Scientific-technical analysis of the ambient temperature effect on the power of gas turbine installation in the conditions of Turkmenistan

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Abstract. The rise of the ambient temperature decreases the performance of the gas turbine installations, i.e. efficiency of the GTI. To study this problem, namely, at what rate a drop of power and other parameters occurs, we decided to use the Mark VI software installed in the laboratory stand of the Department of Electric Power Stations of the State Energy Institute of Turkmenistan. In the result of the obtained data, it was concluded that at 15 °C ambient temperature, a GTI with an installed capacity of 127.1 MW will consume 7.7 kg/s of natural gas, while its energy efficiency is 36% or 100% of its nominal value, at 25 °C ambient temperature GTI consumes 7.3 kg/s of natural gas, its energy efficiency is 34.7% or 84% of its nominal value, and at 40 °C temperature GTI consumes 6.5 kg/s of natural gas, while its energy efficiency is 30% or 60% of its nominal value. Therefore, it can be stated that at elevated ambient temperatures, it is possible to forecast the performance of a GTI of all the capacities, gas consumption and power output in the conditions of Turkmenistan. If at the same time it is necessary to obtain the installed nominal capacity at elevated ambient temperatures, it becomes necessary to install additional cooling sources, where additional energy expenditures will be required, which in turn will lead to an increase in the cost of the electric energy.

1. Introduction

In Turkmenistan the “State Energy Saving Program for 2018-2024” adopted on February 21, 2018 is under the implementation in the form of the projects with the latest results as innovative developments in new technologies, technics and materials [1]. Powerful GTIs built within the adopted plans for the development of the energy sector of our country make a worthy contribution to this process. The quantity and quality of air (cleanliness, temperature, humidity) are considered to be very important for the smooth and reliable operation of the gas turbine facilities built and put into operation in our country [2]. In order for the GTI to operate at full capacity, it is important to maintain the parameters indicated in its passport data. At 15 °C outside air temperature, the capacity of the gas turbine starts to decrease, which means that when the outside air temperature rises above 15 °C, the capacity of the gas turbine decreases due to the lack of a mass amount of air supplied to the compressor.

2. Materials and methods

Simple power cycle settings.
One of the stations that uses fossil fuels is GTI running on natural gas. The block diagram of energy conversion of gas turbines running on natural gas is shown on Figure 1. The main fuel in such stations is natural gas [9].

Characteristics of the analyzed simple cycle power plant operating on natural gas.

In this study, the efficiency of electricity production is considered depending on the ambient temperature installed in the gas turbine with a capacity of 127.1 MW, the appearance of which is shown on figure 2.

![Figure 1. Principal heat diagram of a GTI.](image1)

![Figure 2. Avaza State Electric Power Station with a capacity of 127.1 MW.](image2)

This natural gas GTI consists of the two combined cycle units [2], in Turkmenistan, at GTI power plants, the content of natural gas has the following content depending on the field:

- \( \text{CH}_4 = 92.3 \text{ – } 98\% \).
- \( \text{C}_2\text{H}_6 = 3.8\% \).
- \( \text{C}_3\text{H}_8 = 0.7\% \).
- \( \text{C}_4\text{H}_{10} = 0.2\% \).
- \( \text{CO}_2 = 1\% \).
- \( \text{N}_2 = 2\% \).

The ambient temperature should not be higher than 15 °C for gas turbine facilities to operate at full capacity.

The climate of Turkmenistan is sharply continental and dry. The average January temperature is about 4 °C in the southern regions and -5 °C in the northeast, while there are cases of temperature drops to -22°C, and in the desert areas to -20 – -32 °C. In summer, average temperatures are about 28 °C in the northeast and in the Caspian regions and up to 34 °C in the south (in the mountains, it does not exceed 17 °C). At the same time, in the desert central regions, during the daytime, the heat can reach 50°C, and after sunset it quickly drops to 14 – 18 °C, (daily temperature fluctuations with an amplitude of up to 35 ° are not uncommon). Spring and autumn frosts are not uncommon; they are especially seen in desert regions [10].

In this article, within the Concept for the Development of the Digital Educational System, we decided to conduct a scientific and technical analysis of the possibilities of improving performance using a GTI simulator equipped with a Mark VI control program, located in the laboratory of the Department of Electric Power Stations of the State Energy Institute of Turkmenistan.

The GTI simulator equipment, which is the Mark VI control program, is designed to perform the full functionality of the plant virtually. The device includes such programs as CALIK, CIMLA, Shortcut, ToolboxST.

These programs are intended for commissioning and disassembling of the GTI, the control of faults occurring during operation, the type and amount of fuel consumed depending on the load of the GTI, the pressure of the gas supplied to the GTI, the pressure of the gases supplied to the turbine stages, the temperature of the gases coming out of the GTI, the air supplied to the auxiliary equipment of the GTI, the temperature of the oil supplied to cool the bearings of the installation, the pressure and temperature of the air compressor and temperature of the compressor steps.

