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Performance Analysis of Awbari Gas Turbine Power Plant with Crude Oil

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ABSTRACT

The performance of a gas turbine can be evaluated by its efficiency and net power output which both are affected by ambient conditions (atmosphere air temperature and humidity) and used fuel. In this work, the performance of the gas turbine (SGT5-2000E) has been modelled using HYSES ASPEN software and evaluated by assessing the efficiency, net power, specific fuel consumption (SFC), and fuel-air-ratio (FAR) in a hot weather region at sea level (the Sahara Desert in Libya).

Evaluation of the performance of SGT5-2000E (Awbari gas turbine power plant, south of Libya) has been carried out by modelling the units of the power plant using HYSYS ASPEN and validated against the design data provided by the manufacturer. In addition, two performance scenarios (two different fuels) were drawn for the gas turbine power plant. The first is at a fixed Pressure Ratio (PR) of 12 with a variation of the compressor inlet temperature (CIT) between 0 °C and 50 °C, and the second is at a fixed CIT of 15 °C with a variation of PR ranging from 7 to14 bar.

Additionally, a performance analysis of the Awbari power plant is performed based on CIT and PR. The results show that the CIT has a linear effect on the turbine's efficiency, while the PR has a non-linear effect on the turbine's efficiency. The effect of PR on the net power at fixed CIT has different behaviour depending on its CIT. For different CIT values, the net power reaches the peak at the PR values between 9 and 12. Moreover, using Natural gas as fuel for gas turbine units promotes proper turbine performance compared with crude oil as fuel.

Keywords: *Gas turbine, Hysys Aspen, SGT5-2000E, modelling and simulation*

1. Introduction

By the end of 2020, the electricity demand in Libya was estimated to be 7.5 GW in summer while the available supply of power plant was 4.8 GW, leaving the power deficit of around 2.7 GW [1]. Most of the power are supplied by the combined cycle of gas turbines and steam turbines. Due to the advantage of the long coast, all of them are located in the north of Libya and they are mainly powered by oil and natural gas.

The main advantages of gas turbines can be concluded as follows; low emission of carbon monoxide and nitrogen oxides, low-cost installation, and low-cost power generation[2]. Moreover, it has a wide range of power generation from 3 MW to 480 MW with thermal efficiencies ranging from 30% to 46%,respectively [3]. Nowadays, gas turbines are powered by natural gas, diesel fuel, naphtha, crude, low-Btu gas, vaporized fuel oils, and biomass [4]. The performance of the gas turbine plant is commonly evaluated by its thermal efficiency, output power, and specific fuel consumption, which can be affected by operating conditions including pressure ratio, inlet turbine temperature, and intake temperature of the compressor [5]. The thermal efficiency of gas turbines that were built in the 1940s and 1950s was about 17%. This was because of the low inlet turbine temperature due to metallurgical limitation, low compressor ratio, and low isentropic efficiencies of the compressor and turbine [2]. Recently, a large growth in the technology of gas turbine, the growth of material technology, a new coating and cooling of turbine's blades, and an increase in compressor pressure ratio has led to an increase in the gas turbine thermal efficiency from 15% to over 45% as depicted in Figure 1[4].

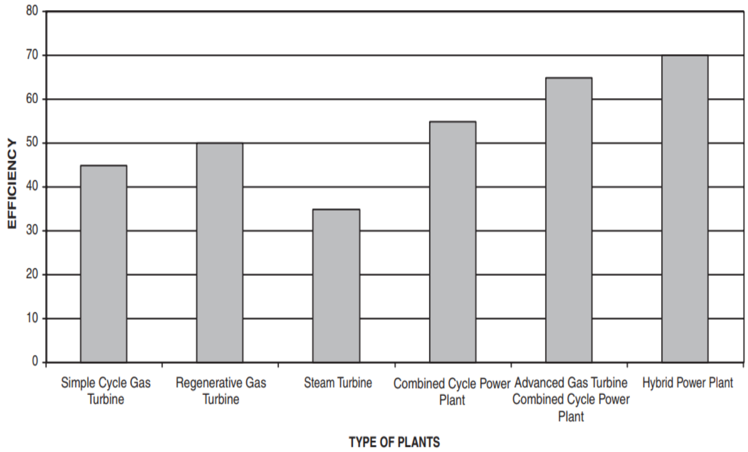

Figure 1: Typical thermal efficiency of different types of power plants [4].

