Thermo-Economic Analysis of Absorption Chiller Integrated with a GE-F5 for Power Enhancement

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The efficiency and output power of gas turbine power plants are heavily affected by ambient air temperature and will strictly decrease by increasing the air temperature. In this paper, the effect of applying an absorption chiller by recovering waste heat from gas turbine flue gas has been investigated. For this purpose, the behavior of a GE-F5 gas turbine was modeled by coding in MATLAB software. According to full-scale monitor and measurement, the results show that by decreasing the inlet temperature to near dew point temperature, the output power would increase about 3.135 MW, which is considerable amount in comparison with the power capacity equals 25 MW. Also, application of chiller system on a GEF5 gas unit in Yazd Zanbagh power plant was analyzed economically. The payback period for the project was obtained to be estimated 11 years, whereas no subsiding considerations, the payback time would be shorter nearby 45% at all. By considering social cost of carbon, payback period decreases to 7 years and 6 months.

Keywords: Off-design analysis; Inlet air cooling; Net Present Value; Overall efficiency; Fuel subsidizing.

1 Introduction

Gas turbine power plants are widely used for electricity production in many countries around the world because of their low capital cost, short synchronization time (required time for a gas turbine to reach the base load from zero speed is about 30 minutes), flexibility with regard to the electricity grid variations and availability in many countries. On hot climate during summer days, the ambient air temperature exceeds 45ºC, and the gas turbine power output decreases significantly by the rated capacity, whereas the electricity demand increases to maximum value due to applying air conditioning and ventilation systems [1].

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Therefore it is necessary to enhance the achievable gas turbine power output by different methods. But cooling the inlet air usually is the simplest way. By these means, there are two inlet air cooling technologies named evaporative cooling method and chiller cooling method (electrical or absorption) [2]. Low humidity climates are so proper for applying purpose of evaporative cooling technology. This consideration must be taken into account that the maximum relative humidity, which is achievable by an evaporative system, whereas the value is nearly 90%. But in humid regions or at some arid area where the water is scarce, chiller cooling system may be applied. In this cycle, chilled water is pumped through an air-water heat exchanger located at the gas turbine inlet duct to cool the incoming air at the compressor entrance. Although the chiller system has the advantage of being able to reduce the air temperature to the value of 5ºC, it has very high initial cost [3].

In the research that done by Mousafarash and Ameri [4], energy, exergy and exergo-economic were analyzed for Montazer Ghaem gas turbine power plant of Tehran in Iran. Based on the outputs, in order to the occurrence of the large temperature difference in the combustion chamber resulting irreversibility, this section has the highest exergy destruction. Furthermore, the net power output reduces due to performance dependence of gas turbine on ambient temperature.

A comprehensive investigation of the media system and fog system was carried out by Amer et al. [5] to compare these systems by the technical and economic point of view. According to results of the performance test, the mean output power of F9 gas turbine was improved by 11 MW (14.5%) due to apply media system and 8.1 (8.9%) MW and 9.5 MW (11%) due to apply fog system in two different units in different locations. Also, an economical study was done and concluded the estimated payback period is between 2~3 years for fog and media systems. However, their research results compare to previously done researches seems too interesting.

Barzegar Avval et al. [6] performed multi-objective optimization considering the exergetic, economic and environmental aspects to find the best design variables. They also performed a sensitivity analysis in this regards. Based on the results, at the lower exergetic efficiency in which the weight of thermo-environment objective is higher, the sensitivity of the optimal solution to the fuel cost is much higher than the location of Pareto Frontier with the lower weight of thermo-environment objective.

An exergy, economic and environment analysis on a 4900 kW absorption chiller integrated with a 159 MW gas turbine unit located at Bushehr-Iran shows that the gas turbine's power during the hottest month (August) by cooling the inlet air in the range of 37ºC to 15ºC increases simultaneously 137 MW to 153 MW and its efficiency rises from 33.4% to 43.2% [7].

E. Kakaras et al. [8] investigated the possibilities and advantages of applying an absorption air cooling system to reduce the gas turbine intake air temperature. They concluded that at any climate conditions, the net output power could increase by at least 10% regards to this cooling method application.

