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Simulation of a GEF5 Gas Turbine Power Plant Using Fog Advanced Cycle and a Systematic Approach to Calculate Critical Relative Humidity

S. M. Arabi[a], H. Ghadamian*[a], M. Aminy[a], H. A. Ozgoli[b], B. Ahmadi[a], M. Khodsiani[a]

[a] *Department of Energy, Materials & Energy Research Center (MERC), Tehran, Iran*
[b] *Department of Mechanical Engineering, Iranian Research Organization for Science and Technology (IROST), Tehran, Iran*

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ABSTRACT

The ambient conditions have a significant effect on the generated power and efficiency of gas turbines [1]. These variations considerably affect power generation, fuel consumption, power plant emissions, and plant incomes. However, cooling the compressor inlet air has been widely used to reduce this deficiency [2]. In this paper, by simulating a specific gas unit in Thermoflow software, the effect of the FOG system on it was studied. Considering the error in determining the capacity of cooling systems based on the average values of dry and wet bulb temperatures, or even considering the worst possible temperature and humidity conditions, it is advisable to use ECDH or Evaporation cooling Degree Hours. Accordingly, by calculating ECDH under at ambient temperatures above 15 °C and changing the conditions of the model, the total production increase of the unit was estimated to be 4.7×10^{6} kWh. In addition, the effect of relative humidity on payback time was examined, which illustrated the critical relative humidity for a gas unit would depend on the price of fuel, the purchase price of electricity, the design parameters of the unit and the expected payback time. For this gas unit, critical relative humidity was monitored based on expected payback time and electricity purchase price. Results showed that for a certain electricity price, at the shorter PBT, the critical RH is lower; therefore, the temperature drop and power enhancement will be greater. In addition, at a certain PBT, as the electricity price increases, the critical RH for the same PBT will be higher.

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NOMENCLATURE

ECDH	Evaporation Cooling Degree Hours (°C.hr)	PBT	Payback Time (year)
EP	price of electricity	Q_{CL}	Designed capacity of cooling system
FP	price of fuel	RH	Relative Humidity (%)
GH	gross heat rate (kJ/kWh)	TD	Dry Bulb Temperature (°C)
H	Operating Hours (hr)	TW	Wet Bulb Temperature (°C)
Ki	initial investment cost	**Greek Symbols**	
LHV	Lower Heating Value (kJ/kg)	η_{gen}	generator efficiency

1. INTRODUCTION

Fossil fuels are non-renewable energy resources and demand for electricity is increasing. Therefore, it is essential to apply methods to generate electricity with higher efficiency in power plants with fossil fuels. One of the most used and popular power plants in recent years are gas turbines. Operation and design parameters have notable effects on gas turbine performance. Many studies have been carried out in these subjects. However, finding the optimal parameters for the best performance such as the climate conditions which the gas turbine unit is placed in, is still a challenge.

In this regard, numerous types of research, and efforts have been carried out for the promotion of the Brayton cycle, the thermodynamic cycle of gas turbine power

*Corresponding Author Institutional Email: *H.Ghadamian@merc.ac.ir* (H. Ghadamian)

plants. Pre-cooling of the compressor's inlet air is one of the most important and most used methods to increase both the thermal efficiency and the generated power of the gas-turbine cycles. The research of Ibrahim et al. [3] shows that a decrease of 10°C in the compressor inlet air temperature increases the gas turbine output power by 1%.

In higher intake air temperature, because the specific volume of the air increases, higher power will be consumed for the compression [4].

The rated capacity of the gas turbine is defined at ISO conditions (1bar, 15°C, 60% relative humidity). the gas turbine (GT) generated power decreases at the ambient temperature above 15°C, or when the plant is located in a warm/hot area, also cooling the inlet air below 15°C can lead to an enhancement of the gas turbine generated power compared to its rated power [5].

Sue and Chuang [6] reported that the location of the power station played an important role in its performance when the ambient temperature increases, the total power output decreases. Chakartegu et al [7] reported that when the intake temperature increases from 15 to 25°C, the gas turbine will lose approximately 7% of its power. The losses reach 15% of the power rating at 36°C of ambient temperature. Rising ambient temperature by 1°C reduces the output power and efficiency of the gas cycle by 0.6 and 0.18%, respectively [8]

The results of research by Najjar et al. [9] showed considerable positive effect of cooling the air before entering the compressor. This research also showed that at intense weather conditions (temperatures above 45°C and relative humidity more than 80%), applying their proposed inlet air cooling method will reduce the temperature of inlet air about 15°C which leads to an increase in net power generation and overall efficiency 35 and 50%, respectively.

