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Technical and Economical Evaluation of the enhancement of gas turbine power plant using air cooling fogging system

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ABSTRACT
This paper investigates *the effect of operating fogging cooling system on gas turbine on its performance, technical and economic study. This study was made for both 4 hours and 10 hours of operating fogger by actual data from power plant in Egypt. The technical study shows that the maximum increase in power is from 18 to 20 MW. When the ambient temperature increased from 25 to 40 C during a typical summer day, The power jumped from 220 to 238 MW after the operation of fogger. Moreover, The specific fuel consumption decreased from 0.218 to 0.214 (1.8% reduction) and the electric efficiency changed from a minimum value of 35% to 35.8 %. The economic indicators such as the net present value (NPV), Internal return rate (IRR), rate of return (ROR), and pay pack period were obtained. The economic study recommends the operation of fogger from 10 AM to 8 PM. The study showed that there is no economic justification when operating the fogger 4 hours because the net present value (NPV) is – 902,716 $ for discount rate of 10% during the period of 20 year. But when operating the fogger 10 hrs. Daily in summer, the net positive value (NPV) is 4,522,493 $, Payback period=5 years, and the internal return rate (IRR) is 26 %.*

1. Introduction

The weather conditions are the main factor effect on gas turbine specially on summer as any power plant gives its base load at the International Organization for Standardization (ISO) design point which depend on ambient temperature and relative humidity, so in summer the power of the plant decreases by 0.8 % for each 1 degree rise in temperature, to solve this problem there are a lot of methods to cooling air inlet as evaporative cooling which divided into media evaporator and fogging system, mechanical refrigeration and absorption chiller. This paper focus on cooling inlet compressor air by fogging system applied on gas turbine in Egypt. [1]

Mahdi Deymi-Dashtebayaz and Parisa Kazemiani-Najafabad [1] Studied the effects of some compressor inlet air cooling methods to increase the performance of Shahid Hashemi-Nezhad gas turbines located in Iran, the methods using in this study are media Pressure drop station, fogging and absorption chiller. This study uses the exergy, environmental, and economic analyses to select the best method of compressor inlet air cooling. The results showed that, the absorption chiller is the best method to make temperature drop for high air inlet cooling and increase thermal and exergy efficiencies by about 2.5 and 3% in hot summer, also using absorption chiller, pressure drop station media and fogging decrease environmental factors as co and co_2 than on simple gas turbine without this methods, also in economic study the net present value and internal rate of return coefficients indicates that the pressure drop station is most economical option. Ali Marzouk and Abdalla Hanafi A [2] Studied thermally and economical evaporative cooling and chiller cooling to enhance the power of 264 MW gas turbine located in El korymat , Egypt , depending on data collected in 2009. The results showed that the energy gained by chiller cooling is 117,027 MWh, the annual cost is $ 7,624,548.9, the net cash flow $3,787,537 and the payback period is 3.3 years. While the annual power gained by evaporative cooling is 86,118 MW, the total annual cost is $1,524,779.7, the net cash flow is $4,503,548 and the payback period is 0.66 year. The thermal efficiency of the power plant increased to 36.46 % while using the chiller, 37.205 % while using evaporative cooling.

M. Mustafa et al. [3] Focus on study the performance of simple and regenerative gas turbine cycles with an existing turbine SULZER S3, at wet and dry compression cases , a numerical model constructed for this purpose, they use fogging cooling air inlet to saturate the air and over spray to decrease the air temperature at various ambient temperature , the results showed that the fogging and over spray decrease the compressor workup to 12 % , The highest thermal efficiency of 44% was achieved when over spray 3% with recuperation was applied at ambient 15 C and 42.9% at ambient 45 C and over spray 4.5 % . Based on this study it can be concluded that the specific fuel consumption is reduced, power will increase.

