Estimation the Performance of Gas Turbine Power Station with Air Cooling Fog System

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Abstract: The purpose of this study is to shed light on the fog system to cool the inside air to the compressor in the gas station to generate electricity. Where it mainly focused on the suitability of the fog system to the hot Iraqi climate throughout the summer period, a simulation analysis of the operation of the gas turbine unit using a fog system at an ambient temperature in the range of 25-55 °C was conducted in the southern Baghdad second station. The fog system proved to be highly effective in raising the effective power, the thermal efficiency and the effective efficiency coefficient of the gas turbine unit as well as a apparent decrease in the specific air flow rate, the specific fuel consumption and the specific heat consumption in the gas turbine unit compared to not using fog system for cooling and for the same operating conditions.

Keywords: fogging system, gas turbine, ambient temperature, power plant.

1. Introduction

Energy sector in Iraq is facing serious issues due to the rapid economy increase and population. Furthermore, the geographical location of Iraq is characterized by long and very hot summer days in most of the cities. Thus, the energy consumption for various applications was maximized especially those related to the building sector which influenced the electric power production [1].

In power generation sector, Iraq is rely mainly on gas power stations to overcome the huge shortage in electricity and these stations are mainly characterised by low efficiency [2]. There are several solutions have introduced to increase the efficiency of gas turbines currently in service and increase the net energy produced. Amongst other solutions, choosing of appropriate fuel according to the type of turbine used[3,4], establishing combined power plants (steam-gas) to recover the heat wasted from gas turbines [5] and cool the air entering the compressor underdry and high air ambient temperature locations [6].
In summer period, the high ambient temperature entering the compressor is the main cause of low power efficiency of gas power plants in Iraq [7]. This is because that the increase of ambient temperature leads to decrease the density of the air and reduce the air mass flow entering the compressor which reduces the plant’s efficiency and supplied energy [8]. Fogging the inlet of the compressor boosts the gas turbine unit power output not only in hot summer, but also in other dry days during the year [9].

An analysis was made based under the annual of New Orleans city weather conditions to assess the potential enhancement of a fleet of 14 small gas turbines' power output by employing an inlet air cooling scheme at a gas process plant. Various gas turbine (GT) inlet air cooling schemes were reviewed. The inlet fogging scheme was selected for detailed studies due to its low installation capital costs. The results indicate a potential of 10% enhancement in power output on a warm, dry day, a 5% enhancement in a typical summer day, but only a 1% enhancement in a hot humid day. It is shown that the relative humidity is the most important factor that affects the impact of inlet fogging. Therefore, the inlet fogging can enhance GT power output not only in the hot summer, but also in other dry days during the year. An annual analysis was also conducted based on New Orleans's annual weather conditions. The results indicate a potential of increased power of 2.34% with inlet fogging to saturated state and additional 5% increased power with 0.5% (wt.) overspray [10].

And in a study conducted by a number of researchers at King Fahd University, the work includes the effect of humidity and ambient inlet air temperature on gas turbine plant configurations with and without fogger unit. GT frames of various sizes/ratings are being used in gas turbine power plants in Saudi Arabia. 20 MWe GE 5271RA, 40 MWe GE-6561B and 70 MWe GE-6101FA frames are selected. Fogger units with maximum mass flow rate of 2 kg/s are considered for the present analysis. Reverse Osmosis unit of capacity 4 kg/s supplies required water to the fogger units. GT PRO software has been used for carrying out the analysis including; net plant output and net efficiency. The relative humidity and temperature have been varied from 30 to 45% and from 80 to 100°F, respectively. The study proved the efficiency and effectiveness of the fog system in this type of station [13].