M. Ameri and S.H. Hejazi [9] presented an intake air-cooling system by using an absorption chiller in the Chabahar power plant. They obtained that, by applying this technique, the output power will 11.3% increase.

In another study, E. Kakaras et al. [10] investigated the behavior of the absorption chiller technology for the purpose of reducing the intake air temperature in simple gas turbine and a combined cycle power plants in assistance with software simulation. The results show that applying chiller air cooling system has higher gain in power output and efficiency than evaporative cooling contributed to a simple gas turbine, independent of ambient air temperature. The results for the Intended combined cycle also demonstrated that the absorption chiller could considerably increase the power output, oppose to an efficiency reduction.

B. Dawoud et al. [11] evaluated the effect of several inlet air cooling techniques on numbers of gas turbine power plants in Oman and found that The LiBr-H_2O cooling system offers 40% and 55% more output energy than fogging method at Fahud and Marmul, respectively.

In this research, the behavior of a Frame-5 Alstom gas turbine which is located in Yazd Zanbagh power plant was modeled by coding in open-source-code Matlab software. A complementary measurement was carried out to validate the code and simulation, the effect of chiller cooling system has been investigated, and the economic analysis was done. Both the [9] and [12] references, the used calculation as same as this research and contain economical calculation and the raised yearly power production. Despite the mentioned references, the calculation in this article is based on GEF5 units and a Matlab development code, which was validated by the measurement process.

2 The specification of the GE-F5 gas unit

The case study unit is an Alstom GE-F5 gas turbine with the nominal capacity of 25 MW which is single shaft, hot end drive and has been operating for 30 years; but partly renewed in (2009). The current operational capacity of this unit is about 19 MW. This unit along with other three similar units of Zanbagh power plant is located at the entrance of Yazd city, At 31.9318° of North latitude and 54.3184° of East longitude. The units' specifications and characteristics in the standard condition are given in Table (1).

In Iran most of the power plants are in operations nearby 30 years old and upper, e.g., Zanbagh power plant, Kahnooj power plant and Kish power plant, same as mentioned. In the recent years by delivery the small size power plants to the private sector as a new investor of operations, the operational lifetime of the units is increased. Even though the service life of installed equipment is 10~20 years, it can be utilized for more decades, as same as the gas turbine unit. Also, the limitation of power producing in 4 months of the year for gas turbine units with less than 100MW nominal power production by Tavanir, makes using chiller cooling method reasonable.

In effect of compressing air in a seventeen stage axial compressor and according to the measured values in the site, the pressure and temperature of the air will increase to 6.46 bars and 310°C respectively at the compressor discharge.

3 The identification of the chiller system and ambient air psychrometric properties

In the chiller cooling system, the outgoing chilled water leaving the chiller is circulated into a heat exchanger which is embedded in the compressor's inlet duct. Since the sensible heat of incoming air is transferred to the chilled water, the temperature of compressor inlet air is reduced, while the relative humidity is continuously increased near to the dew point.

The usual cooling method such as "Fog" and "Media" require less capital investment, however, their running costs are relatively equal. But massive water scarcity in Yazd city plus the uncertainty of sustainable operation considering lack of provided water makes utilizing evaporative cooling system unjustifiable whereas chiller cooling systems are justifiable for instance. Another reason that makes applicable chiller cooling system is the more temperature difference in comparison to other methods, which causes more performance improvement in small gas turbine units. Also Because of high ambient temperature in summer (Near to 40 °C), utilizing evaporative cooling systems require rising amount of water, and this is in contrast with water scarcity.

In gas turbine units, in the compressing stage, the temperature of air passing through compressor rises about 200 °C and in the two first stages of compressor, the temperature rises about 20°C, so the liquid particle will not be formed. Also in the GEF5 type, it is prevented by coating the blades of the beginning stages of the compressor in order to utilize "overspray fogging" systems.