Several studies in the literature have been conducted to analyze the thermal cycle of gas turbine plants to improve their performance based on the thermodynamic equations of energy conservation that state the principle of conservation of energy. This energy analysis provides an energy balance for any energy conservation system [6]. Rahman, et al. [7] carried out a parametric analysis using thermodynamic modelling to study the effect of compression ratio, ambient temperature, air-to-fuel ratio, and turbine inlet temperature on the performance of an open simple thermal cycle of a gas turbine plant. Egware, et al. [8] utilized EBSILON professional software to model and simulate the SGT5–2000E gas turbine (open simple thermal cycle gas turbine) to assess its performance when it operates at variant ambient conditions such as temperature and humidity or when the output power of the turbine less or more than the design output power. Oyedepo and Kilanko [9] studied the effect of cooling the compressor inlet air temperature of the power plant on its performance by using an evaporative cooler. This study shows that any decrement in the inlet air temperature by 5 °C would lead to improving the system efficiency and the net power by 2-5% and 5-10%, respectively. Naeim, et al. [10] carried out research using (C++) to construct a gas turbine power plant and investigate the influence of compressor inlet air temperature, relative humidity and ambient pressure on the performance of the gas turbine power plant. Lebele-Alawa and Jo-Appah [11]conducted a parametric analysis depending on the conservation of energy to investigate the effect of operating conditions on the performance of gas turbine power plants. Ranjan and Tariq [12] have analysed the regenerative simple cycle of a gas turbine based on the first law of thermodynamics and compared its efficiency with a simple cycle of the gas turbine. In this work, a gas turbine is modelled using ASPEN HYSYS and its performance is validated against design data. Then the CIT, PR and LHV are varied to study their effect on the performance of a simple cycle of gas turbine.

2. Gas Turbine Power Plant Thermodynamic Cycle

The main three units of the thermodynamic cycle of a gas turbine power plant are the compressor, combustion chamber, and gas turbine [13]. The inlet air is pressurized by a compressor (isentropic for reversible process and adiabatic for irreversible process). The pressurized air and the fuel are then burned in the combustion chamber (isobaric process). The discharge flue gases at high pressure and temperature are charged into the gas turbine which converts thermal and pressure energy to kinetic energy to produce rotational mechanical energy (isentropic for reversible process and adiabatic for irreversible). The mechanical energy is then transferred by shaft power to the generator producing electricity as illustrated in Figure 2.

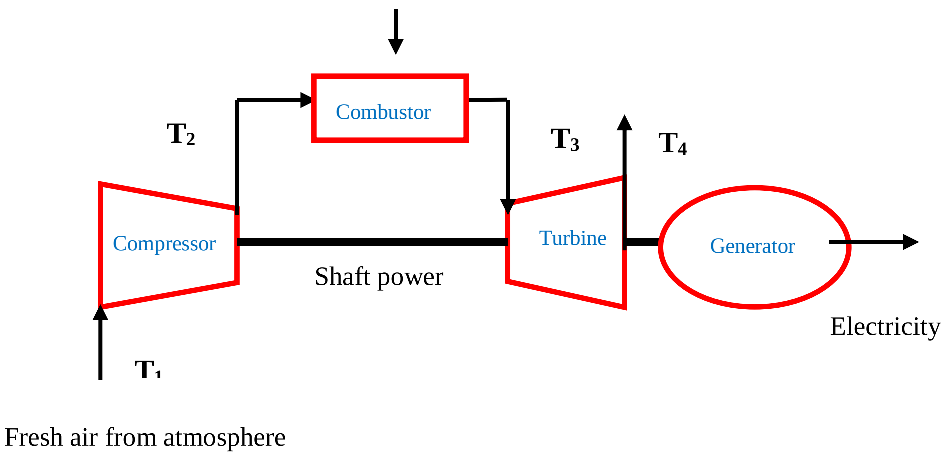

Figure 2: The main components of an open simple cycle of a gas turbine plant

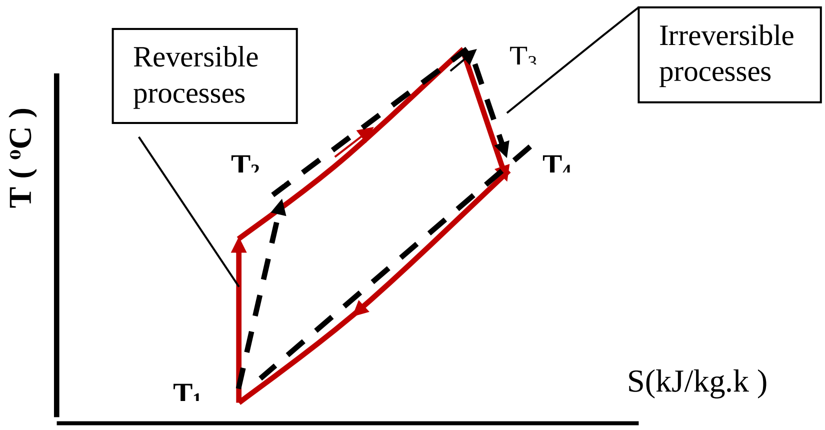

Figure3: T-S diagram of the reversible and irreversible process of gas turbine power

3. SGT5-2000 E Design (Open Simple Cycle)

The engine is designed with a 16-stage axial compressor, which has a variable initial guide vane (IGV). The purpose of IGV is to control the PR, improve the operation at the peak load and reduce the vibration. The turbine has 4-stages integrated with the latest blade and vane design. All moving and stationary blades and vanes for the turbine and compressor can be replaced in place, which shortens outages of the engine operation time. The engine has two combustion chambers equipped with individually replaceable ceramic tiles. All units of the engine are covered by a horizontally split casing which contains the stationary blades of the compressor and turbine. The engine can be fuelled by many types of fuel such as natural gas, propane, ethane, biogas, kerosene, blast furnace gas, distillate oil, crude oils, naphtha, biodiesel, alcohols, and liquefied natural gas.