Noroozian and Bidi [10] applied a turbo expander replacng pressure-reducing valve. The shaft of the turboexpander was coupled to the compressor shaft of a mechanical chiller, which was used for cooling the compressor inlet air. Ameri and Hejazi [11] evaluated the effect of applying an absorption chiller for precooling the compressor inlet air on a gas turbine capacity improvement.

Fogging method for inlet air cooling, because of its lower capital cost, is popular and more acceptable compared to other methods. In hot seasons, the demand for power increases. Therefore, it is important to enhance the gas turbine power generation unit for a higher power generation.

The fogging cooling method is used to compensate for the power drop due to high ambient temperature. Heavy mist of fine-water particles which is called "Fog", is sprayed out of some nozzles, typically installed close to the air filters for spraying enough water to allow the air to reach the saturation state [12]. This will reduce the compressor power consumption due to the reduction of inlet air temperature. In addition, it causes greater power generation, higher efficiency and lower specific fuel consumption [13]. The effectiveness of these actions depends on the humidity of the air and the temperature; in general, not only the maximum increase in the dry and warm air, but also provides significant benefits in wet and tropical environments.

Ehyaei et al. [14] studied the effects of the inlet fog system on the performance of combined cycle power plants. Their results showed that the average output power increases by using inlet fogging method. Inlet fogging system has a positive effect on decreasing gas turbine exhaust air pollutions as well. The performance parameters such as compressor inlet temperature, compressor consumed power, gas turbine power output and cycle efficiency, with existing inlet fogging and wet compression process were investigated [15]. Ehyaei et al [16] studied the effect of a fogging cooling system on the performance of a combined cycle power plant by a comprehensive thermodynamic modeling method. They also specify the optimal design parameters. Their research results showed that by applying a fogging cooling system the efficiency will increase by 17.24, 3.6, and 3.5%, respectively, at three warm months of a year.

2. EVAPORATIVE COOLING SYSTEM

Using evaporative cooling methods is one of the easiest ways to increase the gas turbine's generating power. In the first method called the Media method, by increasing the relative humidity, or in other words, passing the air over wet layers, the dry temperature of the air will noticeably decrease due to the water evaporation.

"Relative Humidity" is the percent of moisture that exists in the air to the maximum amount of moisture that can exist in the air in that temperature, i.e. saturation humidity. In contrast, "Absolute Humidity" is the amount of moisture that exists in the air regardless of temperature.

Other evaporative cooling methods are spraying water into the air stream (fog) which is considered as an adiabatic cooling process and the process occurs in a line with stable wet bulb temperature on a psychrometric chart. Using fog system, especially in environments with low relative humidity in which the difference between wet & dry bulb temperature is high, is a good method.

Working principles of evaporative systems are the absorption of evaporation latent heat from the air by water, hence cooling the air. Accordingly, the evaporative cooling system's overall efficiency is defined based on the equation below, considering the temperature difference:

$$\eta = \frac{T_{1D} - T_{2D}}{T_{1D} - T_{2W}} \tag{1}$$

The W and D indexes refer to wet and dry bulb conditions, respectively.

In a fog system, the high-quality de-mineralized water is passed through stainless steel nozzles with ruby orifices. This process is performed by high-pressure pumps in the range of 70 to 160 bar (normally about 140 bar). The water is sprayed into the air stream in the form of little particles with a size of about 100 microns. The reason for spraying water in small particles is to increase the water contact surface with the air resulting in faster water evaporation rate.

Evaporative cooling systems, because of its low initial investment costs and simplicity of installation, are the most economical cooling methods in hot and dry regions [17-18]. De Lucia et al. [19] presented that evaporative inlet air cooling systems in different atmospheric conditions can promote the generated power by 2-4%. Chaker et al. [20] studied the maximum hours that an evaporative cooling system can operate in 122 different locations.

3. ANALYSIS OF CLIMATIC DATA AND ESTIMATION OF INLET COOLING POWER GAIN POTENTIAL

There are many problems and bugs during the analysis of climatic data. Averaging the data leads to some bugs. For example, Figure 1 shows the relation of dry bulb and wet bulb averages with different months at a specific location.