Table 1 Specification of GE-F5 gas turbines at standard conditions

Manufacturer	Alstom
Model	F5GE5341
Rotational speed (RPM)	5100
Inlet temperature (°C)	15
Inlet relative humidity (%)	60
inlet pressure (kPa)	101.325
Air flow rate (m^3/s)	91.622
Compressor pressure ratio	7.5
Air mass flow rate (kg/s)	111.11
The adiabatic efficiency of comp. (%)	85

In this research, the capacity of the absorption chiller was considered, so that the temperature of air after cooling coil cools down to 3ºC more than ambient air dew point temperature (5.33ºC) to protect compressor blades by erosion damage which is due to condensed air humidity. For designing the absorption chiller system, the average temperature of 36°C was considered for compressor inlet air temperature at summer season according to the Yazd city climate conditions. Also, the site air pressure is 0.86 bar.
The amount of unit mass flow rate in designing conditions is 111.11 kg/s. But at the off-design condition, based on the producer's document and ambient dry temperature, the correction factor of 85 % should be considered for the purpose of calculating the flow. Whereas at investigated conditions, the input air's mass flow is 94.45 kg/s. As a conceptual notification of Zanbagh gas turbines, those are rotary machines with constant volumetric flow rate at constant RPM and only their mass flow rate changes in various ambient conditions. The changes in psychrometric conditions of inlet air due to applying of the chiller cooling system from ambient air conditions (the starting point) to the end (before it reaches the dew point) is demonstrated in Figure (1).
The air conditions at points 1 and 2 are also calculated by PsychroCalc-software, and the results are presented in Table (2).

4 Analysis

4.1 Calculation of the required cooling load for cooling the inlet air of G11 gas unit

In this paper for cooling the inlet air which enters gas turbine compressor, a double-effect Lithium bromide absorption chiller was considered. The required cooling load is the amount of heat energy that must be absorbed by the incoming air faced with the chilled water coils to reduce the air temperature to a bit more than dew point temperature level.
The amount of heat energy which should be absorbed through cooling coils located in the compressor inlet duct was calculated using the equation (1), where Q_{1-2} is cooling load $\dot{M_{air}}$ is compressor's inlet mass flow rate and h_1 and h_3 are Enthalpy per unit mass of air end of pass through cooling coil and Enthalpy per unit mass of dry air at ambient conditions respectively.

$$Q_{1-2} = \dot{M_{air}} \times (h_1 - h_3) \tag{1}$$

Finishing calculating the cooling load in kW to achieve the cooling load regarding tons of refrigeration (TR), the equation (2) was applied.