To increase electricity production in Libya, the gas turbine of Awbari power plant was executed by Enka Company in Fezzan (South region of Libya), with a total capacity of 640MW. The Awbari power plant consists of four units of SGT5-E2000 and it was put on duty in December 2017

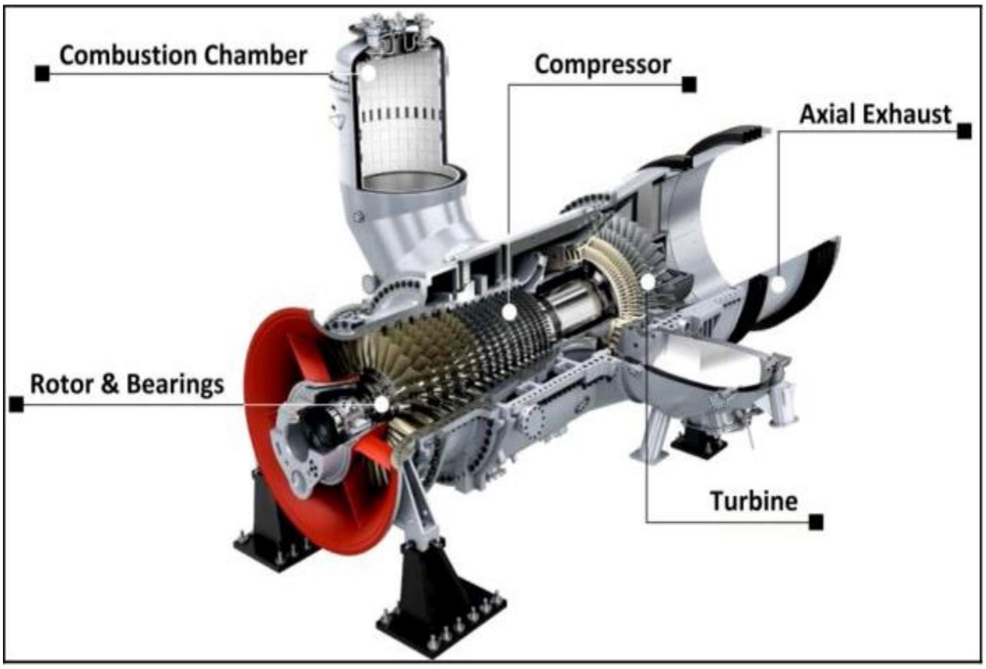

Figure 4: SGT 5-E 2000 unite[14]

4. Modelling and Validation

The modelling and simulations of the gas turbine power plant have been accomplished using HYSES ASPEN and consist of a compressor, combustion chamber, and gas turbine as illustrated in Figure 5. All input data and ambient conditions (ISO conditions) illustrated in Table 1 are provided by the manufacturer with isentropic efficiencies of the compressor and turbine are 90% and 89%, respectively. The results of the modelling and simulation show a good agreement when compared with the data provided by the manufacturer.

Table (1): Design Thermodynamic Parameters of (SGT5-2000E)

Power (MW)	166
Thermal efficiency (η_{th})	34.7
Exhausted Mass flow rate (m_g) (kg/s)	525
Exhausted gas temperature (°C)	541
Heat rate (MJ/KW.h)	103.8
Pressure ratio ($\boldsymbol{r_p}$)	12
Ambient air temperature(°C)	15
Ambient air pressure (bar)	1.0
Lower heating value (LHV)(MJ/Kg)	45.01