On the graph, linear behavior may lead to the conclusion that at a dry bulb temperature of 25°C the wet bulb is expected to be 20°C, which shows reducing the potential of about 5°C; or, in other words, the evaporative cooling potential. However, this result is completely wrong and erroneous. Since the curve is plotted by considering the mean WB temperature and the average DB temperature and does not show the matched conditions of the WB and DB temperature, it shows a very different cooling potential. These types of errors are usual in such studies. Some researchers also consider the "worst-case" of temperature and humidity in terms of evaporative cooling potential. This action is taken to ensure that the fog equipment will meet the required capacity in the worst-case conditions, but in practice, this situation never occurs, or rarely happens [20]. In addition, McNeilly [21] in his research mentions the necessity of avoiding this error. It should be mentioned that in this analysis the profile of ambient air temperature for a complete year or several consecutive years is considered. ECDH (evaporative cooling degree hour) values can be computed by these data. In this method, inlet fogging power enhancement potential at different periods can be analyzed accurately.

In Table 1 a sample calculation of ECDH for Zanbagh power plant is shown; This plant is located in Yazd province, Iran at an altitude of 1285 meters from sea level. This table provides summary data for six months at ambient temperatures above-defined ISO temperature according to registered climatic data for the last 2 years of the operation of the power plant. The last row indicates the total ECDH (annual °C- hours of cooling potential) Which could be the basis for the evaluation of the use of the Fog and Media cooling system for this gas turbine at the mentioned site.

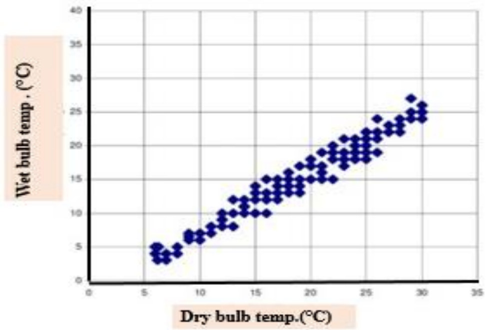

Figure 1. A typical pattern of Correlation of WB and DB temperatures averages in different months [20]

TABLE 1. A sample calculation that computes ECDH for Zanbagh power plant for six months at ambient temperatures above-defined ISO temperature

DB (°C)	Hrs	Avg coincident WB (°C)	Possible Temp. drop	ECDH (°C.Hrs)
52-60	0	27	25	0
50	9	24.8	25.2	226.8
48	20	23.55	24.45	489
46	42	22.55	23.45	984.9
44	96	21.65	22.35	2260.8
42	132	20.62	21.38	2822.16
40	148	19.47	20.53	3038.44
38	161	18.53	19.47	3134.67
36	162	17.43	18.57	3008.34
34	166	16.35	17.65	2929.9
32	164	15.22	16.78	2751.91
30	167	14.12	15.88	2651.96
28	241	13	15	3615
26	203	12	14	2842
24	122	11.65	12.35	1506.7
22	117	11.02	15.98	1284.66
20	96	10.88	9.12	875.52
18	87	10.65	7.35	639.45
16	81	9.6	6.4	518.4
Total ECDH				35550.61

Figure 2 also is a bar chart showing monthly ECDH from another site.

Figure 3 shows a general variation pattern of dry and wet bulb temperatures during a day. It is necessary to note that high relative humidity conditions do not match with high DB temperatures. According to this figure, between 14:00 and 15:30 (afternoon hours), the difference between DB and WB temperature is significant. In this widespread period, applying the FOG system is justifiable. As previously mentioned, the typical fault made by some researchers is designing cooling systems based on the highest relative humidity and the highest temperature which has been given for a month. The problem is that generally the highest RH and highest temperature do not occur simultaneously. It means that generally, the higher RH happens with the lower temperature and vice versa.

3. 1. Fog Inlet Air Cooling in High Humidity Areas

Even at the most humid climates in the warmest part of the day, a considerable decrease in air temperature using evaporative systems has been reported. The temperature of the air affects the amount of moisture that it can keeps. The warmer air can hold more moisture relative to the cooler Air.