Abdul-Malik E. Momin et al. [4] developed a mathematical model to calculate the performance parameters of Marib gas turbine, and model parameters were verified based on real time operation data of the gas turbine units in power station. The gas turbine has fogging cooling system. The results showed that the power consumption of the fogger unit ranges from 150-257 kW which is negligible compared to the net power gained of 19 to 30 MW during the day. The gas turbine efficiency increased from

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29.6 % to 32.1 % due to fogger with natural gas fuel cost, savings about 462 USD per day.

R. Agbadede and B. Kainga [5] modeled the performance of gas turbine with fogger by using gas turbine soft war. They input the ambient condition of Delta Niger region. The mass flow rate of water was 0.4% of the mass flow rate of air to get a reduction of10 C in air temperature. They showed the enhancement of power due to fogger. They enhanced the power of General Electric engine with 120.6 MW design power. Their economic analysis showed that $2.4 million profit was recorded in one year due to fogger cooling. They took the capital cost of the fogger $35/kW increase in power

Tehrani et al. [6] studied the technical feasibility of using different types of cooling air at the inlet of the compressor of gas turbine units. They compared between fogger cooling, media evaporative cooling, air cooled chiller cooling, and water cooled chiller cooling. They considered kazeroun combined cycle power station which is located west Iran as a case study. Based on the study the result showed that the highest and lowest power enhancements were 14.3% and 6.88% for water chiller cooling and media cooling respectively. There sensitivity analysis showed that there is no justification for using the cooling systems if the price of the electricity was lower than 80$ per megawatt

Salman et al. [7] studied the effect of inlet air temperature, relative humidity. Pressure ratio and the firing temperature on the performance of gas turbine when injection of water occurs at the inlet of compressor. They changed the inlet temperature in the range from 10 C to 60 C; the relative humidity from 10 t0 90%; and the firing temperatures were 1100, 1200, 1400, and 1600 K. The results showed that the decreasing the temperature at compressor inlet increases the power and efficiency of the cycle. Increasing the firing temperatures increasing the efficiency. When increasing the pressure ratio the efficiency increases to a maximum value then decrease. The relative humidity gave reverse effect in both the power and efficiency

Ameri et al. [8] take Three units in Iran as media cooling system in Fars power plant, fog cooling system in Ghom and Shahid Rajaie power plants a case study to compare between media system and fog system and studied the technical and economic between them , this study result an increased by 11MW (14.5%) in Fars power plant , 8.1MW (8.9%) and 9.5MW (11%) increased in Ghom and Shahid Rajaie power plants by Application this modify on it , The economic studies show that the payback periods are estimated to be around 2 and 3 years for fog and media systems

Mohammad Reza Majdi Yazdia et al. [9] studied the effect of heat pump , absorption chiller and inlet fogging system applied on different cities in Iran reprehensive different climate condition. This study show the effect of this cooling system in gas turbine parameter as quantity of emitted pollutants, price of electricity generated and capital cost payback period. the result of this study show that for hot climate city the absorption chiller is the appropriate method as it improve the power by 18% , the efficiency by 5.8% , the exergy efficiency by 2.5 % and the payback period is 5.5 years . For hot and dry the inlet fogging system is the best cooling system to mitigate pollutant emissions, fogging is the lowest capital cost, the lower year payback period .Finally all this cooling method have advantage and dis advantage so select the appropriate method depend on increase power, reduce fuel consumption, reduce pollutant emissions, reduce the cost of electricity generated and the climate condition.

Choa Deng et al.[10] Aims to provide the performance of combined cycle power plant by some air inlet cooling systems as fogging, evaporative, mechanical chiller and absorption chiller cooling. The study show that fogging cooling system provide an efficiency improvement of 0.9% per 1 C and provide the power 5% by each 1% increase in fog mass flow rate . the technical study show that fogging cooling system improve the performance of combined cycle power plant by 17% , evaporative cooling by 4% and the mechanical chiller by 13.6 and the absorption chiller is the best as by 23% but very expensive .

