يدرس هذا البحث أهمية إضافة نظام مبرد الامتصاص إلى محطة توليد الطاقة التوربينة الغازية في غرب طرابلس، وهو أحد الأصول الحاسمة للبنية التحتية للطاقة في ليبيا. يستكشف البحث عملية إضافة مبرد امتصاص إلى تشغيل المصنع، والاستفادة من قدرته على استخدام حرارة النفايات من توربينات الغاز لتشغيل مبرد الامتصاص. العمل المنجز في هذه الورقة هو نمذجة وتحسين أداء وحدة توربينات غازية واحدة مستخدمة في محطة غرب طرابلس لتوليد الطاقة باستخدام برنامج *IPSEpro*. علاوة على ذلك، تم تصميم مبرد الامتصاص لتثبيت ظروف مدخل التوربينات الغازية. تشير النتيجة إلى أنه من خلال تثبيت درجة حرارة الهواء الداخل، يعزز مبرد الامتصاص بشكل فعال أداء التوربينات الغازية مثل الكفاءة، مما يؤدي إلى زيادة ملحوظة في إنتاج الطاقة. يترجم هذا التحسن إلى فوائد اقتصادية كبيرة لمحطة الطاقة ويساهم في الاستقرار العام لإمدادات الكهرباء في ليبيا.

الكلمات المفتاحية: مبرد الامتصاص، التوربينات الغازية، طاقة الدورة المدمجة.

Introduction

The ever-increasing global demand for energy, coupled with the need to minimize environmental impacts, has underscored the importance of improving the efficiency and sustainability of power generation systems. Power plants, as the backbone of energy production, must be evaluated not only for their ability to deliver energy but also for their efficiency and economic feasibility [1-5]. This evaluation is essential for ensuring that these systems can meet the growing energy demands while reducing operational costs and environmental footprints. An integrated approach combining energetic, exergetic, and economic analysis provides a comprehensive framework to assess the performance of power plants. Energetic analysis, based on the principles of the first law of thermodynamics, focuses on energy conservation and quantifies the overall energy efficiency. However, it fails to capture the quality of energy transformations [6-9]. To bridge this gap, exergetic analysis, grounded in the second law of thermodynamics, evaluates the irreversibilities within the system and identifies the potential for efficiency improvement. Economic analysis complements these evaluations by assessing the cost-effectiveness of the power plant, including capital investments, operational expenses, and revenue generation [10]. This multi-faceted analysis is crucial for optimizing power plant operations, reducing energy losses, and ensuring financial viability. By integrating these perspectives, stakeholders can make informed decisions about design, operation, and upgrades to enhance the sustainability and profitability of power generation systems. This study explores the application of energetic, exergetic, and economic analysis in power plants, providing a systematic approach to evaluate and improve their performance.

In this context, Gas turbine power plants operating in hot climates suffer from decreased output power and thermal efficiency during the hot summer months. Typically, a combustion turbine loses about 20% of its output power on a hot summer day compared to a cold winter day [11,12]. To mitigate this degradation, various cooling techniques and technologies have been developed over the years. Cooling the turbine inlet air to the ISO condition of 15ºC temperature and 60% relative humidity can restore the design point performance [13,14].

M. Ameri and S. Hejazi [15] stated in their study that for each 1ºC increase in ambient temperature, power output decreases by 0.74%. They also noted that the variation in ambient temperature during summer months typically results in a 20% loss of the rated capacity.

It is well-known that ambient temperature, humidity, and pressure are critical factors in gas turbine performance. Thermodynamic analyses show that thermal efficiency and specific output decrease with increased humidity and ambient temperature, as demonstrated by Tsujikawa and Sawada [16]. El-Hadik [17] conducted a parametric study on the effects of ambient temperature, pressure, humidity, and turbine inlet temperature on power and thermal efficiency, concluding that ambient temperature significantly impacts gas turbine performance, which increases with turbine inlet temperature and pressure ratio. Reductions in power and efficiency due to a 1K temperature rise were found to be around 0.6% and 0.18%, respectively. Inlet cooling methods are particularly important in regions with high ambient temperatures and humid conditions. Qusai and Omar [18] attempted to increase gas turbine power plant efficiency using environmentally friendly methods such as cooling the inlet air with cooling fluids via the ASPEN program. These methods reduce inlet air temperature, thereby increasing power output, improving fuel consumption, and reducing emissions.

Kakaras et al. [19] presented a computer simulation integrating an innovative absorption chiller to reduce intake air temperature in gas turbine plants. They showed that high ambient air temperature variations significantly penalize plant performance. The results indicated that the absorption chiller system provided a greater increase in power output and efficiency than evaporative cooling for a simple cycle gas turbine. In the combined cycle case, the absorption chiller significantly increased power output. Boonnasa et al. [20] analyzed improving the power output of a Combined Cycle Power Plant (CCPP) in Bangkok by reducing intake air temperature to 15ºC. They proposed an absorption chiller to cool the inlet air, reporting a possible improvement in gas turbine power output by 10.6% and the CCPP by 6.24%, with a payback period of 3.81 years.

Libya, with its hot summer climate, faces similar challenges. This paper aims to improve the performance of the existing 671 MW Simple Cycle Power Plant (SCPP) located west of Tripoli. The SCPP consists of four units of SGT5-PAC 2000E Siemens gas turbines, each theoretically delivering 167 MW. The performance assessment of the power plant was conducted by modeling one GT unit (SGT5-PAC 2000E Siemens) using IPSEpro software and then validating the IPSEPro model with actual data as well as the AC model with existing unit data. It should be noted that adding an AC to the GT unit can be identically applied to the other units at the West Tripoli power plant.

Material and Methods

IPSEpro is a set of software modules for creating process models and then using these models throughout the lifecycle of process plants, IPSEpro is based on the concept of “standardized” components that are used to build the model of a complete process. Each model is mathematically represented by a set of equations and variables. To build the mathematical model of a process means to join all equations of the component models into a single system of equations. IPSEpro provides efficient data management, powerful mathematical methods, and an intuitive graphic interface (based on Windows) so that the user can fully concentrate on the technical aspects of his problems [21].

IPSEpro has flexibility at two levels, known as the component and process levels. The first, provides unlimited flexibility in defining the characteristics of the component models that are used for modeling processes. This allows the user to build component model libraries that exactly match his application requirements, while the second, allows complete freedom in arranging the available components in order to represent a process scheme. A graphical user interface facilitates and accelerates substantially the development of process schemes, and the presentation of the results of calculations. The user can compute energy and exertion with the use of this software, which can compute all of the thermodynamic parameters of the process streams [22]. In this paper a custom unit named "Full Comprehensive Library" was created using Model Development Kit (MDK) which contains all the components required for the modeling process.

Modeling and Validation

The GT unit for the West Tripoli power plant is presented, followed by the validation of the model using IPSEpro and also additionally the thermodynamic equations for this process are provided, Furthermore, the AC system model that is also presented with the working parameters and also the thermodynamic equations.