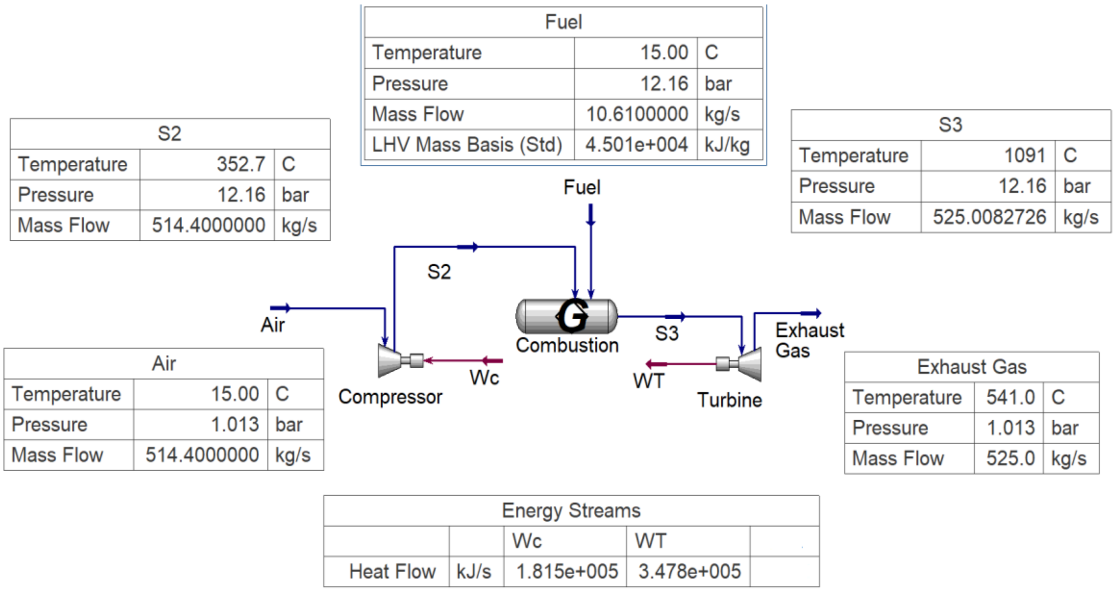

Figure 5: Schematic process diagram of SGT5-2000E with validation results

5. Performance evaluation of gas turbine using different types of fuel

Based on the validated model, the simulation of the process has been carried out using two types of fuel having different values of LHV to estimate the effect of fuel type on the system performance including net power, efficiency, SFC and FAR. The abovementioned parameters were investigated and the results were performed using two types of fuels namely; Natural gas and crude oil.

6. Results and discussion

6.1. The effect of CIT and PR on the gas turbine performance for different fuels (crude oil and natural gas).

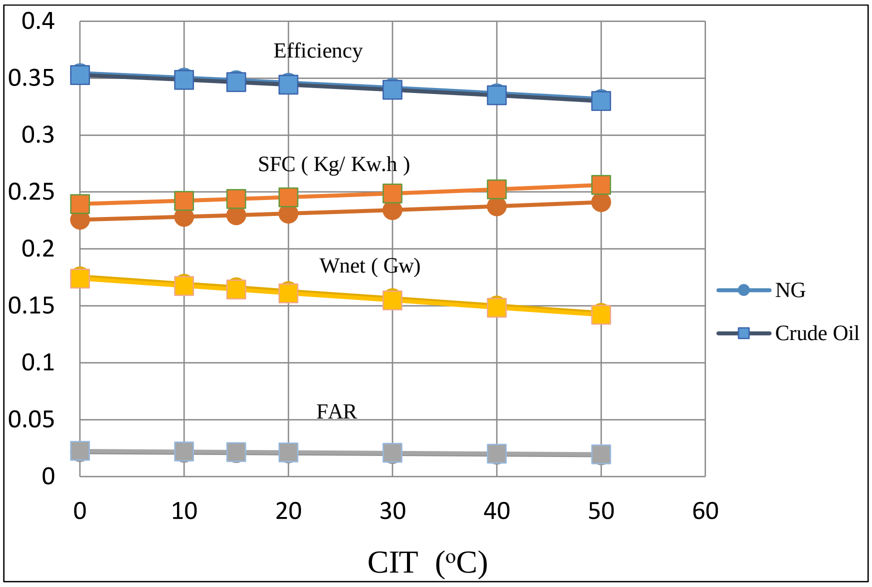

Figure 6: Performance of gas turbine for two fuels (ΔLHV = 2500 kJ/kg) with varied CIT and fixed PR at 12.

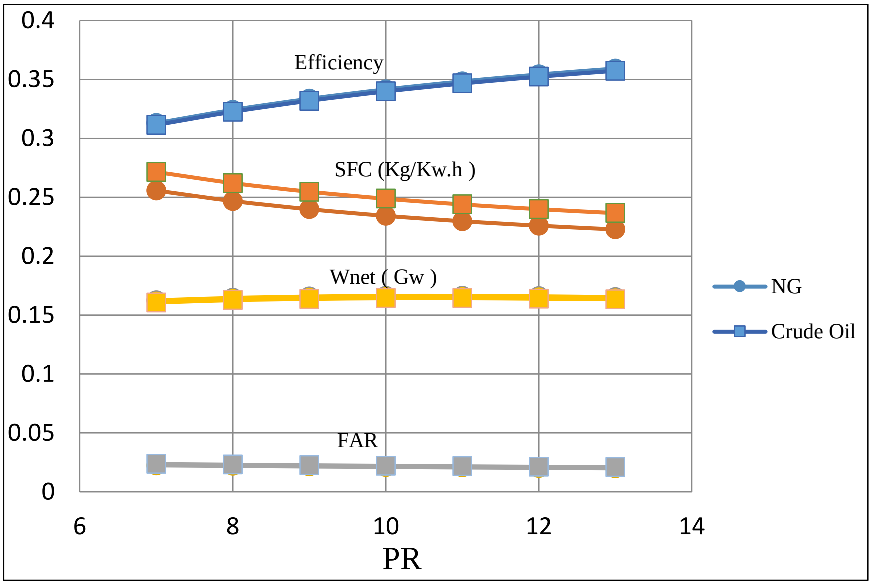

Figure 7: Performance of gas turbine for two fuels (ΔLHV = 2500 kJ/kg) with varied PR and fixed CIT at 15°C.