According to recent survey, the evaporative cooling method is the most economical and suitable for hot and dry climate. The other methods as absorption chiller and mechanical refrigerators are expensive and not suitable for that ambient condition. The purpose of this paper to study the Technical and Economical Evaluation of enhancement gas turbine power station using air cooling fogging system by actual performance test results are present on gas turbine in Egypt electrical grid. Most of the similar papers are given its results by commercial companies which have not been justified by an independent research. Each company claims that its system is the best.

2. Power plant description:

The power plant is a 750 MW combined cycle power station consists of 2*264 MW gas turbine units and a 250 MW steam turbine. It is manufactured and installed by Siemens (V94.3A2). The exhaust of these stations is the heat source of the steam power station. As shown in Table 1 the ISO design data for each of the two gas turbine power station.
The main component of the plant is 15 stage axial compressors, 4 stage turbine, and annular type combustion chamber, fired by natural gas. However, the power drops significantly in summer at the time of the day when the load curve reaches its peak of power demand. This is due to the change of weather conditions and the air quality. Therefore, installing cooling system to cool air before entering the compressor is essential. It has fogging cool system for each gas turbine.

Table 1: Gas turbine design data [2]

Item	Rate
Gas turbine output, MW	264
Air inlet temperature (ISO), C	15
Relative humidity, %	60
Average air mass flow rate, kg/s	652.71
Ambient pressure, bar	1.013
Exhaust gases temperature, C	586
Exhaust gases flow rate, kg/s	666
Heat rate, kJ/kWh	9435.4
Gas lower heating value, kJ/kg	47040
Compression ratio	15
Inlet temperature to turbine, C	1350
Fuel gas mass flow rate, kg/s	14.6
Efficiency, %	37

3. The Effect of Temperature of air inlet compressor on the electric power generated:

Gas turbine is designed at ISO conditions as ambient temperature and relative humidity of 15_C and 60% respective. But if the ambient temperature increases to 40_C in summer, gas turbine power deceases to 80 % rated. Figure 1 shows gas turbine output power versus ambient temperature for a 264 MW gas turbine.

There are many Power augmentation methods available for existing gas turbines include:

- Cooling air before inlet the compressor: This will be explained here. [2]
- Steam or water injection into the combustor: While commonly applied for NOx control, it also boosts power due to the increased mass flow and higher specific heat of the products of combustion going through the turbine. The increased specific heat of the products of combustion and better heat transfer results in higher blade metal temperatures, and control systems often compensate for this by backing off on the firing temperature. [2]
- Increasing the firing temperature: In this case, hot section durability must be carefully considered. [2]

The air inlet cooling method divided in to:-

1- Evaporative cooling :
2- High pressure fogging :
3- absorption chiller :
4- Mechanical refrigerated cooling :
5- Thermal energy storage :

These systems have advantage and dis advantage so select the appropriate system to apply depend on climate condition so in Egypt climate the evaporative cooling is the appropriate apply system. [10-11]

As shown in Figure 1 a relation between the electric power and ambient temperature at the inlet of compressor in case of fogger on, the power increase higher than in case of fogger of, as when the ambient temperature increase than 30 C, air density decrease ,the air mass flow rate decrease, and compressor work increase so the power out decrease, but when fogger on the mass flow rate increase from water injection into the compressor and so inlet compressor temperature decrease so its compression work decrease result total power increase . This figure show that operating the fogging system must be at high temperature more than 30 C to improve the gas turbine performance as required. This data collected on summer 2018 for actual testing data from the gas turbine. The data were fitted and the following equations are obtained. A curve fitting of the data are the source of the following equations:-