Modeling of Gas Turbine Unit for West Tripoli Power Plant

The GT unit that is modeled is the Siemens SGT5–2000E. The modeling of the GT unit was done based on nominal conditions for the Model ISO parameters that were taken from [21]. The model constructed in IPSEpro consists of an air compressor, a combustion chamber, a gas turbine, and a generator, which was modelled by selecting the GT block from the advanced power plant library. The inlet of the the compressor was connected with an ambient air source, the outlet of the turbine was connected to an ambi ent sink, and the combustion chamber was connected with the fuel source. Figure 1 shows the schematic diagram of the GT unit. The ISO values of ambient air temperature, pressure, pressure ratio, exhaust mass flow rate and temperature from were used to perform the modelling of the SGT5–2000E Turbine, the assumptions made in the modelling of the Power plant as [22], follow that the simulations are performed at steady state, also neglecting the transient impact caused by start-up and shut down during operation and finally, the pressure drops was considered for each component nominal pressure drops

Table 1: GT Unit Model validation for ISO Design Data.

Parameters	ISO Values [22]	Model Values
Power (MW)	166	165.93
Heart Rate (kJ/kWh)	10375	10400.742
Thermal Efficiency (%)	34.7	34.61
Turbine Exhaust Temperature (ºC)	541	538.11
Exhaust mass flow rate (kg/s)	525	523.341
Pressure Ratio (rp)	12	12
Ambient air temperature	15	15
Ambient air pressure (bar)	1.013	1.013
Lower Heating Value, LHV (MJ/kg)	45.011	45.011

Thermal and Exergy and Economic Analysis

Thermal Analysis

Energy analysis is utilized to determine the losses within a system by focusing solely on the quantity of energy in each process stream, without considering the quality of the energy content. In contrast, exergy analysis identifies the specific locations of energy degradation by examining both the quality and quantity of energy [23].

Exergy Analysis

The total inlet and outlet exergy $\dot{E}_i$ can be determined as the sum of physical $\dot{E}_{ph}$, chemical $\dot{E}_{ch}$, potential $\dot{E}_{po}$, and kinetic $\dot{E}_{ki}$ exergies, in the absence of magnetic, electrical, and nuclear exergies, as shown in the equation (1).

$$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch} + \dot{E}_{po} + \dot{E}_{ki} \quad (1)$$

In this paper, potential exergy is neglected due to the assumption that the difference in elevations between the environment and the stream is small. Additionally, kinetic exergy is disregarded, as it is commonly omitted in many exergy studies under the assumption that there is no significant velocity gradient [24]. By neglecting terms, the total Exergy is expressed as equation (2).

$$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch} \quad (2)$$

$\dot{E}_{ph}$ represents the total physical exergy rate of moving the stream from its initial state to the dead state. The specific physical exergy $\dot{e}_{ph}$for the stream is calculated as shown in the equation (3).

$$e_{ph} = (h_i - h_0) - T_0(s_i - s_0) \quad (3)$$

Here, h_i and s_i represent the initial enthalpy and entropy, respectively. T_0 , h_0 , and s_0 denote the dead state values of temperature, enthalpy, and entropy, respectively.

e_{ch} is the total stream chemical exergy rate, which accounts for the variation in composition from the stream state to the dead state. The specific chemical exergy e_{ch} of the stream is calculated as shown in the equation (4).

$$e_{ch} = \sum x_k e_{k,ch0} + RT_0 \sum x_k ln(x_k \gamma) \quad (4)$$

Here, x_k represents the concentration of component k, $e_{k,ch0}$ is the standard chemical exergy of component k, and γ is the component chemical potential coefficient, which equals one for an ideal mixture. It should be noted that this term may vanish if there is no change in the fluid composition.
Finally, the exergy efficiency and exergy destruction $\dot{E_D}$ were calculated using equations (5-6) as derived from the referenced source [25].

$$\eta_{exergy} = \frac{P_{net}}{\dot{E_\imath}} \quad (5)$$

$$\dot{E_D} = \dot{E_\imath} - \dot{E}_e - P_{net} \quad (6)$$

Economic Analysis

To assess the economic analysis in this paper, the Payback Period (PBP), Net Present Value (NPV), Average Rate of Return (ARR), and Profitability Index (PI) are calculated and briefly described below.
The PBP is the time it takes for the cumulative cash inflows from an investment to equal the Total Capital Investment (TCI), also known as the breakeven point. This is calculated as shown in the equation (7) [26].

$$TCI = \sum_{j=1}^{PBP} CFN_j \quad (7)$$

Where CFN_j is the recurrent net cash flow.

The NPV (Net Present Value) is the present value of all future cash inflows discounted back to the present, minus the initial investment cost. Essentially, it indicates how much wealthier you are after making the investment compared to not making it. The value of NPV can be positive or negative. A positive NPV means that the project's income exceeds the investment, which is preferable. Conversely, a negative NPV indicates that the project could not recover the investment costs and should be avoided. NPV is calculated as shown in the equation (8) [26].

$$NPV = \sum_{j=1}^{t} \frac{CFN_j}{(1+r)^j} - TCI \quad (8)$$

Where CFN_j is the net cash flow over the lifetime t and r is the discount rate, which represents the revenue minus the outgoing expenses.
ARR (Average Rate of Return) is the average annual rate of return earned on the investment over its lifetime. ARR is calculated as shown in the equation (9) [26].

$$ARR = \frac{\underline{NP}}{TCI} \quad (9)$$

Where $\underline{NP}$ is the average annual net profit.
PI is the ratio of the present value of all future cash inflows to the initial investment cost. A PI greater than 1 indicates a profitable investment, while a PI less than 1 suggests it’s not worthwhile. PI is calculated as in equation (10) [26].

$$PI = \frac{NPV}{TCI} \quad (10)$$

$$W_C = \dot{m}_a c_{pa}(T_2 - T_1) \quad (11)$$

Where $\dot{m}_a$ is the air mass flow rate, cpa is the air specific heat capacity, T2 is the temperature at the outer of the compressor and T1 is the temperature of the inlet of the compressor.

$$W_T = \dot{m}_g c_{pg}(T_4 - T_3) \quad (12)$$

Where $\dot{m}_g$ is the gass mass flow rate, cpg is the gas specific heat capacity.

$$P_{thermal} = W_T - W_C \quad (13)$$

The electrical power generated, Pnet is expressed in equation (14).

$$P_{net} = P_{thermal} - P_{loss} \quad (14)$$

Where P_{loss} is defined as the total losses for mechanical, generator and auxiliary losses. The gas turbine thermal efficiency ηGT was computed as given in equation (15), the heat rate of the GT unit (HR) was computed using equation.

$$\eta GT = \frac{P_{net}}{\dot{m}_f \, LHV} \quad (15)$$

Meteorological Data

Power is affected by environmental changes. In this project, the Dry Bulb Temperature (DBT) is taken into consideration. Meteorological DBT data related to Tripoli, Libya, was collected on a monthly basis from following references [25-27]. Tripoli, the capital and largest city of Libya, is situated on the northwestern coast of the country, facing the Mediterranean Sea. The city is characterized by hot and dry summers, and mild and wet winters. Figure 2 illustrates the monthly maximum and minimum DBT temperatures, as well as the average DBT temperature for each month of the year 2023.