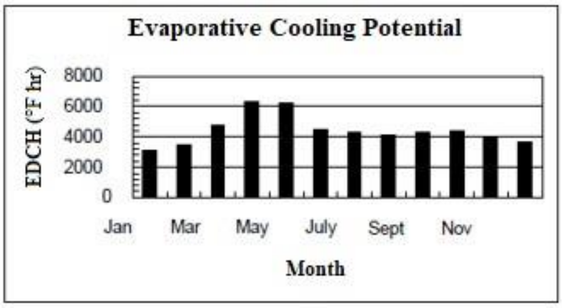

Figure 2. A typical pattern of ECDH in different months for an example site [20]

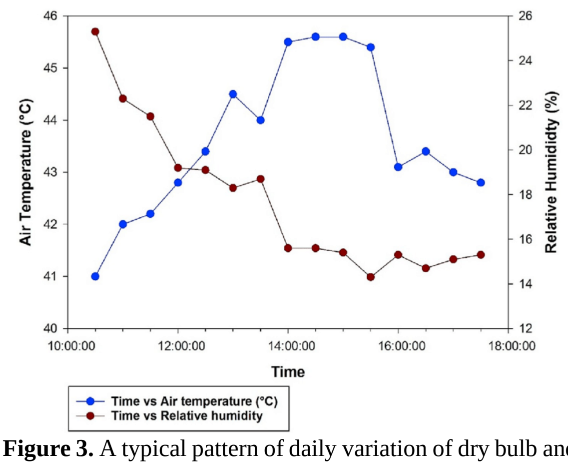

Figure 3. A typical pattern of daily variation of dry bulb and wet bulb temperatures [20]

RH is highest at low air temperature hours in a day(mornings and evenings) and lowest in the times with high air temperature (afternoons).

The fogging cooling systems are inexpensive and easy to install and make a small amount of pressure drop, and are used in humid climates in the summertime.

4. SIMULATION OF A SPECIFIED GAS TURBINE POWER PLANT

4. 1. Technical Details of the Simulated Unit

Gas turbine function matches the Bryton cycle; its main components are compressors, combustion chambers and turbines.

Gas turbine simulation and performance study in this research have been performed on a GEF5 gas unit in the Zanbagh power.

The technical specifications of the gas unit at standard conditions are given in Table 2. In addition, an overview of the unit is shown in Figure 4.

In this research, the GT unit operational data during one year was applied. Air is compressed in a seventeen stage axial compressor.

Ambient dry bulb temperature (Compressor inlet air temperature) of 36°C and an atmospheric pressure of

TABLE 2. Specification of Alstom GE-F5 gas turbines at standard conditions

Rotational Speed	5100	RPM
Inlet temperature	15	°C
Inlet relative humidity	60	%
Pressure ratio	9.7	
Inlet air pressure	101.325	kPa
Intake air flow rate	91.622	m^3/s
Compressor pressure ratio	7.5	
Combustion efficiency	99	%
Specific heat capacity of the air	1.005	kJ/kg K
Specific heat capacity of flue gas	1.15	kJ/kg K
Lower heating value LHV	46670	kJ/kg
Isentropic efficiency of comp.	88.4	%
Isentropic efficiency of the turbine	89.6	%
Air mass flow rate	111.11	kg/s
The adiabatic efficiency of comp.	85	%
Fuel (natural gas)mass flow rate	1.69	kg/s
Mass of exhaust	112.8	kg/s
Flue gas temperature	521.2	(°C)
Flue gas specific heat (CP)	1.1339	
Output power	15.574	MW

Figure4. Overview of the simulated unit

0.86 bar is considered for this simulation. According to the air temperature compared with the standard condition, the operating mass flow rate of the unit was computed.

4. 2. Simulation Software Thermoflow is thermal engineering software for modeling and simulation of the power and cogeneration units. It is a fully flexible software that allows modeling a broad range of mass and heat balances in power plants. Since 1987, Thermoflow has been one of the pioneers in the development of thermal engineering software for industrial plants. GT PRO, the first product of this company, is known worldwide as the most popular program for designing and simulating a gas turbine machine that can predict the performance of the plant as a function of its fixed equipment, control set-points, loads, and ambient conditions.

In this research GT, PRO 21.0 was used to model the gas turbine with and without a fogging system.