In a similar study conducted at the Gdańsk University of Technology, Poland, about ship drive applications, it was found that the power output production of gas turbines drops on hot days. Very often, power demand is high. In such circumstances augmenting gas turbine power output has an important impact on ship’s voyage economics. The dependency of marine gas turbine on the ambient temperature (power output and efficiency drops with ambient temperature increase) makes inlet air fogging an effective gas turbine power compensation. Power augmentation is a result of water direct evaporation. By this means, the wet bulb temperature is attained at the inlet of compressor. Then, further enhancement of gas turbine power can be attained by fog intercooling. Water excess in form of micron size particles enters compressor. This causes reduction of the gas turbine compressor work. Investigation has been conducted in order to examine the applicability of inlet air fogging in marine gas turbines. Different areas of ship’s voyage have been taken into account. The use of inlet air fogging in marine gas turbines must be evaluated based on the gas turbine characteristics, climate profile of ship’s voyage, and expectations of gas turbine power augmentation [14].

This study experimentally studied the use of the fog cooling system for cooling the hot air entering the compressor unit in gas power plants to increase its density and increase its efficiency.
2. Methodology

This study was carried out at the second operating south Baghdad power production plant by using GE MS 5001 PA gas turbines which are running using natural gas. Table 1 shows the technical characteristics of these uniaxial gas turbines, and the study was carried out under ISO conditions [11].

Table 1. Technical characteristics of uniaxial gas turbines GE MS 5001 PA.

| Equipment                       | Parameters                      | Units | Value   |
|---------------------------------|---------------------------------|-------|---------|
| Compressor                      | Air consumption                | kg/s  | 122.2   |
|                                 | Enhancement degree compressor pressure | bar  | 10.5    |
| Combustion chamber              | Air consumption                | Kg/s  | 122.2   |
|                                 | Gas temperature before Gas turbine | ºC | 1100    |
| Fuel consumption                |                                |       |         |
| Gas turbine working             | Gas consumption                | kg/s  | 2.6     |
| Output power                    | Outgoing temperature gases     | Kg    | 26800   |
| Efficiency                      |                                | ºC    | 487     |
|                                 |                                | %     | 26.3    |

According to the Iraqi Meteorological Authority, temperatures in (June, July, and August) months are the hottest in the year ranging from 25 ºC - 55 ºC. Table 2 shows the static operating conditions of the gas turbine unit. These conditions are used as the boundary condition for the analysis of a gas turbine power plant with and without cooling system. Based on these conditions, the required fuel consumption, gas consumption, gas pressure and temperature will be calculated for gas turbine unit at the gas turbine plant [12].

Table 2. Static operating conditions of the Gas Turbine Unit

| Static operating conditions     | Unit     | Value  |
|---------------------------------|----------|--------|
| Absolute pressure               | kpa      | 101.325|
| Absolute temperature            | K        | 288    |
| Combustion efficiency fuel in the combustion chamber | % | 99    |
| Temperature before gas turbine  | K        | 1373   |
| Net calorific value natural gas | kJ/kg    | 43543  |
| Mechanical efficiency of the turbine | % | 93    |
| Compressor efficiency           | %        | 90     |
| Turbine efficiency              | %        | 90     |
| Specific mass heat capacity air | kJ/(kg K) | 1.004 |
| Gas constant of air             | J/(kg K) | 288    |
| Specific mass heat capacity gas | kJ/(kg K) | 1.15   |

The cooling system based fog system to cool the incoming air to the compressor has been linked. The fogging system consists of four high-pressure pumps and a set of electric valves and 480 nozzles.
divided into 16 stages and each stage contains 30 nozzles. Pumps are controlled by a PLC system and a system for the temperature and ambient air humidity monitoring is used as shown in figure 1.

![Image of cooling fog system](image1)

**Figure 1.** The cooling fog system

The high internal pressure allows a mist to form and the high pressure pump unit passes the aerosol jets, which subsequently interact with the nozzles. System performance depends on stack work and pumping unit production capacity. The fog assembly includes a certain number of nozzles, fittings and a pump unit as shown in Figure 2 [12].