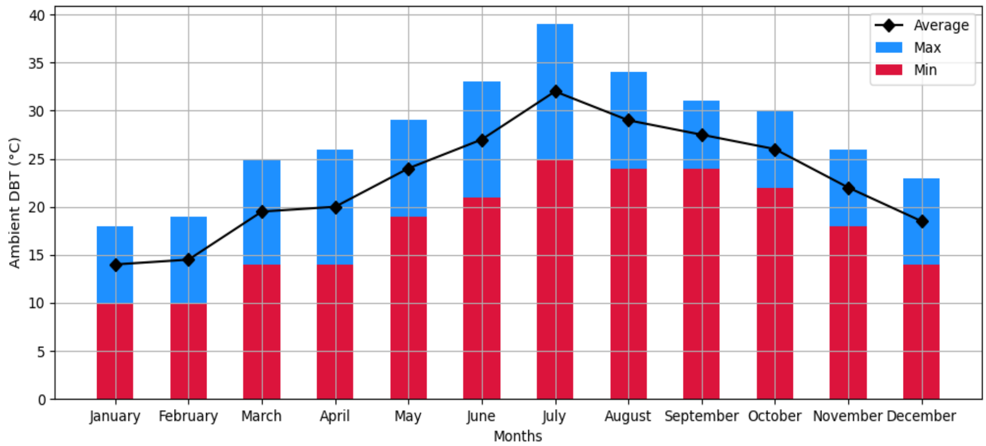


Figure 1: Monthly Maximum, Minimum and Average DBT Temperature for Tripoli City, Libya 2023.

Results and Discussion

The performance of the modeled standalone GT unit and coupled with an AC is evaluated using exergy analysis. Furthermore, economic analysis was carried out to assess the feasibility of using an AC.

Performance of Modeled GT Unit Coupled with AC

It is now known that controlling the GT air inlet tempera ture will result in improving the SCPP plant performance indicators. An AC model is used to cool the inlet temperature and stabilize it at ISO condition (15ºC).

The GT unit inlet is connected to the AC through a heat exchanger in which the chilled water that is produced by the AC chiller cools down the ambient air temperature and the cool air enters the GT unit. The assumption made is that the AC has the capability of producing chilled water that cools down and stabilizes the inlet ambient air temperature at 15ºC for all different ambient air conditions. The performance evaluation was performed through exergy analysis. The exergy efficiency and exergy destruction of both scenarios were calculated by varying the ambient air temperature from 15ºC to 45ºC with an incremental increase of 5ºC and under 100% load conditions.

Exergy is the portion of energy that can be used to perform useful work in a specific environment, it's not simply the amount of energy available but also its quality and potential to do work. Therefore, exergy efficiency represents the percentage of available energy that is actually converted into useful work and on the contrast, exergy destruction refers to the irreversible conversion of valuable, high-quality energy into unavailable forms like heat. Figure 2 shows the exergy efficiency of both scenarios, where it can be seen that as the ambient air temperature increases, the total input exergy due to natural gas and air decreases and the total output exergy due to exhaust gas increases and therefore, reducing the exergy efficiency. However, the AC stabilizes the inlet conditions, leading to an improvement in output power which leads to improved exergy efficiency. The improvement factor at 45ºC is calculated to be 1.44%. Furthermore, Figure 3 shows the exergy destruction of both scenarios, where it is found that the amount of difference in exergy destruction is 45.11MW.

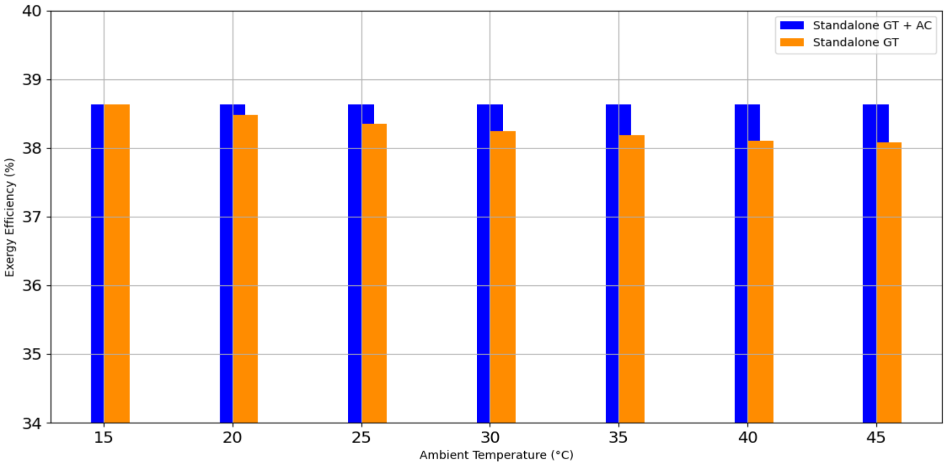


Figure 2: Effect of Ambient Temperature on Exergy Efficiency at two scenarios.

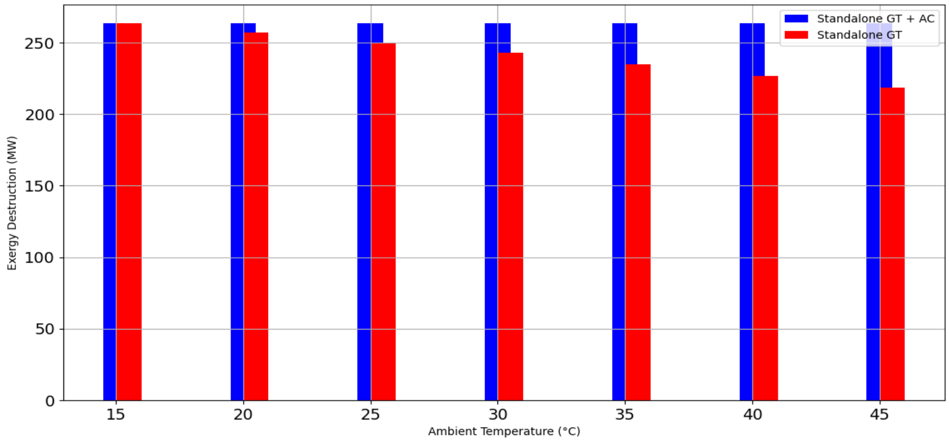


Figure 3: Effect of Ambient Temperature on Exergy Destruction at two scenarios.

The air density decreases and therefore reduces the air mass flow that is flowing into the compressor which results in reduced power output. Correspondingly, Fig.4 shows the thermal efficiency of the GT unit at different loads. The thermal efficiency is proportionally related to the output power and therefore, it can be seen that as the ambient temperature increases, the thermal efficiency decreases. At 100% load and 15°C, the GT thermal eff efficiency is 34.61% and it is reduced by an average of 1.33% for every 5°C ambient temperature rise. For the 75%, 50%, 25% load conditions, the thermal efficiency drops by 1.73%, 2.23% and 3.25% respectively. A high inlet air temperature also increases the compressor work and therefore the fuel mass flow decreases, which lowers the thermal efficiency of the GT unit.