$$\text{TR} = \frac{Q_{1-2}}{3.5167} \tag{2}$$

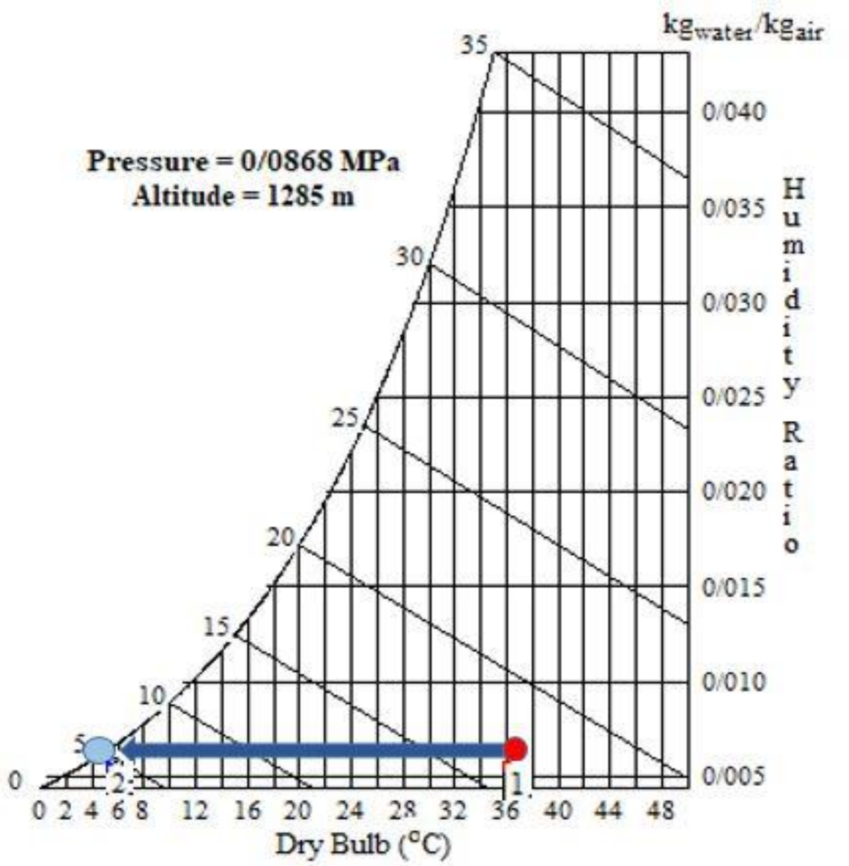

Figure 1 Psychrometric conditions in the cooling process

Table 2 Ambient air psychometric parameters

Parameter	**Location**	
	1	**2**
Dry bulb temperature (°C)	36.0	5.0
Wet bulb temperature (°C)	17.1	5.0
Dew point (°C)	5.09	5.0
Relative humidity (%)	14.75	100
Enthalpy ($kJ.kg^{-1}$)	52.46	20.86
Humidity ratio ($kg_{water}/kg_{dry\ Air}$)	0.0063	0.0063
Vapor pressure (kPa)	0.000129	0.00087
Degree of saturation (%)	13.88	100
Specific volume ($m^3.kg^{-1}$)	1.033	0.929

By substituting values, required cooling capacity was equivalent to 654.25 TR. Based on the data in the products documents of a local factory and available capacity for chillers for required cooling load a 700-ton chiller is a proper capacity to be installed.

4.2 Off-design analysis

In order to predict gas turbine behavior at off-design conditions, an off-design analysis process is considered. The algorithm with a full code development consists of three nested loops, each of them are integrated into corrections side to contributed assumptions value (TIT, compressor pressure ratio and compressor’s input mass flow rate) [13]. To verify this developed code, some precise and calibrated measuring equipment was applied to measure the required parameters of working unit and also peripheral conditions. As a finding, obtained results validated the high accuracy of this code.

As an advantage of this research, the calculations of this paper are firstly made on real and operative GEF5 units, and secondly, the unit parameters are obtained through coding in MATLAB software, whereas the codes are validated with the detailed measurement performances.

4.3 Implementation of chiller cooling system over the new proposed model

To analyze the effects of chiller cooling method in a conceptual study at any peripheral conditions, considering temperature and humidity and the altitude of the units' location, the behavior of the cooling system is determined and investigated on psychometrics chart.

In the chiller cooling system, as shown earlier, the air properties changes by initial dry bulb temperature at constant humidity ratio to 100% relative humidity on the psychometric chart and then the temperature decreases at saturation state to a temperature of 5°C. To calculate the increase in gas unit production rate due to the application of chiller system the above-mentioned situation was implemented on the new simulated model. The output results of the software by applying chiller systems are shown in Table (3).
The calculations are based on the psychometric chart and the assumptions are same as the assumptions in "Thermoflow" software, which is an ordinary & industrial software for simulation of gas turbine units. It should be mentioned that the percent error, because of the air condition which is close to ideal condition, is negligible in the calculations of compressor and inlet air cooling approach. Although these errors are notable in post-combustion sections, those would be corrected by experimental-calculation correction factors.

4.4 Increase in gas unit production rate and its fuel consumption

Regarding the Yazd city climate, the hot season period which the chiller system applied is about five months (mid of May to mid of October) plus 8 hours daily operation (10:00 AM to 18:00 PM). Based on the code results, the amount of power increase due application of chiller system is 3,135 kW.