4. 3. Simulation Process A simulation in GTPRO software was carried on in order to get a general view of the situation. At first, a GE-F5 gas turbine unit with a simple cycle fueled with natural gas was selected. Then the properties of components were adjusted to fit the model on the real unit. It should be mentioned that the F5 model is not included in the software library, but according to the manufacturers operating manual, this type fits exactly with "General Electric GE 3411N", which is available in the software library.

The simulation of the gas turbine unit with a fogging inlet air cooling systems contains the following assumptions:

-The ambient air contains 23.3% oxygen and 76.7% nitrogen by mass.

-The combination of gas fuel is considered methane.

-The pressure and temperature of natural gas in the feed line are 22.4 bars and 25°C respectively.

-The pressure loss of the combustion chamber is considered to be 3%.

-The mass flow rate of ambient air and its pressure and temperature are considered to be constant. The outputs of the simulation of the investigated gas turbine at basic mode are shown in Figure 5.

- The effectiveness of the fogging system was considered 95%. This parameter represents a decrease in the air temperature to 95% of the difference between the dry and wet temperature of the inlet air.

4. 4. Verification of the Model In order to verify and ensure the modeling, by transferring calibrated measuring equipment to the site, some parameters of the operating unit in several positions accurately measured and compared with the values obtained from the model.

Table 3 shows the comparison of some measured values in the site with values obtained from the model at different hours of a day. Exhaust temperature, Compressor discharge temperature and Fuel consumption of the unit were considered for validation.

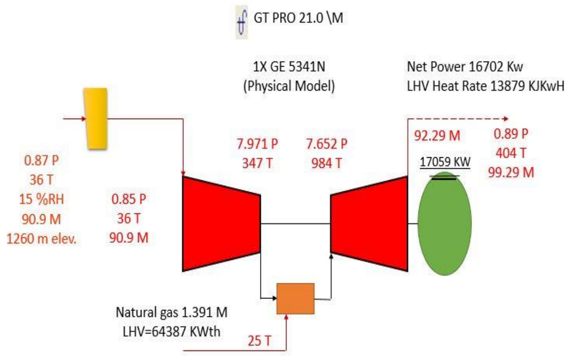

Figure 5. Simulation outputs of the investigated gas turbine at basic mode

TABLE 3. Comparison of some measured values with values obtained from the model

Deviation (%)	Model	Site	Time	
1.76	760.3	747.1	10:00	**Exhaust temperature**
1.30	757.8	748.1	12:00	
0.18	750.4	749.1	13:30	
1.50	737.9	749.1	15:00	
0.066	570.3	574.1	10:00	**Comp. discharge temperature**
0.29	576.5	578.1	12:00	
0.32	581.0	579.1	13:30	
0.39	578.9	581.1	15:00	
1.40	6510.7	6603.0	10:00	**Fuel consumption**
0.41	6481.2	6508.0	12:00	
1.09	6349.0	6419.0	13:30	
1.86	6205.9	6323.5	15:00	

According to these results, the model created in the software is highly consistent with the actual behavior of the unit. Therefore, the Fog system for cooling the incoming air according to calculated ECDH values was implemented on the model to evaluate its impact on unit performance.

Figure 7 shows the modeling of an investigated gas turbine by applying a fogging system at one of the ECDH value.

Several simulations for the different values of ECDH which are presented in Table 1 were done and the outputs of each stage are included in the final calculations.

4. 5. Results of Simulation The of the gas turbine performance simulation was done by GT PRO 21.0 software. Table 4 shows the output of the simulation. A sensitive analysis is required to show the influence of inlet temperature variations on the net power output, thermal efficiency, specific fuel consumption and heat-rate. This is done by using Thermoflow software.

Table 4 shows the results of simulations for comparison of the unit performance with and without the fogging system at a certain climate condition. According to the results, the gas turbine with a fogging system performs better than the gas turbine without a fogging system. The results show that by applying the fogging system, a drop occurs in the temperature system readings. the temperature drop in the exhaust is a confirmation for the cooling inside the system.

The results showed that by applying a fogging system, the thermal efficiency of the gas turbine system will increase as a result of a decrease in intake air temperature. The net power of the cycle also will increase because of decreasing the compressor consuming power and increasing the mass flow rate of gases that hit the turbine blades. According to the results of the model, applying fog system in the above-mentioned conditions will lead to increasing the power generation and cycle efficiency by 8 and 0.6%, respectively.