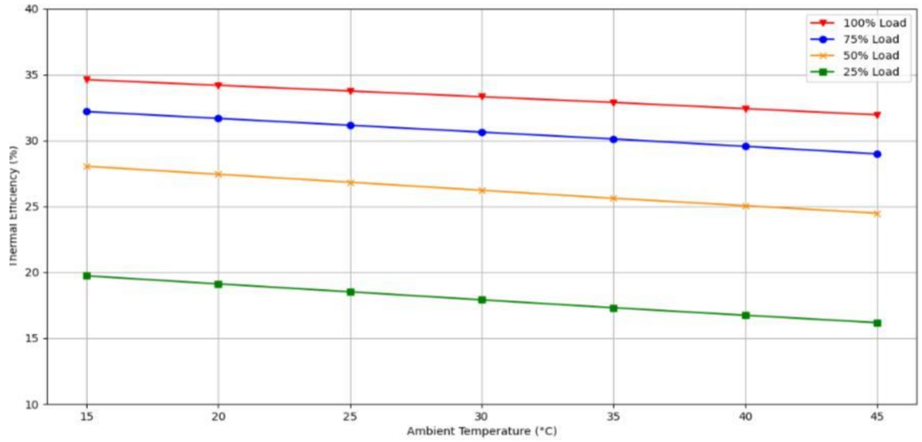


Figure 4: Effect of Ambient Temperature on Thermal efficiency.

Meteorological data was used to assess the power output of the GT unit throughout the year 2023. Figure 5 illustrates the effect of changes in ambient temperature on the GT unit's output power each month. As observed, the output power declines with the rise in ambient air temperature. June, July, and August experience the highest temperatures and thus record the lowest output power. This issue can be addressed by using an absorption chiller powered by exhaust gas, where the AC cooling is delivered to the GT inlet air, leading to power savings and preventing degradation in output power. The increase in output power when using the AC in June, July, and August is calculated to be 8.15%, 11.98%, and 9.64%, respectively. This highlights the importance of cooling methods, such as AC, for power plants in Libya, especially during the summer period when there is a significant rise in ambient air temperature. Figure (5) shows the difference in out between the stand alone gt unit and the gt unit cupelled with the ac.

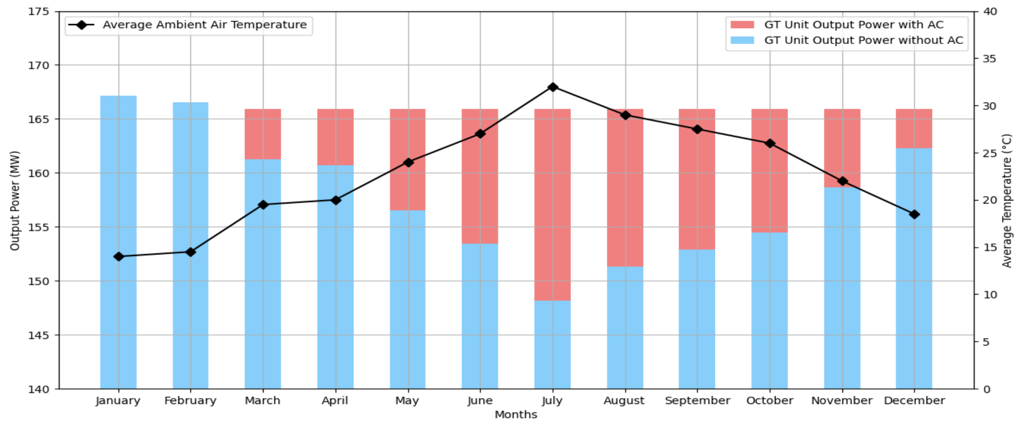


Figure (5): The difference in out between the stand alone gt unit and the gt unit cupelled with the Ac.

Economic Analysis

Practically every new project requires an economic study, even if the project is highly efficient. The main purpose of economic analysis is to design and select acceptable projects that contribute to the economy of the region or country. Therefore, using economic analysis can assist in decision-making regarding whether to proceed with the project. Economic analysis requires consideration of many factors. In this project, the economic indicators studied are PBP, ARR, NPV, and PI.

Furthermore, it should be mentioned that the West Tripoli Power Plant under study consists of four GT units, but for simplicity, the economic analysis is carried out for a single GT unit. Two scenarios are studied: the first scenario is based on the existing single GT unit in the power plant, and the second scenario is based on the same GT unit with an AC attached. The proposed AC is a single-effect refrigeration system used to provide inlet air to the GT unit.

The capital cost of the GT unit was obtained from official sources and is estimated to be $106 million. The capital cost of the AC was obtained from [24] and is estimated to be $2.28 million. The profitability of the GT unit is calculated by totaling the expenses and determining the net profit after selling the electricity. This study considers two different scenarios with the GT unit operating at full load with a yearly average temperature of 22.8°C. The project's lifetime is assumed to be 25 years with an 8%

interest rate and the system running for 85% of the hours per year. Additionally, the annual cash outflow includes expenses for operation and maintenance (O&M), calculated as a function of the GT unit per year.
For the SCPP, according to the Libyan Electrical Company, the operating fuel is natural gas, with a cost estimated at $0.16/kg [24], which is used in this study. The O&M costs are evaluated separately for the SCPP and the AC according to [24]. Moreover, revenue or sales income profit is represented by the annual cash flow balance of O&M costs against revenue income. In this study, the product sold is electrical power. According to the Libyan Electricity Company (GECOL), the electricity selling tariff in Libya is $0.07/kWh according to [24]. In this study, the fuel price is varied from $0.12 to $0.24/kg and the electricity selling price from $0.05 to $0.1/kWh, to demonstrate the sensitivity of the economic indicators to such changes and to determine when the project becomes uneconomical.

Profitability Evaluation

An economic evaluation is performed to determine the profitability of the proposed system. The standalone GT unit produces 167 MW of net electricity under ISO conditions. However, due to the climate in Tripoli, which affects the inlet air temperature, there are fluctuations in output power. The average temperature throughout the year is 22.8ºC, and this power drop can be mitigated by adding a single-effect absorption chiller to reduce the ambient inlet air temperature to the ISO condition of 15°C. At 22.8ºC, the output power is 157 MW. A project/economic lifetime of 25 years is assumed to be a reasonable estimated length of time for this plant. Table 2 shows the PBP, NPV, ARR, and PI for both scenarios.