Figure 2 Case study power plant

Accordingly, the total surplus electrical energy that is produced in mentioned period is calculated as follows:

$$\text{Surplus produced power} = (\text{Increased power}) \times (\text{working hours in a day}) \times (\text{days of a month}) \times (\text{No. of the month}) = 3135 \times 8 \times 31 \times 5 = 3887400\ \text{kWh} \tag{3}$$

The attendance of chiller system, based on modeling results, cause an increase in fuel consumption due to the power increase, which is 0.136 kg/s per unit.

4.5 Calculation of wasted energy by G11 unit's exhaust

In this analysis, the wasted energy by the G11 unit exhaust was calculated and then observing the dew point temperature and other constraints, the amount of recoverable energy was calculated. The results are shown in Table (5).

5 Economic analysis of chiller system

The basis of most design consideration is economic. The system must also be economical and show an adequate return on investment. In economic considerations of chiller system the capital costs, current costs, earnings due to the application of this system, interest rate and etc. should be considered.

Table 3 Output results in two modes

Parameter	Base mode	By chiller
Net output power (kW)	15493	18628
Efficiency (%)	22.38	24.63
Comp. power consumption (kW)	27231	24477
Fuel consumption (kg/s)	1.469	1.605

Table 4 Applied technical parameters of the studied case

Parameter	Amount
Ambient Temperature (°C)	35.1
Fuel Consumption (kg/s)	1.472
Flue Gas Temperature (°C)	521.2
Flue Gas Specific Heat (C_P)	1.1339
Power Output (MW)	15.574
Efficiency Cycle (%)	22.45

Table 5 Results of the calculated annual losses of energy and annual recoverable energy by the exhaust unit

Parameter	Amount
Ratio of losses to the total energy input (%)	61.63
Annual operating hours (hr/year)	1240
Annual losses of exhaust gasses (GJ/year)	118765.6
Equivalent wasted natural gas per year (m^3/year)	298409.8
The annual amount of recoverable energy from exhaust (GJ/year)	67323.0
equivalent barrels of crude oil for recoverable energy per year (BBL/year)	11485.6

5.1 Costs

Costs of the scenario consist of capital cost and current costs. Capital cost includes designing, Purchasing, Installation & initiating the chiller system (Including purchasing and installation of one 700 ton steam absorption chiller and its accessories, Preparation of inlet air cooling coils, chilled water and cooling tower piping network, Purchase and installation of the heat recovery boiler, Preparation of valves and fittings, electrical equipment, control systems, pumps, insulators, Required construction and foundation for cooling coils, Related installation, commissioning and delivery of all equipment).Based on the inquiries conducted by some domestic companies (Local active companies) the total capital cost for implementation of the chiller system is 440,000 USD. Current costs are consist of: 1. the extra fuel cost due to the power increase, 2. consumed electricity cost and the cost of repairs, 3. maintenance & utilization. There is also a current cost because of production halting the damage. Installing the chiller equipment on a unit takes about 40 days, but most of the installation activities can be done without stopping the gas turbine power plant. Therefore it is planned in one of the maintenance exits, and there won't be any need to stop the production. Hence, no costs will be considered in this part.Based on simulation results, since the gas fuel density is 8.45 kg/m^3 at available working pressure, the increase in fuel consumption during an operation period (5 months) equals to 71846.627 m^3. Considering the local fuel price of 1.92 USD Cents per cubic meter of consumed gas, the extra cost fuel due to power increase in a period is 1,379 USD.

The cost of repairs, maintenance & utilization, contains repairs & maintenance of chiller complex, boiler & cooling coil, fixing the leaks & possible replacement of defective parts. The chiller system utilization is automatic & it doesn't require a resident technician. This cost equals 6% of capital cost; according to obtained data from the similar projects. [12] The chiller system's consumed electricity is related to the pumps & compressor. Regarding the required cooling capacity & experimental data in similar power plants, the consumed power of the system is 13 kW. So the amount of consumed electricity in a period is 15600 kWh and the consumed electricity cost for the mentioned period (calculating 1.17 USD Cent/kWh) is 183 USD.