Figure 6 shows the relation between Wnet, efficiency, SFC, and FAR with different values of CIT at a fixed PR of 12 for the two types of fuels (natural gas and crude oil). Both the efficiency and Wnet gradually decline by increasing CIT while FAR is slightly affected by the increase in CIT. SFC noticeably rises with the increase in CIT. From Figure 6, it can be concluded that the efficiency, Wnet, and FAR match each other for both types of fuel while SFC is slightly higher when using crude oil compared with NG. In contrast, as shown in Figure 7, increasing PR at a fixed CIT of 15 ^{o}C leads to a steady rise in the turbine efficiency and a visible decrease in SFC. Wnet reaches the peak at PR of 12 while FAR is almost not affected by this change.

Four indications (efficiency, Wnet, SFC and FAR) are applied in this research to assess the gas turbine performance using two different types of fuels (NG and crude oil). At a constant PR of 12 and different CIT values (0^{o}C, 10^{o}C, 15^{o}C, 20^{o}C, 30^{o}C, 40^{o}C and 50^{o}C), the highest efficiency was 35% at 0 ^{o}C and the lowest was 33% at 50^{o}C for NG as the turbine fuel. Almost the same results of efficiency at the same parameters were found for crude oil as a turbine fuel.

Wnet has the same behaviour under the same conditions for the two types of fuel. The highest values of Wnet are 176MW and 174MW at 0 ^{o}C for NG and crude oil, respectively. Higher values of SFC are at the highest degrees of CIT for both fuels of NG and crude oil, 0.24 and 0.256, respectively.

The same parameters were examined at a constant CIT of 15 ^{o}Cand different PR values. Using NG, the efficiency rapidly rises from 30% to 36% with the increase of PR from 8 to 14. However, for the same range of PR, the efficiency increases from 30% to 34% using crude oil. Wnet experienced a slight increase for all conditions from 160 MW to 165 MW and it was slightly higher when using the NG rather than crude oil. Specific Fuel Consumption (SFC) shows the propriety of using NG for the gas turbine unit. SFC was noticeably lower for using NG compared with crude oil, 0.25 and 0.27 respectively at PT of 8. Generally, it is obvious that using NG as fuel for gas turbine units promotes proper turbine performance compared with the use of crude oil.

6.2. Effect of CIT and Pr on the performance of the Awbari power plant

The validated model has been applied for the input data of the gas turbine of the Awbari power plant to investigate its performance (Wnet, efficiency, SFC, and FAR) by variation of CIT and PR.