![Image of schematic of fog cooling system](image2)

**Figure 2:** Schematic of the fog cooling system proposed for gas turbine power plant.
The injection of mist through the air inlet has the characteristic of evaporative cooling, thus the system can be considered as a cross-flow heat exchanger. Cooling by the evaporation of liquid in the surrounding air is a physical phenomenon in which the body and the liquid connected to it are cooled by latent heat. Thus, the amount of heat required to vaporize the liquid is taken from the environment. Direct evaporative cooling is used to lower the air temperature due to the specific heat of evaporation and change the liquid state of water to the gaseous state. In this process, the energy in the air does not change. The dry and warm air is replaced by cold and moist air. Therefore, the heat from the outside air is used to evaporate the water. The automatic fogging system is controlled by a programmable logic controller (PLC), a human-machine interface (HMI), and special software. The control unit reads the environment temperature and humidity data from the weather station and takes into account some of the data entered by the user as well as reads several pump safety devices, including the inlet and outlet pressure switches, the water flow meter, and performs many warnings, safety and communication functions. The PLC controls the pumps and valves that supply the fog nozzle arrays with pressurized water and activates the valves individually and optimally, according to the cooling capacity, which is continuously calculated from the ambient temperature and relative humidity of the air. The fog cooling system will not be effective at air temperatures below 15 °C, and high relative humidity of more than 60% [13-15].

Results and discussions

The analysis of the gas turbine unit operation with the use of the fogging system was carried out at an ambient temperature in the range of 25 °C- 55 °C.
Figure 4. The change in the effective power of the gas turbine unit depending on the ambient temperature (t).

From Fig. 4 we can notice that the change in the effective power of the gas turbine unit was 22500-16000 k.V.h without using the fogging system, but after using it, the capacity decreased in the range 25000-22000 k.V.h.

Figure 5. The change in the thermal efficiency ($\eta_{th}$) of the gas turbine unit depending on the ambient temperature.

Figure 5 shows that the change in the thermal efficiency of the gas turbine unit was 0.25 - 0.225 without using the fogging system, while the thermal efficiency has changed from 0.26 to 0.25 when using the fogging system.
In Figure 6, we note that the change in the effective efficiency coefficient of the gas turbine unit was 0.219 - 0.19 without using the fogging system, while the effective efficiency coefficient decreased from 0.225 to 0.21 when using the fogging system.

Figure 7. The change in the specific air flow rate in the gas turbine unit depending on the ambient temperature.
From Figure 7, we noticed that without using the fogging system the change in the specific air flow rate in the gas turbine unit was 18.5-23 kg / k.V.h, while when using the fogging system, the decrease was from 17.7 to 19.5 kg/k.V.h.

**Figure 8.** The change in the specific fuel consumption of the gas turbine unit depending on the ambient temperature.

In Figure 8, it can be noted an increase in fuel consumption from 0.378-0.425 without using the fogging system, whereas it increased from 0.368-0.381 using the fogging system.

**Figure 9.** The change in the specific heat consumption of the gas turbine unit depending on the ambient temperature.
In Figure 9, the specific heat consumption increased from 16500-18500 kJ/k.V.h without using the fog system, and the heat consumption increased from 1600-16600 kJ/k.V.h when using the fogging system. From the above analysis, the effectiveness of the fogging system is evident to increase the efficiency of gas stations in Iraq, operating at a temperature within the studied range.

**Conclusion**

According to the results obtained from using the fog system to cool the air entering the compressor in the gas station, it can be considered that the fogging system has a good practical solution to increase the efficiency of gas power plants. The system showed high efficiency compared to the case without using it under high ambient temperature 25 °C – 55 °C. The study showed a decrease in the effective power, the thermal efficiency and the effective efficiency coefficient of the gas turbine unit. Moreover, also showed increase in the specific air flow rate, the specific fuel consumption and the specific heat consumption in the gas turbine unit compared to not using fog system for cooling. Thus, we can consider the fogging system is a foolproof, economical and inexpensive method. This opens new and broad horizons for relying on the fogging cooling system in gas stations to maximize the electric power generation in Iraq, which has exceptional work in the hot, dry and long summer.

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