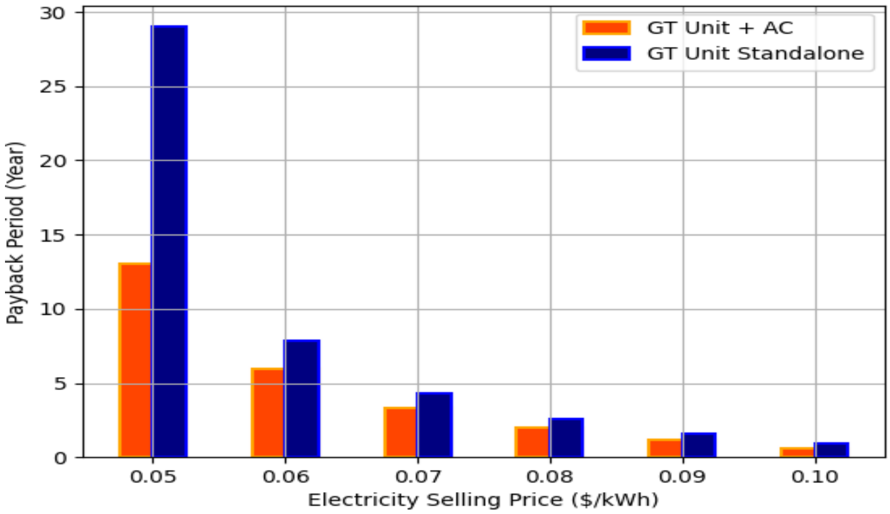
Table 2: Comparison of Economic Analysis for Two Scenarios

	GT Unit Standalone Average Temperature (22.8°C)	**GT Unit Standalone + AC ISO Temperature (15°C)**
Lifetime (Year)	25	25
Electricity Selling Price ($/kWh)	0.07	0.0 7
Fuel Price ($/kg)	0.16	0.16
PBP (Year)	4.3	3.3
NPV ($ Million)	245.0	309.9
ARR (%)	31.0	36.2
PI	2.3	2.9

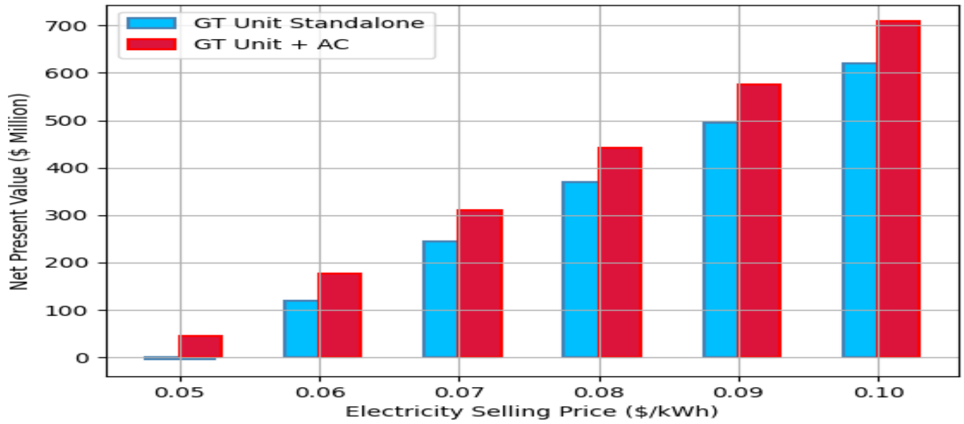
Looking at Table 2, for the GT unit without AC, the project total capital investment would be paid back within 4.3 years, with an ARR of 31% and a PI of 2.3, resulting in an NPV of $245 million over 25 years of plant operation. By adding the AC to the GT unit to operate the plant at an inlet air temperature of 15°C, the PBP could be reduced to 3.3 years, with increases in NPV, ARR, and PI to $309.9 million, 36.2%, and 2.9, respectively. Despite the additional capital expenditure of $2.28 million, the addition of the absorption chiller to the SCPP significantly improves all the economic indicators.

Electricity Selling Price Sensitivity Study

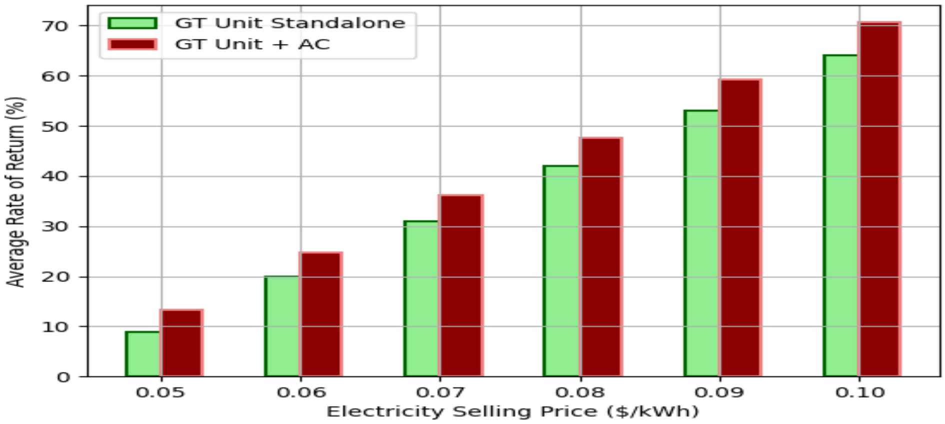
The main reason for performing this sensitivity study with different electricity prices was to identify the break-even point, which is to determine the minimum electricity price at which each model becomes economically viable, meaning its costs are covered by its revenue from electricity generation. Furthermore, this study aims to assess how increasing electricity prices affect the economic indicators of each model. Variations in electricity price were chosen in steps of $0.01/kWh, ranging from $0.05/kWh to $0.1/kWh. This range was chosen to determine at what price the project will no longer be preferable.
Furthermore, this study aims to assess how increasing electricity prices affect the economic indicator This range was chosen to determine at what price the project will no longer be preferable. On the other hand, the fuel price for the models is fixed at the real rate of $0.16/kg. The previously mentioned operating conditions were also used, ensuring that all models operate at full load under Libyan environmental conditions with an average temperature of 22.8°C. Moreover, the lifetime of this project was considered to be 25 years. The effect of electricity selling prices on economic indicators is displayed in Figure 7.


GT Unit + AC
GT Unit Standalone
Payback Period (Year)
0
5
10
15
20
25
30
0.05
0.06
0.07
0.08
0.09
0.10
Electricity Selling Price ($/kWh)

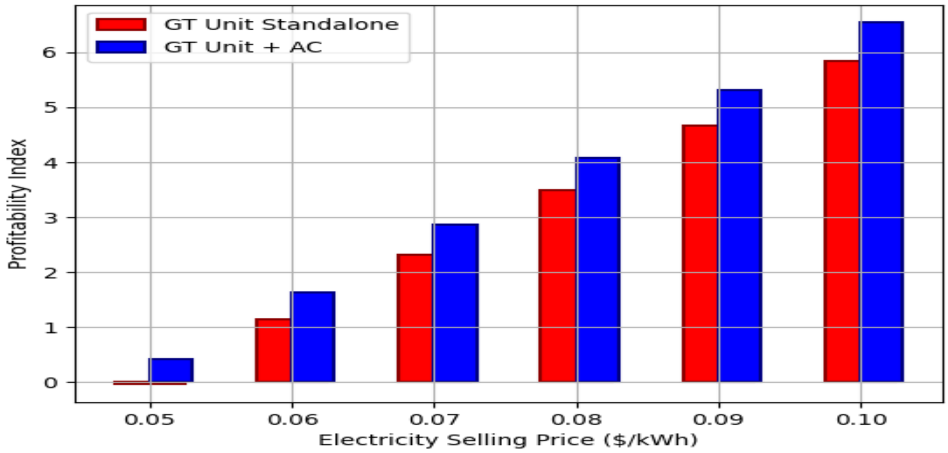
(a)