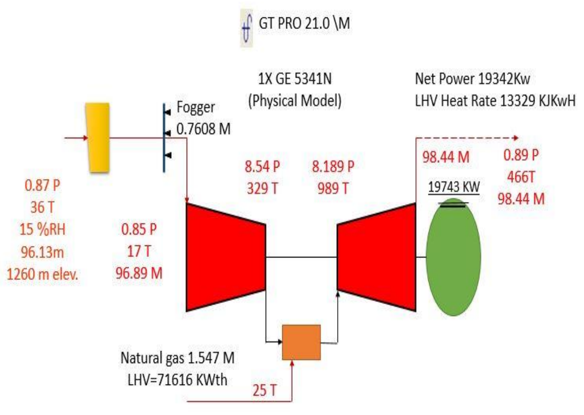

Figure 7. Output results of simulation with a fog system

The Specific fuel consumption of the cycle by using the fog system is lower than specific fuel consumption in the base cycle. Therefore, the use of the fog system, in addition to reducing energy consumption, will also reduce environmental pollutants. By examining the model in all of the ECDH values in Table 1, the overall increase in the power production of the gas turbine cycle using fog system will be about 35550.61 kilowatt-hours per year. This value is more accurate to be considered for designing, Economic analysis or to determine the cooling system capacity in comparison with considering average data or the worst scenario.

5. FINDING CRITICAL RELATIVE HUMIDITY

For finding critical relative humidity, the economic analysis and especially the payback period should be considered.

5. 1. Economic Analysis In economic considerations of fog system the capital costs, current costs, earnings due to using this system, interest rate, etc. should be considered .

a) Electricity production enhancement The net increase in net production is obtained from the following equation:

$$\Delta W=\Delta W_C+ \Delta W_{gt} -\Delta W_l - \Delta W_f \quad (2)$$

By applying the fog cooling system, the changes in power output include:

1) the net power output of the cycle increases since by reducing compressor inlet air temperature its power consumption decreases (ΔW_c);

2) the generated power of gas turbine increase since air density rises as Ti,c declines (ΔW_{gt});

3) because of installing cooling systems in the passage of inlet air, the pressure of inlet airdrops and as a result of the generated power decreases (ΔW_l);

4) all kinds of evaporative cooling system have some subsidiary installations which have energy usage (W_f).

The extra income which will be gained through applying the fog cooling system, is

$$I_{ext} = \Delta W.\, \eta_{gen}.\, EP \quad (3)$$

where EP is the price of electricity and η_{gen} is generator efficiency.

b) Extra fuel consumption By applying the fog system, the entering air mass flow increases, and as a result, the fuel consumption will be raised. This extra fuel consumptions of unit (ΔF, kg/s) can be calculated by:

$$\Delta F=(W_e.GH_e- W_0.GH_0)/(3.6LHV) \quad (4)$$

GH in this relation is the gross heat rate. Also, the Subscript e shows the values for the gas power plant with a fogging system and subscript 0 refers to the unit lacking a fogging system.

c) Initial investment cost The considered capacity for the evaporative cooling system has a major impact on the needed capital cost. The amount of initial investment can be calculated from the following equation.

$$I=ki \cdot Q_{CL} \quad (5)$$

In the above equation, Q_{CL} refers to the evaporative cooling system considered capacity, and ki shows the capital cost for a unit of cooling load.

5. 2. Finding Critical Relative Humidity for an Expected Payback Period The annual net profit by applying the fog system includes the following items :

- The obtained income from sales of extra generated power,
- The yearly fee for maintenance and repair of the fogging system and additional fuel consumption.

$$S=(\Delta w.\eta_{gen}.EP- \Delta F.\ FP).H-MC \quad (6)$$

which EP is the price of a Kilowatt-hour of generated power, H shows the number of working hours and FP is the price of a cubic meter of natural gas.

To gain a profit (S>0), the Extra income should be greater than the sum of the mentioned cost.

MC is the annual maintenance and operation costs of the system and ηgen is the generator efficiency.

$$PB=I/S \quad (7)$$

Several factors affect critical relative humidity, including: designed specifications of the power plant, ambient condition, power purchase price, Predicted PBT and the price of natural gas. Figure 8 shows the critical RH calculation steps for a Predicted PBT.