$$Pe_d = 267.755 - 1.42047\ T_1 \quad (1)$$

21 C<T1<35 C

$$Pe_w = 253.616 - 0.9418\ T_1 \quad (2)$$

18 C<T1<22 C

As

Pe_d = Electric power for dry compression, MW

Pe_w = Electric power for wet compression, MW

T_1 = Air temperature at compressor inlet, C

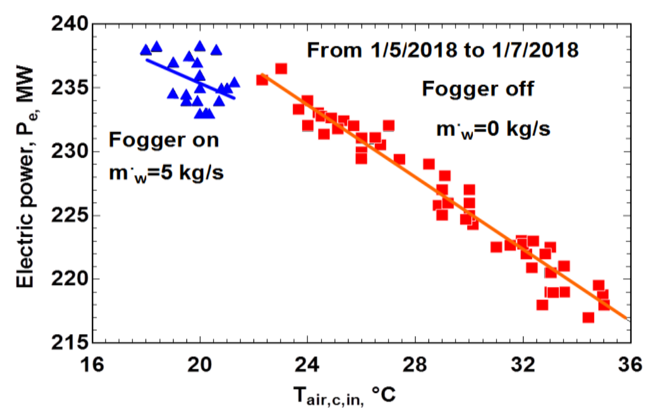

Figure 1: Electric power versus air temperature for fogger on and off conditions

4. Fogging System Description:

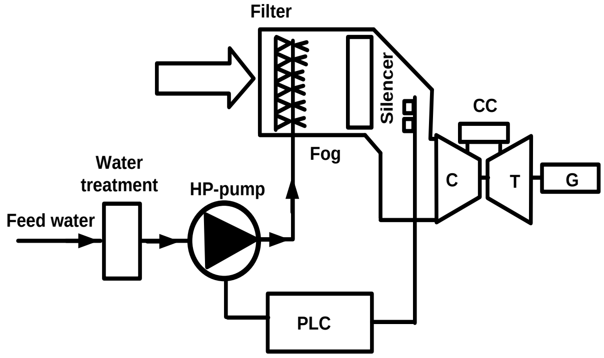

Figure 2: Schematic diagram of fogging cooling air inlet compressor method

The fogging cooling system based on spraying atomized water high pressure 100-250 bar into the compressor inlet air stream; this water, flowing through compressor stages, because of the heating due to the pressure increase, evaporates and cools the air stream. Following the drop in the compressor discharge temperature, compressor work decreases and mass flow Increases, because of the water injected into the compressor; Consequently, there is a significant enhancement of the gas turbine power output [12] . It is Consists of a series of high pressure pumps positive displacement plunger type with 200-250 bar head that are mounted on a skid, PLC based Control system with temperature and humidity sensors, and an array of fog nozzles installed in the inlet air duct as shown on figure 2. Sensors are provided to measure relative humidity and dry bulb temperature. Special programming codes use these measured parameters to compute the ambient dry bulb temperature and the wet bulb depression, i.e. the difference between the dry bulb temperature and the wet bulb temperature. They quantify and control the amount of evaporative cooling that is possible with the ambient conditions. The system turns on or off fog cooling stages to match the ability of the ambient conditions to absorb water vapor. The control system also monitors pump skid operating parameters, such as, water flow rates and operating pressure, and provides alarms when these parameters are outside acceptable ranges[13]

5. Hourly variation of electric power and ambient wet and dry bulb temperature:

As shown in Figure 3 the variation of the power, dry and wet bulb temperature of the ambient air with 4 hours fogger on from 5 PM to 8 PM on May 2018 in Egypt power plant. The electric power for both dry and wet compression was calculated by equations 1, 2 and plotted on the figure with the data obtained from the power station. It was assumed that the air temperature at the inlet of compressor is the same as ambient temperature in case of dry compression during fogger off condition. During the fogger on condition, it was assumed that the air temperature at compressor inlet is equal to the wet bulb temperature. When the ambient temperature is increased from 25 to 35 C, the power drops from 238 to 220 MW as gas turbine is constant volume machine so when temperature rise density decrease, mass flow rate decrease and power decrease. It means 0.8% reduction in power for each 1 degree C rise in temperature. The figure shows that the power calculated by equations 1, 2 is fitted well with the data of fogger off conditions. There is 2% deviation from the data during fogger on operation. The figure shows that there is no potential for operating fogger during the period from 12 AM to 7 AM. The potential for power generation is high in the period from 10 AM to 7 PM. The figure shows the jump in power which happened due to the 4 hours operation of the fogger. It was better to operate it for the mentioned 10 hours. May be the 4 hrs. operation period is related by the power demand. The figure shows a 12 % increase in power is happened when operating the fogger. It jumps from 220 MW to 238 MW.