GT Unit Standalone
GT Unit + AC
Net Present Value ($ Million)
0
100
200
300
400
500
600
700
0.05
0.06
0.07
0.08
0.09
0.10
Electricity Selling Price ($/kWh)

(b)


GT Unit Standalone
GT Unit + AC
Average Rate of Return (%)
0
10
20
30
40
50
60
70
0.05
0.06
0.07
0.08
0.09
0.10
Electricity Selling Price ($/kWh)

(c)



(d)

Figure 6: Influence of Electricity Selling Price on (a) PBP, (b) NPV, (c) ARR, (d) PI.

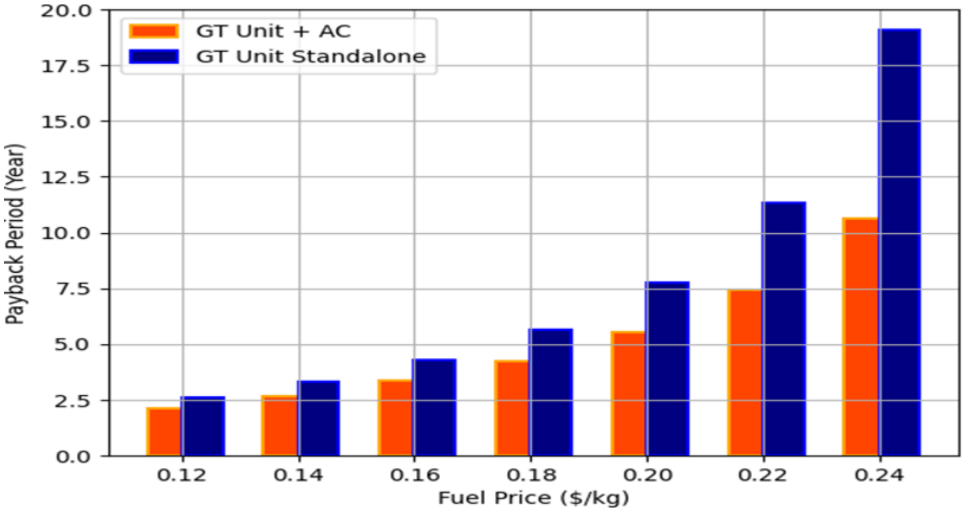
The effect of the variation in electricity prices on the payback period (PBP) is illustrated in Figure 6a. At an electricity price of $0.05/kWh and below, the standalone GT unit is considered non-profitable as the PBP exceeds the assumed project lifetime, indicating that recovering capital costs cannot be achieved within the project's duration. Conversely, the PBP could be reduced to 0.9 years if the electricity price increased to $0.1/kWh. Additionally, the NPV at the lowest price is negative due to high initial and O&M costs.

For the GT unit coupled with the AC model, the PBP at the lowest price is found to be 13 years and can be reduced to 0.6 years at the highest price, making it more profitable than the standalone model. Figures 6b, 6c and 6d display the effect of the variation on NPV, ARR, and PI, respectively. It is evident that these indicators increase as the selling prices increase due to higher profits generated from selling electricity. Moreover, it is apparent that the GT unit coupled with the AC model has better indicator values, primarily due to the increased capacity leading to higher profits.

Fuel Price Sensitivity

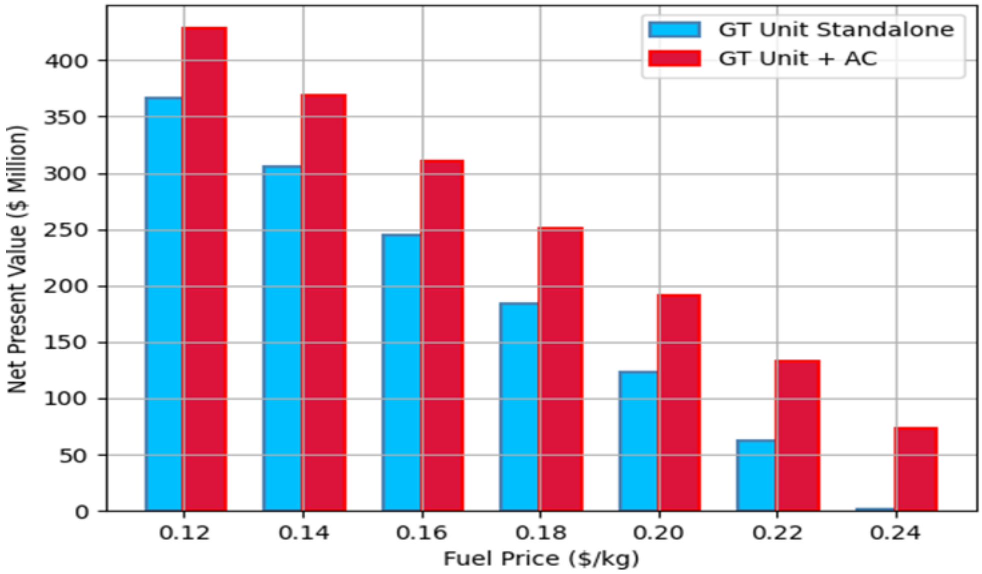
The fuel price has a major impact on economic indicators because it constitutes a significant portion of the recurrent cash outflow. To investigate the effect of fuel prices, the price was varied from $0.12/kg to $0.24/kg in steps of $0.02/kg. Figure 8 displays the effect of fuel prices on economic indicators.

Figure 8(a) shows that as the fuel price increases, the PBP rises from 2.1 years to 19.1 years for the standalone GT unit and from 2.1 years to 10.6 years for the GT unit coupled with AC. The latter is the better option due to higher revenue generation compared to the increasing recurring cash outflow. At higher fuel prices, both configurations become unprofitable when the PBP exceeds the assumed project lifetime. On the other hand, the NPV decreases with increasing fuel prices, dropping from $366.9 million to $1.2 million for the standalone model and from $428.2 million to $73.5 million for the model coupled with AC, as shown in Figure 6b. This decline is due to decreasing profit as fuel cash outflow increases. Additionally, the ARR and PI exhibit similar behavior to NPV when fuel prices rise, as displayed in Figures 6c and 6d. Overall, this indicates that all models will not be viable at high fuel prices. This factor should be taken into consideration before starting the project, especially when the electricity selling price is assumed to be fixed at $0.07/kWh.