5. 3. Variation of Critical RH with Ambient Temperature, Electric Price, and PBT If RH in the gas unit location is less than the critical RH, then the real payback time is shorter than Predicted PB and vice versa. In order to evaluate the installation of an evaporative cooling system on a gas unit, the mean values of critical RH are considered.

In Figure 9, the values of critical RH at several PBT and yearly mean temperature can be observed. To find the average annual temperature, we consider the average temperature of five warmest months of the year from May to September.

As is evident in a shorter time of PBT, the values of critical RH are also smaller. Obviously, this is if the annual average temperature is assumed to be constant. Because there is a higher difference between WB and DB temperature in a lower RH, considerable temperature drops and more generated power is possible which leads to more yearly income and shorter PBT. In addition, for a longer payback period, the critical RH for different annual temperature gradually approach each other. The reason is that by increasing RH to a high level, the effect of cooling and temperature drop decreases and the behavior of the system at different temperatures will be roughly the same.

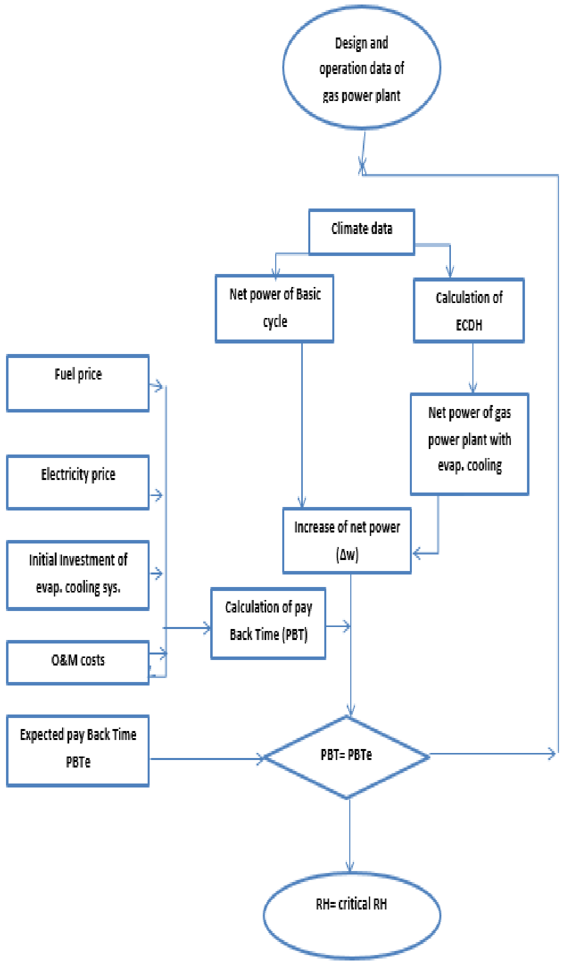

Figure 8. Flow chart for finding critical RH

The sensitivity analysis of critical RH shows that critical RH is affected by PBT and electricity price, which is shown in Figure 10.

According to the chart, for the specified PBT, at the lower electricity price, the critical RH should be lower in order to cause greater power enhancement. By greater power enhancement, the total increase in the income is equal to the case with higher electricity prices and higher critical RH. Also for a specified electricity price, at the shorter PBT, the critical RH is lower, and as a result, the reduction in temperature and power enhancement is greater. This result is also evident, when the values of power price increase, the values of critical RH also increase for the same amount of payback time. Therefore, as the electricity price increases, the critical RH for the same PBT is higher. For example, for PBT of 3 years, the critical RH for electricity price of 0.07 $/kWh is 21 and is 41% for electricity price of 0.12 $/kWh.

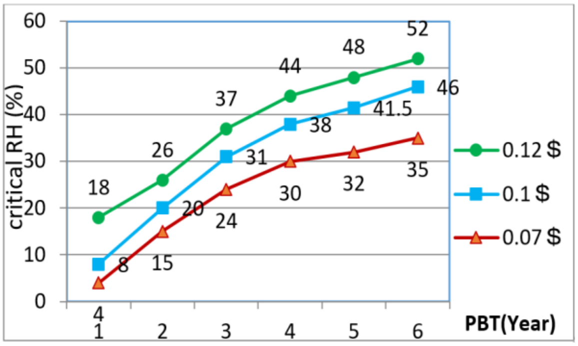

Figure10. Critical RH variation with electricity price in Iran and PBT

6. CONCLUSION

Using the mean values of WB and DB for evaluation of the cooling capability of an evaporative system leads to incorrect estimation, because the Minimum and maximum values of WB and DB do not coincide simultaneously. In addition, we have considered the "worst-case" of temperature and humidity in terms of evaporative cooling potential. In practice, this never occurs or it rarely happens. In the analysis, the profile of ambient air temperature for a complete year or several consecutive years is considered. ECDH values can be generated employing these data and accordingly, accurate and detailed analysis of inlet fogging power gain potential at different periods can be done.