5.2 Incomes

Excess electricity produced by using chiller system occurs in peak hours & the selling price of each kWh electricity in peak hours is 1.17 USD Cent. So the earning made for the unit in a period of utilization is 45,483 USD.

5.3 Payback period calculation

The Payback period is the time required to recover the cost of an investment. To calculate the payback period the net present value method was applied which is one of the standard methods for the purpose of analyzing the economic plans. In this method, the cash flow (earnings & costs) based on the occurrence time (earning or costs) will be converted to the current rate, so in the cash flow, the time value of cost & income are considered. The capital cost is 440,000 USD and in each period the total costs are 1,562 USD and the earnings of each period is 45,483 USD. The annual interest rate is considered 15% (including all of product annual inflation rate, interest rate & risk rate), the annual increase in energy price is considered 13% and the life of the equipment was considered ten years. The calculation results are presented in Table (6). The last row of the last column in the Table (6) is the net present value of the project and the calculations show that the project is not cost-effective and economic. Based on the above results, the payback period of this system is more than 11 years, which seems no interest to be considered.

6 Environmental aspects

Sustainable development approach would be admired when the efficiency improving methods in power generation systems can lead to the reduction of environmental pollution. Adding the absorption air cooling system to the investigated gas turbine will result in a reduction in carbon emissions as a benefit of the system. Changes in pollutants values are presented in following descriptions. It should be mentioned that environmental solutions are mid-term and long-term solutions. In the recent years in Yazd, because of rising numbers of tile factories and steel factories and their environmental problems, and also the location of the studied power plant (which is near to the residential areas), the environment is one of the most important priorities.

In the normal operating condition of the unit, a complete measurement including combustion gas analysis was done that gained results value are presented in the Table (7). The above values were measured at the normal production with normal condition of the unit when the power production was about 15.5 MW. With 18.628 MW power generation in the gas unit, change of CO_2 emission rate base on inlet air temperature is shown in Figure (3). The Social Cost of Carbon (SCC), also known as the shadow price of carbon, is the estimated future economic loss caused by emitting one metric ton of carbon today.

Table 6 NPV calculation

Year	Cash flow	Present value (10^3×USD)	Cumulative present value (10^3×USD)
Current year	$\frac{-440}{(1+0.15)^0}$	-440	-440
1st year	$\frac{(45.483-1.562)\times(1+0.13)^1}{(1+0.15)^1}$	43.16	-396.84
2nd year	$\frac{43.921\times(1+0.13)^2}{(1+0.15)^2}$	42.41	-354.43
3rd year	$\frac{43.921\times(1+0.13)^3}{(1+0.15)^4}$	41.67	-312.76
4th year	$\frac{43.921\times(1+0.13)^4}{(1+0.15)^4}$	40.94	-271.82
5th year	$\frac{43.921\times(1+0.13)^5}{(1+0.15)^5}$	40.23	-231.59
6th year	$\frac{43.921\times(1+0.13)^6}{(1+0.15)^6}$	39.53	-192.06
7th year	$\frac{43.921\times(1+0.13)^7}{(1+0.15)^7}$	38.85	-153.21
8th year	$\frac{43.921\times(1+0.13)^8}{(1+0.15)^8}$	38.17	-115.04
9th year	$\frac{43.921\times(1+0.13)^9}{(1+0.15)^9}$	37.51	-77.53
10th year	$\frac{43.921\times(1+0.13)^{10}}{(1+0.15)^{10}}$	36.85	-40.68
11th year	$\frac{43.921\times(1+0.13)^{11}}{(1+0.15)^{11}}$	36.21	-4.47
12th year	$\frac{43.921\times(1+0.13)^{12}}{(1+0.15)^{12}}$	35.58	+31.11

In this context, “carbon” is an abbreviation of carbon dioxide (CO_2), the most important greenhouse gas. Economists calculate SCC by assigning a monetary value to all of the harms that are predicted to arise in the future from emitting one metric ton of carbon. Based on US government study in (2015), the social cost of carbon is 37 USD per ton of CO_2.
The fuel of gas turbines is natural gas. The natural gas in the area is consist of 85% methane and 12% ethane with 3% of others. For simplification, we consider that natural gas is consist of 86% methane and 14% ethane, it is because of normally available codes of combustion equation of ethane and methane, hence, 1.14 kmol CO_2 is produced by burning 1 kmol natural gas.