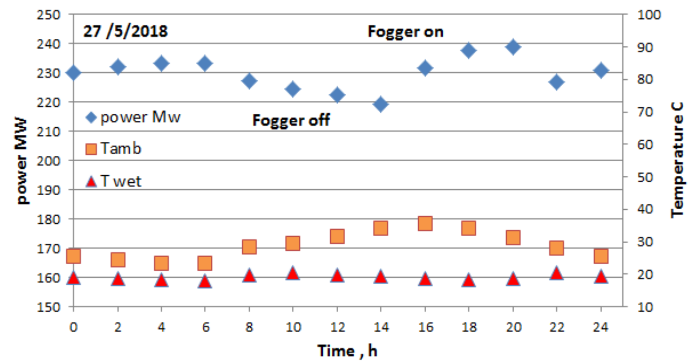

Figure 3: Electric power, dry & wet bulb temperature of the ambient air versus the time with 4 hours Operation of the fogger.

6. Effect of air temperature in compressor inlet on specific fuel consumption

As shown in Figure 4 the specific fuel consumption versus the air temperature at the inlet of the compressor for both foggers on and off conditions in summer 2018. The data shows linear relation for both cases. The figure shows that the data are more scattered during fogger off operation as compared with the case of fogger on operation due to the variation of relative humidity in the case of operation without fogger while the relative humidity approaches 100 % during fogger operation, as the specific fuel consumption decrease in case of fogger on as air mass flow rate increase so fuel mass flow rate increase to keep air to fuel ratio constant, therefore the specific fuel consumption increase with increase ambient temperature because of increased losses due to increase amount of flue gases .

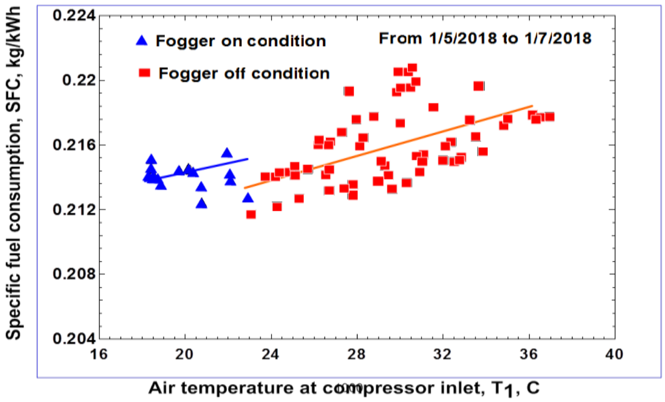

Figure 4: Specific fuel consumption versus time for fogger on and off conditions.

The data were fitted, and the following equations are obtained. A curve fitting of the data is the source of the following equations

$$SFC_d = 0.2048 + 0.000395T_1 \quad (3)$$

23 C<T1<37 C

$$SFC_w = 0.208 + 0.0003\ T_1 \quad (4)$$

18 C<T1<23 C

Where:

$SFC_d =$ Specific fuel consumption for dry compression

SFC_w Specific fuel consumption for wet compression

7. Hourly variation of specific fuel consumption

As shown in Figure 5 that practical data of specific fuel consumption for both cases of fogger on and off conditions. The specific fuel consumption decreased from 0.218 to 0.214 (1.8% reduction) due to the operation of fogger in a typical summer day.