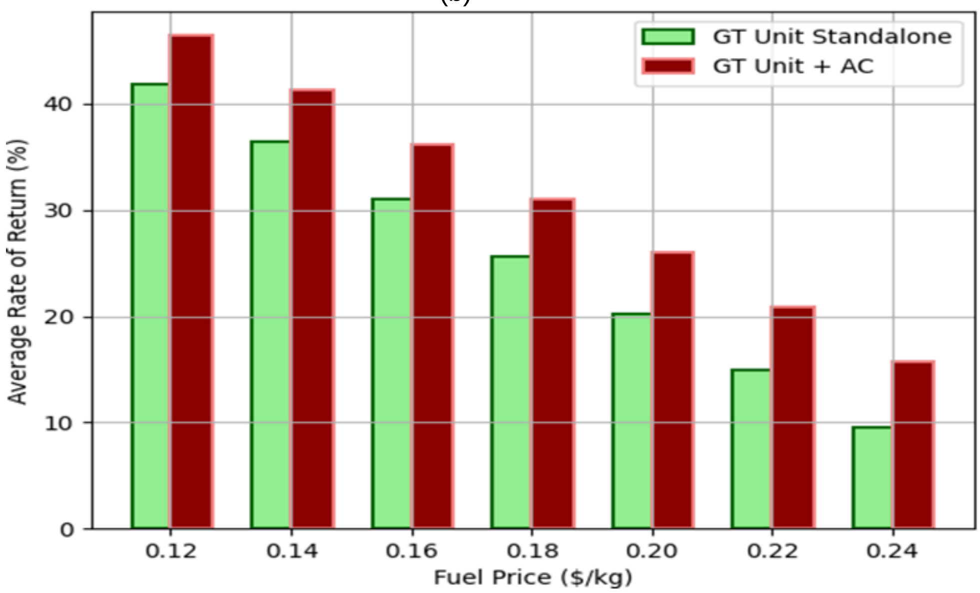
GT Unit + AC
GT Unit Standalone
Payback Period (Year)
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0.12
0.14
0.16
0.18
0.20
0.22
0.24
Fuel Price ($/kg)

(a)



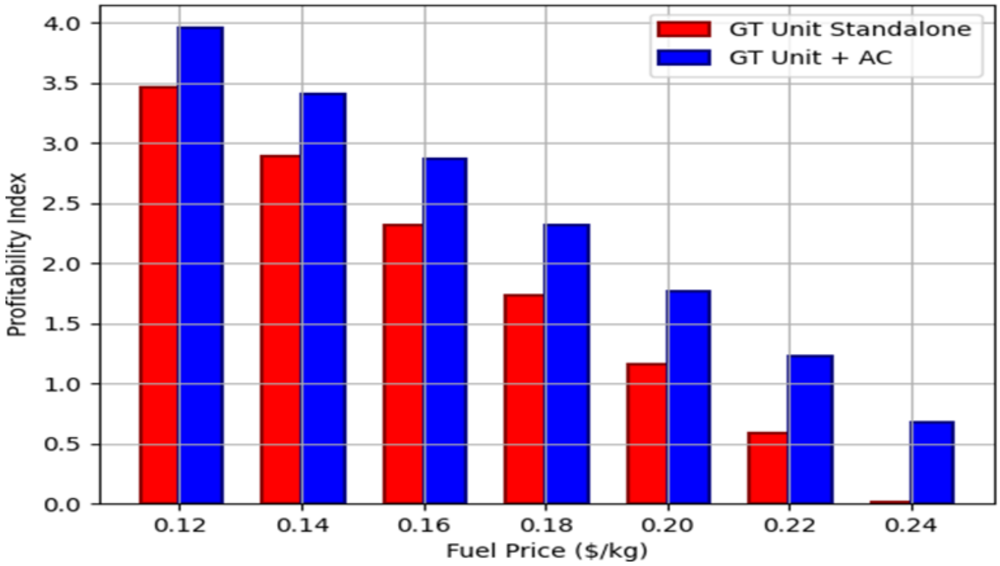
GT Unit Standalone
GT Unit + AC
Net Present Value ($ Million)
400
350
300
250
200
150
100
50
0
0.12
0.14
0.16
0.18
0.20
0.22
0.24
Fuel Price ($/kg)

(b)



GT Unit Standalone
GT Unit + AC
Average Rate of Return (%)
40
30
20
10
0
0.12
0.14
0.16
0.18
0.20
0.22
0.24
Fuel Price ($/kg)

(c)



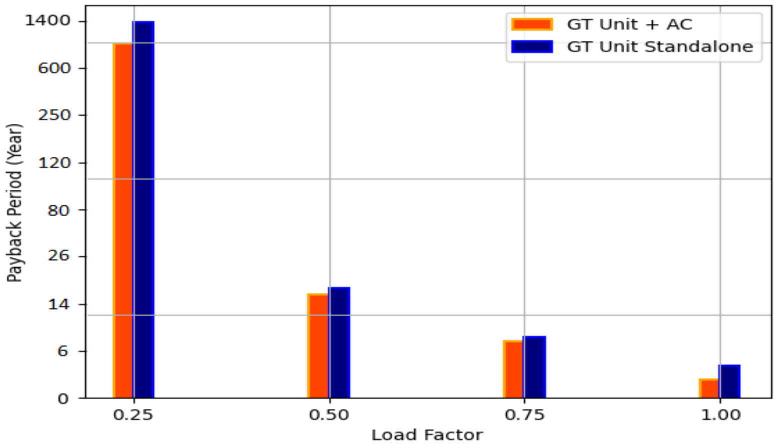
(d)

Figure 7: Influence of Fuel Price on (a) PBP, (b) NPV, (c) ARR, (d) PI.

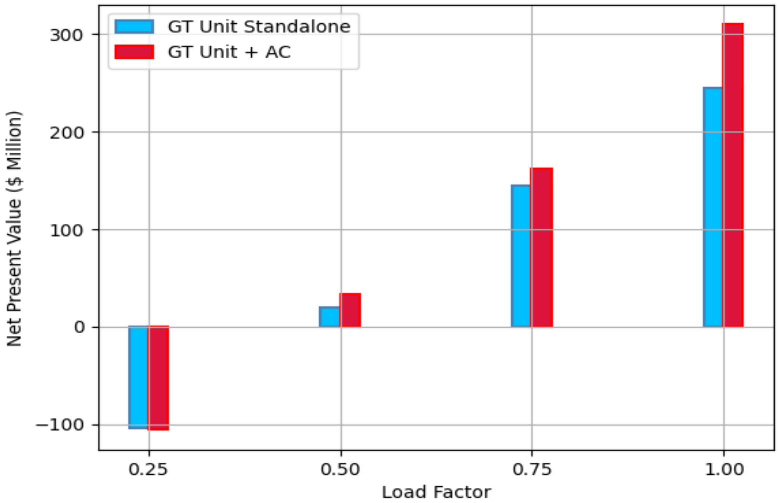
Load Factor Sensitivity Study

The main purpose of this study is to identify the effect of the load factor on economic indicators. To investigate this, the load factor was varied from 0.25 to 1.00 in steps of 0.25. Figure 7 displays the effect of the load factor on economic indicators. In Figure 7(a), the effect on PBP is shown. It can be seen that as the load factor increases, the PBP decreases from 1405.9 to 4.3 years for the standalone GT unit and from 981.5 to 3.3 years for the GT unit coupled with AC. This observed effect is primarily because an increased load factor leads to higher power generation, which in turn results in higher revenue.