Equation. Calculation formula of the adiabatic parameters to determine efficiency of the GTI [11]:

\[
\frac{m}{k} = \frac{k - 1}{k} \tag{1}
\]

where: \( k \) – the value of the adiabatic parameters (equals to 1.4 for natural gas).

Calculation formula for determining the average values when an air temperature in front of the gas turbine is \( T_3 = 15 \) °C:

\[
\tau = \frac{T_i}{T} \tag{2}
\]

where: \( T_i \) is the ambient air temperature for the GTI; \( T_a \) is the temperature of the gas supplied to the first stage of the gas turbine.

Calculation formulas for determining the efficiency of a GTI:

\[
\Psi_{GTI} = \frac{\Psi_{oil} \cdot \tau(1 - \frac{1}{\lambda^m}) - (\lambda^m - 1)(\frac{1}{\Psi_k})}{\tau - 1 - (\lambda^m - 1)(\frac{1}{\Psi_k}) \cdot \lambda^y_k} \tag{3}
\]

where: \( \tau \) - the average temperature of the gases; \( \lambda^m \) - compressor pressure level; \( \Psi_k \) - compressor efficiency; \( \Psi_{oil} \) - combustion chamber efficiency.

Calculation formulas for determining the energy efficiency of a gas turbine facility:
\[ \Psi_{GTI}^{s} = \Psi_{GTI}^{i} \cdot \Psi_{GTI}^{m} \tag{4} \]

where: \( \Psi_{GTI}^{i} \) - internal efficiency of the GTI; \( \Psi_{GTI}^{m} \) - mechanical efficiency of the GTI.

3. Results and Discussion
The parameters in Table 1 were obtained directly from the 9E Gas Turbine Manual, Model MS9001E. The values in Table 2 are the ambient temperature, compressor outlet temperature, exhaust gas temperature, specific fuel consumption, output power, which were obtained directly using the Simulink program, and the energy efficiency was obtained using the calculated values [11].

Table 1 also shows the ambient air temperature at the GTI during the operation of the simulator equipment, the pressure level of the compressor, the temperature of the gases burned in the first working stage of the GTI, the compressor efficiency, combustion chamber efficiency, relative efficiency accepted for gas turbine, adiabatic coefficients for gas turbines, fuel heat transfer rates, heat transfer rates depending on gas density [12-18].

**Table 1. Design parameters and their values.**

| Parameters | Design Data | Units |
|------------|-------------|-------|
| 1 Power output | 127.1 | MW |
| 2 Heat efficiency | 34 | % |
| 3 Ambient temperature, \( T_f \) | 15 | °C |
| 4 Compressor efficiency, \( \Psi_{k} \) | 90 | % |
| 5 Depending on the calculations, the pressure level, \( P \) | 10 | ata |
| 6 Exhaust temperature, \( T_3 \) | 1200 | °C |
| 7 Combustion chamber efficiency, \( \Psi_{oi} \) | 0.99 | |
| 8 Relative efficiency of a gas turbine, \( \Psi_{oi} \) | 0.9 | |
| 9 Fuels, \( \dot{m}_f \) | 7.7 | kg/s |
| 10 The ability to release heat depending on the density of the gas, \( \rho \) | 0.78 | kJ/m³ |

**Table 2. Working parameters of the turbine.**

| S/N | \( T_1 \) (°C) Ambient temperature | \( T_2 \) (°C) Compressor exit temperature | \( T_3 \) (°C) Exhaust temperature | \( \dot{m}_f \) (kg/s) Fuel supply | P (MW) Power output | Efficiency (%) |
|-----|----------------------------------|-----------------------------------|-----------------------------------|-------------------------------|------------------|-----------------|
| 1   | 10                               | 320                               | 545                               | 7.9                           | 140.5            | 36.6            |
| 2   | 11                               | 324                               | 547                               | 7.8                           | 138.5            | 36.5            |
| 3   | 13                               | 328                               | 548                               | 7.8                           | 136.4            | 36.2            |
| 4   | 15                               | 331                               | 549                               | 7.7                           | 134.3            | 36              |
| 5   | 17                               | 335                               | 550                               | 7.6                           | 132.2            | 35.5            |
| 6   | 19                               | 339                               | 551                               | 7.5                           | 130.2            | 35.2            |
| 7   | 21                               | 342                               | 552                               | 7.5                           | 128.2            | 35              |
| 8   | 23                               | 346                               | 553                               | 7.4                           | 126.2            | 34.9            |
| 9   | 25                               | 350                               | 554                               | 7.3                           | 122.6            | 34.7            |
| 10  | 27                               | 353                               | 555                               | 7.2                           | 118.8            | 34.5            |
| 11  | 29                               | 356                               | 556                               | 7.1                           | 115.4            | 34.1            |
| 12  | 31                               | 360                               | 557                               | 7.0                           | 112.7            | 33.9            |
When the ambient temperature is 15 °C, the heat is considered to be normal for the gas turbine, in this case the gas consumption, the amount of heat released and the other parameters of the installation do not exceed the specified nominal, the results of the simulation test are shown on Figure 3 below.