$$SFC = \frac{\dot{m_f}}{P_e} \quad (5)$$

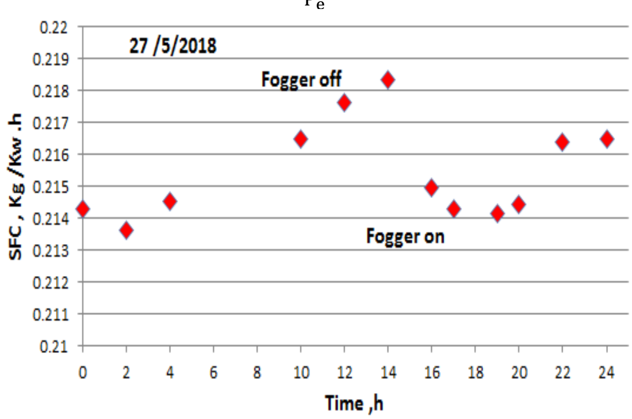

Figure 5: Specific fuel consumption versus time for both foggers on and off conditions during days of summer months

8. Hourly variation of electric efficiency

The electric efficiency is defined as:

$$\eta_e = \frac{P_e}{\dot{m_f} \times L.C.V.} \quad (6)$$

The fuel consumption of the natural gas in the data was given in units Nm3/hr. considering a density value of 0.799 kg/m3, the mass flow of fuel in kg per hour is calculated as follow:

$$\dot{m_f} = 0.799 \times \dot{v_f} \quad (7)$$

As shown in Figure 6 the electric efficiency changed in the range from 34.2% to 36%. The efficiency increased from 1.7 to 2.8% during the operation of the fogger as power increase also mass flow rate increase and inlet temperature decrease.

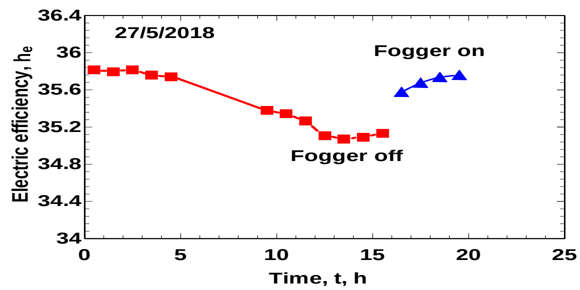

Figure 6: Electric efficiency versus time for both fogger on and off conditions during days of summer months

9. Energy gain due to the operation of the fogger in summer season:

In the recent situation, the fogger operates for 4 hours during summer 2018. May be this is due to the limitations of the required load. The question which may be raised is these hours of operation are economically visible or not. This section and the following section will be devoted to answer this question.

As shown in Figure 7 the monthly increase in energy due to operating the fogger four hours daily from 4 PM to 8 PM, and for 10 hours operation from 10 AM to 8 PM. The data correspond to fully opened inlet guide vane (IGV). The yearly increase en electricity is 8914 MWh in case of 4 hrs. Operations and 21511 MWh in case of 10 power operations

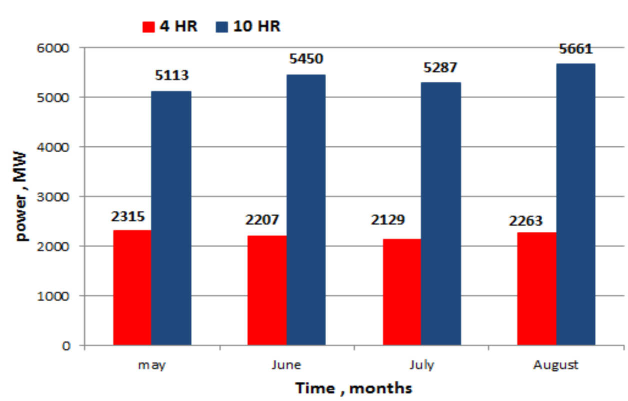

Figure 7: Increase in electric energy for summer months due to the operation of fogger cooler

10. Fuel consumption for the extra generated electric energy

The price of natural gas in Egypt is sold by the unit of metric million British thermal unit (MMBTU), where the British thermal unit (BTU) =1.055 kJ.