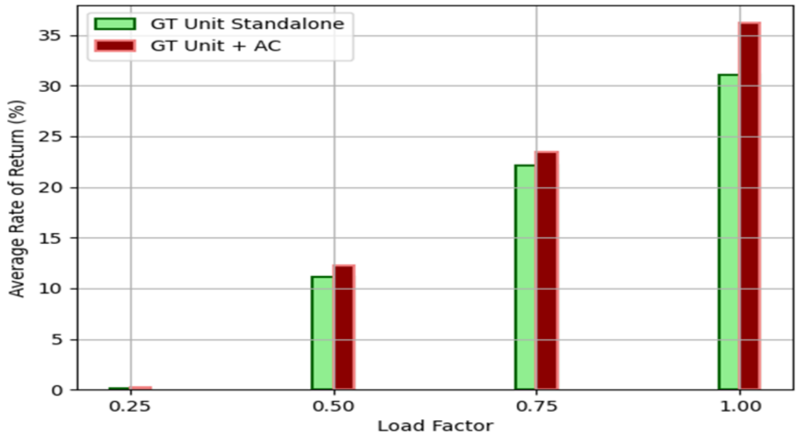
Furthermore, as illustrated in Figure 7b, the NPV increases from -$104.4 million to $245.0 million for the standalone unit and from -$105.9 million to $309.9 million for the unit coupled with AC. Finally, the ARR and PI exhibit the same behavior as the NPV when the load factor increases, as shown in Figures 8c and 8(d). By observing all indicators, it is found that it is not feasible to operate the power plant at low load factors. It is best to utilize the capabilities of the power plant by operating at high load factors to generate higher power and consequently higher revenue.



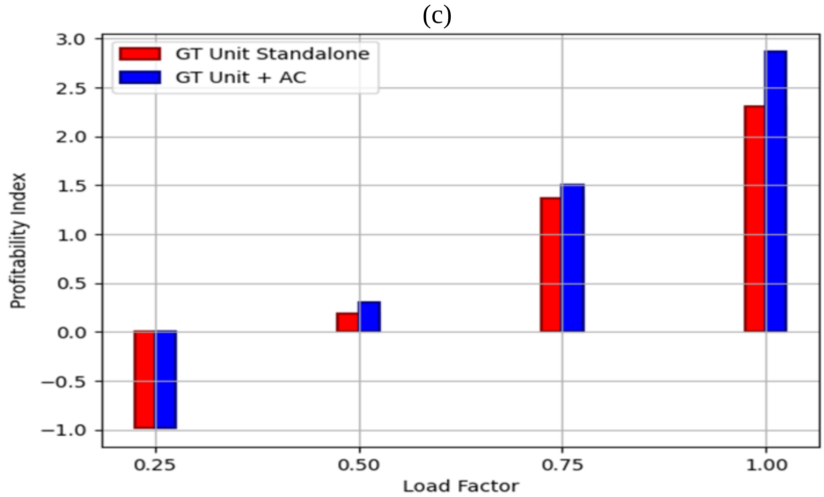
(a)



(b)



(c)



(d)

Figure 8: Influence of Load Factor on (a) PBP, (b) NPV, (c) ARR, (d) PI.

This paper was carried out to study the effect of energy, exergy and economic analysis on existing simple cycle power plant west Tripoli power plant and proposed absorption chiller using IPSEpro software. The result showed the following: In this paper, West Tripoli Power Plant was chosen. For simplicity, only a single GT unit was investigated. The proposed model was coupling the standalone GT unit with a Single Effect LiBr-H2O AC through a heat exchanger to cool the inlet ambient air temperature down to ISO conditions. The GT unit and the Single Effect LiBr-H2O AC were both modeled and validated using IPSEpro software. The evaluation process was performing exergy analysis to observe

exergy efficiency and exergy destruction and also economic analysis to observe the economic indicators of the GT unit and determine its profitability.
The exergy efficiency represents the percentage of available energy that is actually converted into useful work and was found to be 38.63% for the standalone GT unit at ISO conditions and 100% load. Furthermore, when coupled with the AC, the efficiency is stable regardless of temperature increase. Comparing the Standalone and with AC GT unit against the meteorological data obtained shows that there is an increase in power that can be achieved when using the AC in the months June, July and august, which are calculated to be 8.15%, 11.98%, 9.64% respectively. The profitability evaluation showed that the PBP can be reduced from 4.3 to 3.3 years, the NPV can be increased from 245 to 309.9 million$, the ARR can be increased from 31 to 36.2 % and the PI can be increased from 2.3 to 2.9. By adding an ACH driven by exhaust gas significantly improves economic indicators despite additional capital expenditure.
For the electricity selling price sensitivity study, it was shown that as the selling price increases the PBP decreases and on other hand, the NPV, ARR and PI increase due to increased profit generated. The fuel price sensitivity study, showed that as the fuel price increases the PBP increases, whereas, the NPV, ARR and PI decrease due to increased expenses. The Load Factor sensitivity study, showed that as the load factor increases the PBP decreases, whereas, the NPV, ARR and PI increase due to increased revenue from higher generated power.

Conclusion

This paper was carried out to study the effect of energy, exergy and economic analysis on existing simple cycle power plant west Tripoli power plant and proposed absorption chiller using IPSEpro software. The result showed the following:

- The evaluation process was performing exergy analysis to observe exergy efficiency and exergy destruction and also economic analysis to observe the economic indicators of the GT unit and determine its profitability.
- The exergy efficiency represents the percentage of available energy that is actually converted into useful work and was found to be 38.63% for the standalone GT unit at ISO conditions and 100% load. Furthermore, when coupled with the AC, the efficiency is stable regardless of temperature increase.
- Comparing the Standalone and with AC GT unit against the meteorological data obtained shows that there is an increase in power that can be achieved when using the AC in the months June, July and august, which are calculated to be 8.15%, 11.98%, 9.64% respectively.
- The profitability evaluation showed that the PBP can be reduced from 4.3 to 3.3 years, the NPV can be increased from 245 to 309.9 million$, the ARR can be increased from 31 to 36.2 % and the PI can be increased from 2.3 to 2.9. By adding an ACH driven by exhaust gas significantly improves economic indicators despite additional capital expenditure.

Moreover, For the electricity selling price sensitivity study, it was shown that as the selling price increases the PBP decreases and on other hand, the NPV, ARR and PI increase due to increased profit generated. The fuel price sensitivity study, showed that as the fuel price increases the PBP increases, whereas, the NPV, ARR and PI decrease due to increased expenses. Thus, the Load Factor sensitivity study, showed that as the load factor increases the PBP decreases, whereas, the NPV, ARR and PI increase due to increased revenue from higher generated power.

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