| S/N | Ambient temperature (°C) | Compressor exit temperature (°C) | Exhaust temperature (°C) | Fuel supply (kg/s) | Power output (MW) | Efficiency (%) |
|-----|--------------------------|---------------------------------|--------------------------|--------------------|-------------------|----------------|
| 13  | 33                        | 363                             | 558                      | 6.9                | 110               | 33.7           |
| 14  | 35                        | 367                             | 559                      | 6.8                | 107.4             | 33.5           |
| 15  | 37                        | 370                             | 560                      | 6.8                | 104.8             | 33.4           |
| 16  | 39                        | 374                             | 561                      | 6.7                | 102.3             | 33.3           |
| 17  | 41                        | 377                             | 562                      | 6.6                | 99.9              | 33             |
| 18  | 43                        | 380                             | 563                      | 6.5                | 97.4              | 32             |
| 19  | 44                        | 382                             | 563                      | 6.5                | 96.1              | 30             |

Figure 3. Indicator of the GTI at ambient temperature 15 °C.

When the ambient temperature is higher than 15 °C, this heat exceeds the nominal values for the gas turbine, i.e. when the ambient temperature is 32, 40, and 44 °C, the gas consumption, the amount of heat released, and other parameters of the installation exceed the nominal value, the result is shown on Figures 4-6 below.
Figure 4. Indicator of the GTI at 32 °C ambient temperature.

Figure 5. Indicator of the GTI at 40 °C ambient temperature.
Figure 6. Indicator of the GTI at 44 °C ambient temperature.

If the ambient temperature rises above 15 °C, the capacity of the gas turbine facilities reduces due to the lack of air mass supplied to the compressor.

Under local conditions, the ambient temperature in summer reaches 32 – 40 °C and in some cases up to 44 °C. This indicator has a huge impact on the change of the productive capacity of the facility. The results are shown on figures 7-11.

Figure 7. Effect of an ambient temperature on the power output.
Figure 8. Effect of an ambient temperature on the fuel consumption.

Figure 7 represents the effect of ambient temperature on the power output. It shows that the power output decreases as the ambient temperature increases. It also shows that as the ambient temperature increases from 25°C to 44°C, the power output decreases from 122.6 to 96.1MW.

On Figure 8 the effect of an ambient temperature on the specific fuel consumption is shown. This shows that the specific fuel consumption decreases with increasing ambient temperature, as turbine power drops. It also shows that as the ambient temperature rises from 15 °C to 44 °C, the specific fuel consumption decreases from 7.7 kg/sec to 6.5 kg/sec.

Figure 9. Effect of an ambient temperature on the power output.
Figure 10. Effect of an ambient temperature on the energy efficiency factor.

In Figure 9 the effect of an ambient temperature on the installation with the capacity of 127.1 MW is shown, which is accepted as 100%. As can be seen from the figure with the increase in ambient temperature, the power starts to drop, or more precisely at an ambient temperature of 15 °C the turbine operates at 100% power, at a temperature of 25 °C it produces 82% of the rated power, and at a temperature of 44 °C it produces 60% at rated power.

Figure 11. Effect of an ambient temperature on the exhaust gas temperature.

Figure 10 shows the effect of an ambient temperature on the energy efficiency factor. This shows that the energy efficiency coefficient decreases with increasing ambient temperature. It also shows that
when the ambient temperature rises from 23°C to 44°C, the energy efficiency ratio reduces from 34.9% to 30%.

Figure 11 shows the effect of an ambient temperature on the exhaust gas temperature. It can be seen from the graph that as the ambient temperature increases, the exhaust gas temperature also increases, at an ambient temperature of 10 °C, the exhaust gas temperature is 545 °C, and at 44 °C, the exhaust gas temperature is 563. This shows that with an increase of an ambient temperature per 1 °C, the exhaust gas temperature increases by 0.529 °C.

4. Conclusion
With an increase of an ambient temperature by 1.8 times, it leads to a decrease in power by 1.3 times. Based on the results obtained with the help of the software, it is possible to determine the exact prices of natural gas consumed in a variable load under the influence of the external air to the gas turbine installation, determine the energy efficiency and potential of the GTI, and also to maintain service life of the GTI and prevent from unplanned repairs and accidents.

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