As shown in Figure 8 the fuel consumption for the increased energy due to the operation of the fogger. The total yearly fuel energy consumption was 71122 MMBTU in case of 4 hours operation and 177,679 in case of 10 hours operation

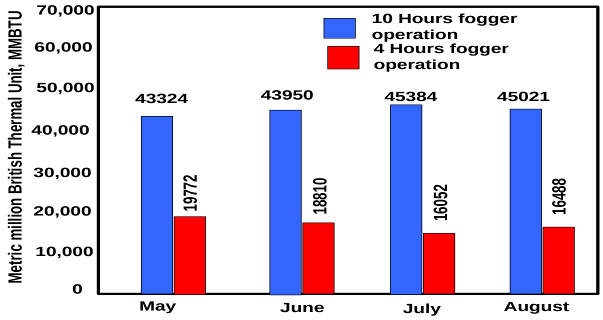

Figure 8: Fuel consumption for the extra energy due to the operation of fogger in summer

11. Economic analysis for inlet cooling systems:

The basis of most design decisions is economic. Designing a system that functions properly is only one part of the engineer's task. The system must also be economical and show an adequate return on investment , The better way of evaluating the economic feasibility of a cooling system is Through cost-benefit analysis in which the additional revenues are calculated as a result of cost of electricity (COE) and rate of return (ROR) for additional MWh [8]

From the previous section, the yearly electric energy increases during fogger operation time were 7930 MWh, and 19001 MWh for 4 and10 hour's fogger daily operation, respectively. The fuel consumed for generating the extra energy were 71,122 MMBTU, and 177,679 MMBTU for (4) and (10) hours daily operation respectively

The following assumptions were made during this study

1- The capital cost of fogger was assumed to be 200 $/KW increase in power due to fogger
2- The average increase in power 18 MW
3- The yearly operation and maintenance cost =0.03 of the initial cost
4- The price of fuel=3.25 $/MMBTU
5- The water flow rate into fogger 5 kg/s
6- Price of de-mineralized water=1 $/m3
7- Cost of kw hr. generated = 0.08 $[10]
8- Fogging operating 4hr,10hr /day, 4 months / year

11.1. Installed Cost of Fogging system

Capital cost of fogging system was estimated by adopting the suggestions provided in Egypt industrial market as 200: 250 $/Kw.h, From the fogging studies, when fogging was implemented for the industrial gas turbine operated under increased ambient temperature of 298.15K, the engine gained 16000 Kw power output [5].

Therefore, installed capital cost of fogging system =

200 $ * 18000 = 3,600,000 $

11.2. Annual Fuel Cost arising from Power Augmentation

In case of 4 hrs. daily operation for 4 summer months, the fogger operates 492 hrs. per year. In case of 10 hrs. daily operation, it operates 1230 hrs. Figure 5 show that the average specific consumption during the operation of fogger is 0.214 kg/Kw.hr. In Egypt.

The price of Million British Thermal Unit in Egypt is 3.25 $. Since the calorific value of natural gas is 47000 KJ/kgf, the price of 1 kg fuel is calculated as follow

Price of 1 kg fuel $= (\frac{47000}{1.055\times1000000}) \times 3.25 = 0.145$ $

Fuel Cost (4h daily) =492*18000*0.214*0.145=274,802 $/year

Fuel Cost (10h daily) = 1230*18000*0.214*0.145

= 687,004 $/year

11.3. Operation and Maintenance Cost of Fogging System

Operation and maintenance cost of 3% of total capital cost [3]

Therefore,

O. &M. cost=0.03*3,600,000=108000 $/year

11.4. Water treatment cost

Water flow rate input to the fogger=5 kg/s

Water consumed 4 hrs. Daily=5*3600*492/1000

=8856 m3/year

Water consumed 10 hrs. Daily=5*3600*1230/1000

=22,140 m3/year

Assuming the cost of water 1$/M3 in Egypt

Water cost (4hrs) =8856*1=8856 $/year

Water cost (10 hrs.) =22140*1=22140 $/year

11.5. Annual Cash gained

As total cost per year= fuel cost+ Operating & maintenance cost+ water cost = 341654 $
So, Cash per year = 631040 – 341654 = 292746 $