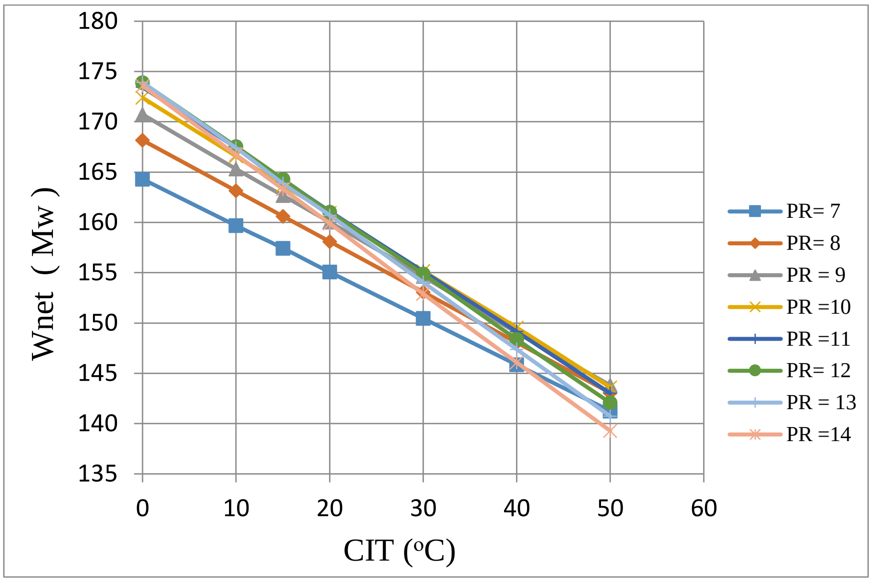

Figure 8:Relation of Wnet with CIT at different values of PR

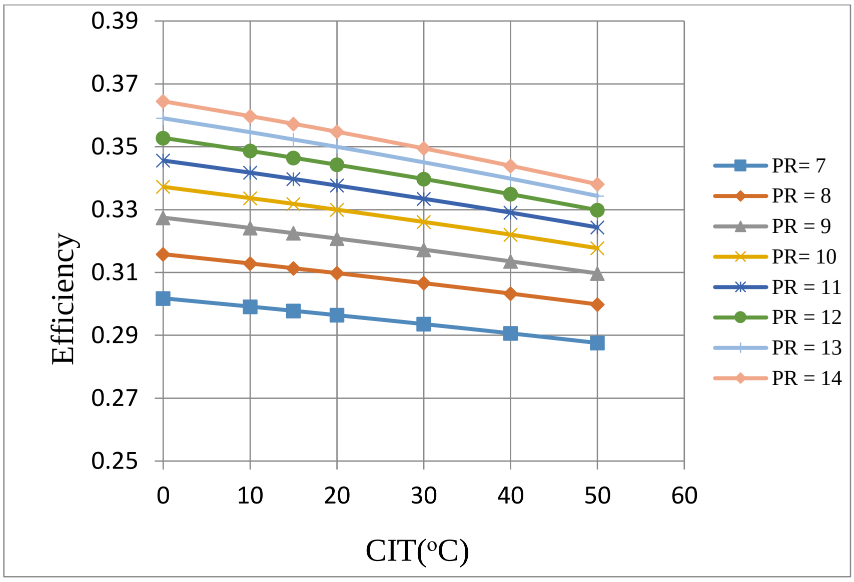

Figure 9: Relation of efficiency with CIT at different values of PR

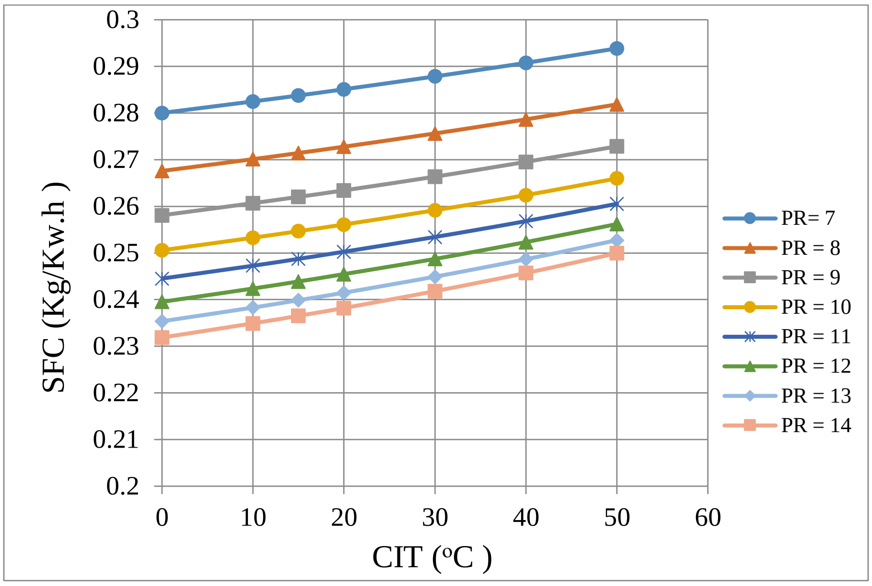

Figure 10: Relation of SFC with CIT at different values of PR

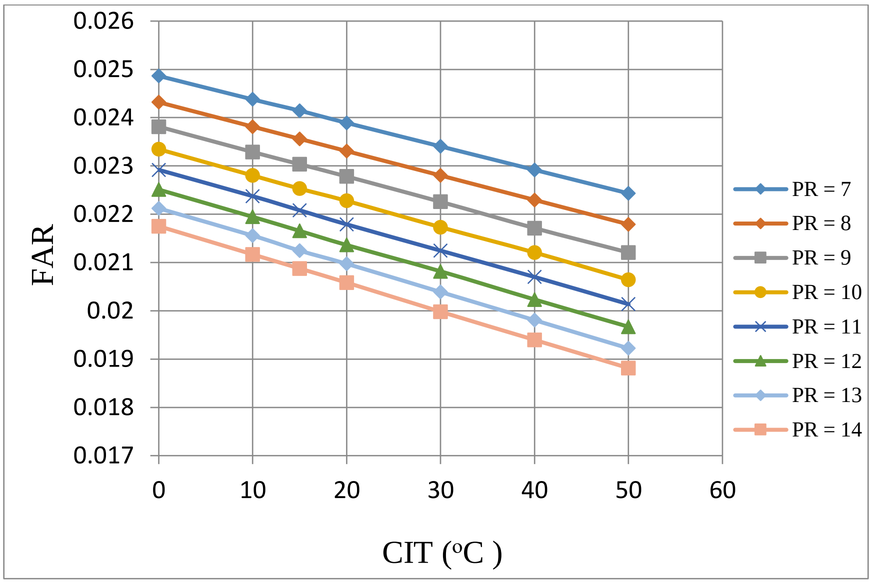

Figure 11: Relation of FAR with CIT at different values of PR

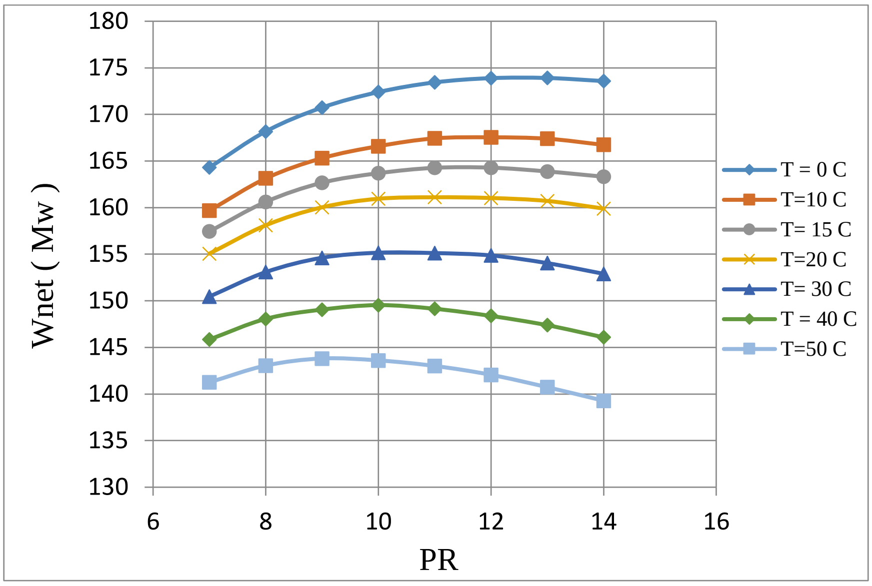

Figure 12: Relation of Wnet with PR at different values of CIT

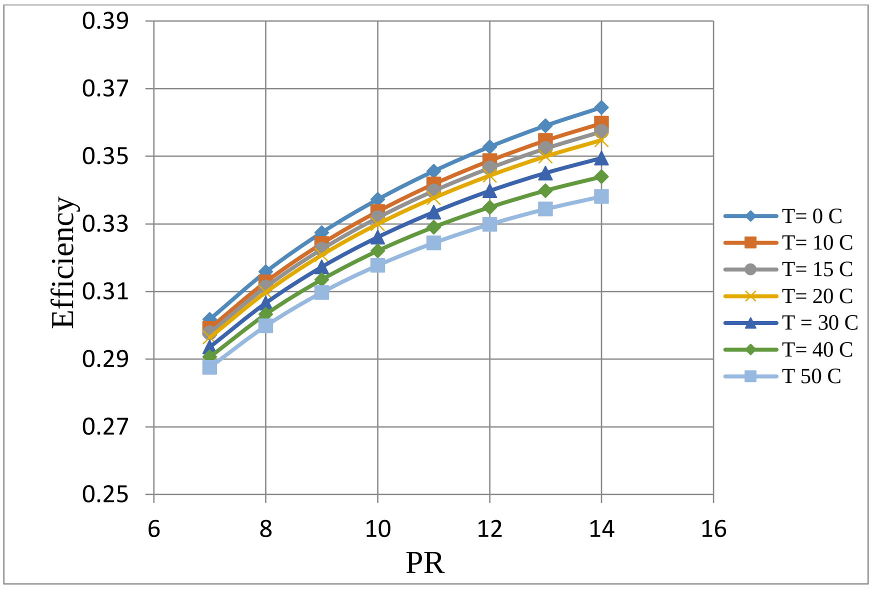

Figure13: Relation of efficiency with PR at different values of CIT

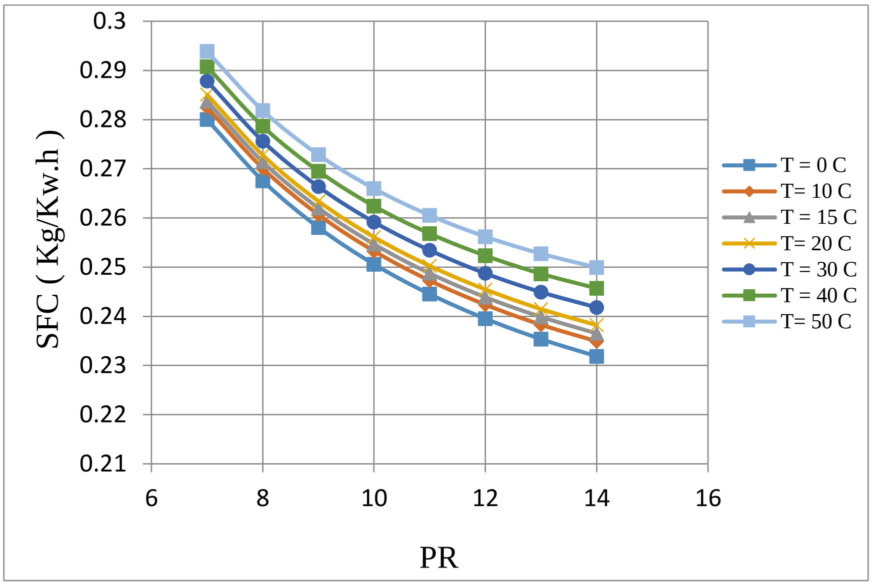

Figure14:Relation of SFC with PR at different values of CIT

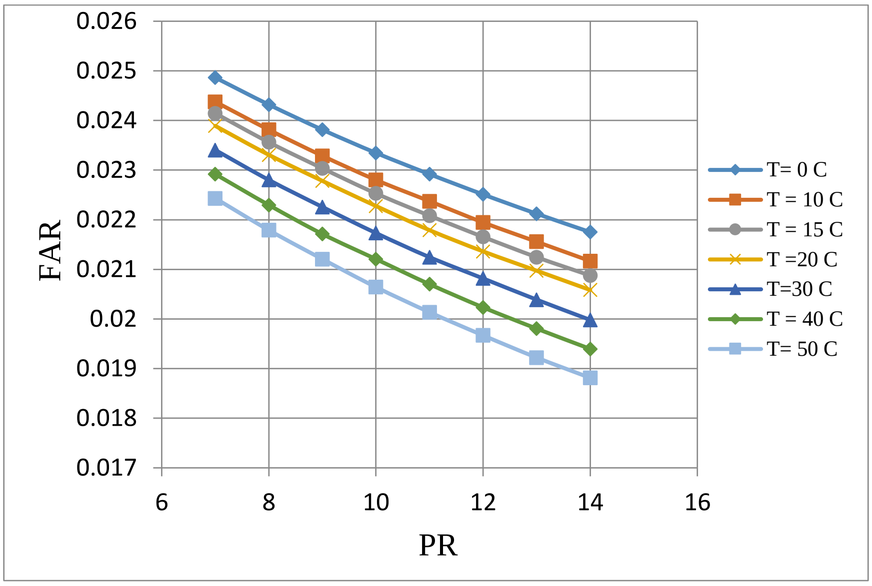

Figure 15: RelationofFAR with PR at different values of CIT

All Curves of Wnet, efficiency, SFC, and FAR with varied CIT and fixed PR have a linear behaviour and a non-linear behaviour for different values of PRand fixed CIT except the behaviour of FAR (almost linear). Figures 8 and 9 show that increasing CIT leads to a reduction in the Wnet and efficiency at fixed PR. However, this reduction of Wnet has a different slope for each PR (higher PR produces a sharper slope). Figures 10 and 11 illustrate the effect of CIT on SFC and FAR at different values of PR. Increasing CIT leads to an increase in SFC and a decrease in FAR.