The contributed equations are in following:

$$86\ CH_4 + 2 \times 86\ O_2 \rightarrow 86\ CO_2 + 2 \times 86\ H_2O \quad (4)$$

$$14\ C_2H_6 + 3.5 \times 14\ O_2 \rightarrow 2 \times 14\ CO_2 + 3 \times 14\ H_2O \quad (5)$$

Table 7 Combustion gas analysis results in exhaust gas

Measured parameter	Unit	First time at 12:30	Second time at 13:30	Third time at 15:00
Flue gas temperature	°F	730	944	951.1
O_2	%	18	18.35	18.61
CO_2	%	1.5	1.47	1.30
CO	ppm	2	4	0
NOx	ppm	Miss Measurement	44	47
SO_2	ppm	Miss Measurement	2	14
Combustion Efficiency	%	Miss Measurement	16.8	20.7
Excess air	%	Miss Measurement	548.1	648.2

Table 8 Natural gas consumption (measured values)

Time	Ambient air temperature	Natural gas consumption (measured) (Nm^3/hr)
9:00	31.6	6668.14
10:00	32.5	6603.05
11:00	35.9	6651
12:00	37.0	6508.03
13:30	37.0	6419.04
15:00	37.3	6323.54

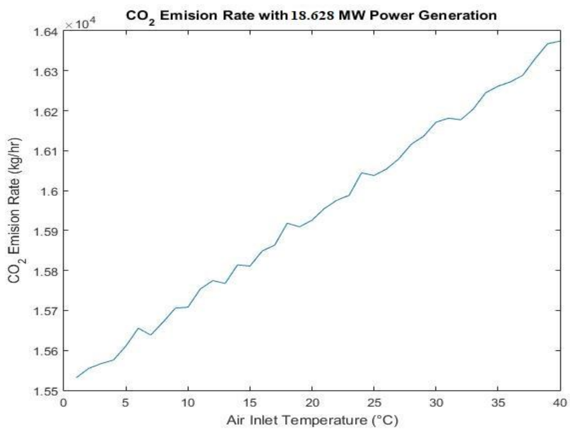

Figure 3 CO_2 emission rate with 18.628 power generation

Table 9 NPV calculation

Year	Cash flow	Present value (10^3×USD)	Cumulative present value (10^3×USD)
Current year	$\frac{-440}{(1+0.15)^0}$	-440	-440
1st year	$\frac{(45.483+19.229-1.562)\times(1+0.13)^1}{(1+0.15)^1}$	62.05	-377.95
2nd year	$\frac{63.150\times(1+0.13)^2}{(1+0.15)^2}$	60.97	-316.98
3rd year	$\frac{63.150\times(1+0.13)^3}{(1+0.15)^4}$	59.91	-257.07
4th year	$\frac{63.150\times(1+0.13)^4}{(1+0.15)^4}$	58.87	-198.2
5th year	$\frac{63.150\times(1+0.13)^5}{(1+0.15)^5}$	57.85	-140.35
6th year	$\frac{63.150\times(1+0.13)^6}{(1+0.15)^6}$	56.84	-83.51
7th year	$\frac{63.150\times(1+0.13)^7}{(1+0.15)^7}$	55.85	-27.66
8th year	$\frac{63.150\times(1+0.13)^8}{(1+0.15)^8}$	54.88	+27.22