By examining the model in all of the ECDH values in Table 1, the overall increase in the power production of the GEF5 gas turbine by applying fog system will be about 35550 kilowatt-hours per year. This value is more accurate for designing economic analysis or for determining the cooling system capacity in comparison with average data or the worst-case scenario. In addition, the simulation of the GEF5 gas turbine showed that by using the fog system, at the same time, the efficiency increases, the compressor power consumption, and heat-rate decreases .

As mentioned earlier, several factors affect critical RH, such as designed specifications of the power plant, ambient condition, power purchase price, Predicted PBT and the price of natural gas. A review of critical RH under different climate conditions illustrated that for a shorter expected PBT the less value of critical RH will be obtained at a specific yearly average temperature.

According to the critical RH sensitivity analysis results, if the PBT is considered to be fixed for higher power purchase price higher value of critical RH will be achieved. That means the value of critical RH depends on the power purchase price and considered PBT.

7. ACKNOWLEDGMENT

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Persian Abstract

چکیده

میزان راندمان و توان خروجی توربین‌های گاز با تغییر شرایط محیط متغیر است. این تغییرات به‌شدت بر میزان تولید برق، مصرف سوخت، انتشار آلاینده‌ها و درآمد نیروگاه تاثیر می‌گذارد. با این حال، خنک کردن هوای ورودی کمپرسور توربین‌های گاز به طور گسترده‌ای برای جبران این معایب مورد استفاده واقع شده است. در این مقاله، با شبیه‌سازی یک واحد گازی مشخص در نرم‌افزار Thermoflow، اثر سیستم خنک‌کاری فاگ بر روی آن مورد بررسی و تحلیل قرار گرفته است. با توجه این که در اکثر تحلیل‌های موجود، میانگین مقادیر دمای خشک و دمای مرطوب، یا در برخی موارد بدترین حالت از نظر دمایی و رطوبتی مبنای تعیین ظرفیت سیستم‌های خنک‌کن قرار می‌گیرد و این موضوع سبب خطا و انحراف در محاسبات می‌گردد، استفاده از ECDH یا درجه–ساعت خنک‌کاری تبخیری به جای شرایط قبلی توصیه می‌گردد. با محاسبه‌ی ECDH در دماهای محیط بالاتر از ۱۵ درجه‌ی سانتیگراد و تغییر شرایط مدل، کل میزان افزایش تولید واحد با بکارگیری سیستم خنک‌کاری فاگ معادل ۴/۷×۱۰⁶ کیلووات ساعت تخمین زده شد. همچنین تاثیر رطوبت نسبی بر مدت بازگشت سرمایه طرح‌های خنک‌کاری مورد بررسی قرار گرفته است که مشخص گردید رطوبت نسبی بحرانی برای یک واحد گازی به قیمت سوخت، قیمت خرید برق، پارامترهای طراحی واحد و مدت بازگشت سرمایه پیش‌بینی شده بستگی خواهد داشت. رطوبت نسبی بحرانی برای واحد گازی مورد مطالعه، بر اساس زمان بازگشت سرمایه پیش‌بینی شده و قیمت خرید برق فعلی مورد بررسی قرار گرفته است. نتایج نشان می‌دهد که برای یک قیمت خرید برق مشخص، با کاهش زمان بازگشت سرمایه مورد انتظار، رطوبت نسبی بحرانی، پایین‌تر است. بنابراین میزان کاهش دما و افزایش قدرت، در نتیجه به‌کارگیری سیستم‌های خنک‌کن بیشتر خواهد بود. همچنین در یک مدت بازگشت سرمایه مشخص، با افزایش قیمت برق، رطوبت نسبی بحرانی برای همان مدت بازگشت سرمایه بالاتر خواهد بود.