Figure 12 shows that the highest values of Wnet are obtained at the lower CIT. It is about 174 MW at 0°C of CIT compared with CIT at 50°C where the highest value of Wnet is 144 MW. The peak of Wnet at 0°C, 10°C, 15°C, and 20°C of CIT are reached at the values of PR between 11 and 12. A higher temperatures of 30°C, 40°C, and 50°C, the peak of Wnet is at low values of PR of 10, 10 and 9, respectively. Thus, the design value of PR set by the manufacturer should be modeified by the installation company based on climate conditions of the region.

The efficiency is strongly affected by both, the values of PR and the CIT. It is increasing rapidly with the increase of PR and is affected inversely by the increase in CIT as depicted in Figure 13. The highest efficiency is obtained at 0°C of CIT and PR of 14. The SFC and FAR decrease steadily with the increase of both CIT and PR. Figure 14 shows that higher values of SFC can be gained at both 50°C of CIT and PR of 7 while the FAR is at a higher value at lower CIT as illustrated in Figure 15.

7. Conclusions

The gas turbine power plant of Awbari was modelled and simulated using ASPEN HYSES. The developed model was validated against design data provided by the manufacturer of the turbine. The results showed very good agreement against the design data. Based on the obtained results, the following conclusions can be drawn:

- The effect of fuel on the performance of gas turbines depends on its LHV. The higher LHV the better performance.
- Compressor inlet temperature (CIT) has a linear effect on the performance of the gas turbine. However, the pressure ratio (PR) has a non-linear effect on the performance excluding FAR.
- Net power, efficiency and FAR have the same behaviour with increasing CIT at fixed PR (reduction), while SFC has the opposite behaviour. Moreover, the slope of reduction of net power depends on the PR as the PR increase, the reduction becomes more sharply.
- Using NG as fuel for gas turbine units promotes proper turbine performance compared with crude oil.
- SFC and FAR behave similarly at varied PR and fixed CIT. They decline as the PR increase.
- The effect of PR on net power at fixed CIT has a curved shape depending on the CIT; it reaches the peak at the PR values around 12 for lower CIT and around 10 for higher CIT.

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