Based on Table (3), by the application of a chiller, the power generation and fuel consumption rate are respectively equal to 18628 kW and 1.605 kg/s. Within the base mode, in purpose to produce 18628 kW, fuel consumption rate is equal to 1.644 kg/s. So the reduction in fuel consumption rate is equal to 0.039 kg/s. based on the calculation in section 4.4, working hours of a gas unit in a year is equal to 1240 hours. Based on the combustion equations and calculation, it is concluded:

$$0.039\,\frac{kg}{s}\,Natural\ gas\times\frac{1240\times 3600\ s}{1\ year}\times\frac{1\ m^3\ Natural\ gas}{0.755\,\frac{kg}{s}\,Natural\ gas}\times\frac{1.14\ m^3\ CO_2}{1\ m^3\ Natural\ gas}\times\frac{1.977\ Kg\ CO_2}{1\ m^3\ CO_2}=519701\ Kg\,\frac{CO_2}{year} \quad (6)$$

So social cost of producing 519.701 tons of CO_2 is equal to 19,229 USD. By considering this cost value, it is possible to re-calculate the payback period considering carbon cost reduction. The results are informed in Table (9). Based on Table (9), with considering social cost of carbon, the payback period decreases to 7 years and 6 months.

7 Conclusion

According to the Yazd city climate, the utilization of chiller system was considered based on 155 days annual applications (May to October), eight sunny hours a day. It is also considered the designing condition of chiller system nominated temperature and relative humidity at 36°C and 15% respectively.

In this research, a comprehensive code is developed on on-going operational gas turbine unit to simulate the dynamic behavior of the system. Considering this overall activity, an innovative quantitative approach to integrated aspects are taking place. These aspects are a combination of technical, economic and environmental calculations simultaneously.

Analyzing the results shows that application of chiller system in order to cool the input air of GEF5 units in hot and dry weather of Yazd city, caused an increase in input air mass flow rate and a decrease in the compressor's consumption work in utilization period; so that the amount of increase in productive power of each unit would be 3.135 MW in the effect of installing absorption chiller system and considering the relative humidity of 100% regarding system's output air, which is considerable amount in comparison with the power capacity equals 25 MW. The extra fuel consumption due to installing chiller system is equal to 0.136 $kg.s^{-1}$.
The calculations of return on investment have also shown that return on investment period of absorption chiller is more than 11 years. This long payback period time is contributed to the low currently fuel price in IRAN. This pattern is the result of governmental subsidizing in the case of fuel price in IRAN. So In this case, the economic analysis in the countries besides the Persian Gulf, whereas no subsiding considerations, the payback time would be shorter nearby 45% at all. By considering social cost of carbon, payback period decreases to 7 years and 6 months.
This means that due to the environmental aspect, the projects might be reasonable, which shows the value of environmental aspect.

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Nomenclature

h= Enthalpy
$\dot{M}$= Mass Flow Rate
NPV= Net Present Value
Q= Cooling Load
TIT= Turbine Inlet Temperature
TR= Tons of Refrigeration
USD= United States Dollar

چکیده

راندمان و توان خالص خروجی توربین‌های گازی، با افزایش دمای هوای محیط، کاهش می‌یابند. برای جبران این عیب، روش‌های خنک‌کاری هوای ورودی به کار گرفته می‌شوند. در تحقیق حاضر، تأثیر استفاده از چیلر جذبی با استفاده از بازیاب حرارت اتلافی گازهای خروجی توربین گاز، بررسی شده است.
بدین منظور رفتار یک واحد توربین گازی مدل GE-F5 به وسیله کدنویسی در نرم‌افزار Matlab مدل شده و کد تولید شده با بانک اصلاعاتی حاصل از اندازه‌گیری واحد مذکور، صحت‌سنجی گردیده است. واحد مورد بررسی در نیروگاه شهید زنبق یزد قرار دارد. نتایج نشان می‌دهند که با کاهش دمای هوای ورودی تا نزدیک دمای نقطه شبنم، توان تولیدی واحد به میزان ۳/۱۳۵ مگاوات افزایش می‌یابد. همچنین دوره بازگشت سرمایه نصب سیستم مذکور حدود ۱۱ سال می‌باشد. این مدت با درنظر گرفتن هزینه زیست‌محیطی تولید کربن، به ۷ سال و ۶ ماه کاهش می‌یابد؛ که این نشان از اهمیت بالای زیست‌محیطی استفاده از خنک‌کاری هوای ورودی با چیلر جذبی دارد.