11.6. Discounted yearly profit and Economical parameters

To consider the effect of time on the value of money, the yearly discounted factor (DFi) is calculated as follow

$$DF_i = \frac{1}{(1+r)^i}, \qquad i = 0,1,2,3 \ldots\ldots\ldots 20 \qquad (9)$$

Where:

i=year number=20 year

R=interest rate=10%

The discounted cash flow for each year ($DCASHF_i$) is the yearly cash flow of the year $CASHF_i$ multiplied by the discount factor(DF_i), can calculate by the following equation: _

$$DCASHF_i = CASHF_i \times DF_i \qquad (10)$$

To get the pay pack period, the accumulated cash flow is calculated starting from the negative value of the initial cost. The years passed until the accumulated cash flow reaches zero value is payback period.[14-15]

To get the net present value (NPV) is calculated by the following equation: _

$$NPV=-\text{Initial cost}+\sum_{i=1}^{n} DCASHF_i \qquad (11)$$

Table 2: Economic analysis for 4 and 10 hrs. Operation of the fogger

Item	Parameter	4 Hr. operation	10 Hr. operation
		Cost $	Cost $
1	Cost of inlet Fogging system	3600000	3600000
2	Annual Cost of Fuel consumed	274,802	687,004
3	Annual Cost of Water Consumed	8856	22140
4	Operation and Maintenance Cost	108000	108000
5	Total Cost	391,658	817,144
6	Cost of Extra Electricity Generated	708,480	1,771,200
7	Cash per year	316,822	954,065
8	Net present value (NPV)	-902,716	4,522,493
9	Payback period (10% discount factor, 20 year)	-	5 years
10	Internal Return rate (IRR)	-	26%

12. Conclusion

The technical performance and economical consideration of El korymat gas turbine power plants were considered in this study. The results showed that when the ambient temperature increased from 25 to 35 C during a typical summer day, the power decreased from 238 to 220 MW. A 0.8 % decrease in power for each 1 degree rise in temperature. The power jumped from 220 to 238 MW after the operation of Fogger. A 12 % increase in power was achieved. This study recommends the operation of Fogger from 10 AM to 8 PM. The specific fuel consumption decreased from 0.218 to 0.214 (1.8% reduction) due to the operation of Fogger in a typical summer day. During the day, the electric efficiency changed from a minimum value of 35% to 35.8 %. The efficiency, increased by 1.7 % due to the operation of the fogger. Therefore, adding a fogger before the inlet of the compressor can recover this power loss. The performances of fogger during typical days in summer were considered. The electric efficiency during summer changed in the range from 34.2% to 36%. The efficiency increased from 1.7 to 2.8% during the operation of the fogger. The specific fuel consumption varied during the days of summer from a maximum value of 0.220 kg/kWh to a minimum value of 0.214 kg/kWh. When operating the fogger, it drops to the minimum value of 0.214. The yearly electric energy increases during fogger operation time were 7930 MWh and 19001 MWh for 4, 10 hours fogger daily operation, respectively.

The fuel consumed for generating the extra energy were 71,122 MMBTU, and 177,679 MMBTU for 4, 10 hours daily operation respectively. . A sensitivity analysis of these economic parameters with the fixed of electricity price as 80 cent /Kw.h. The results of the economic study showed that when operating the fogger 4 hrs. The net present value is negative for discount rate of 10% during the period of 20 year, so there is no economic justification for operation of the fogger 4 hrs. Per day in summer but when operating the fogger 10 hrs. Daily in summer, the net positive value (NPV) is 4,522,493 $, Payback period=5 years, and the internal return rate (IRR) is 26 % .

Egypt have 155 gas turbine power plant which generated power 24664 MW , Based on the results from the power plant according to fogging system improve the power increase with minimum 12% of its base load , so if this improve applied on all our plants , power enhancement would be 2959 MW[16].

Abbreviation and symbols

$\dot{m}_f$	**Fuel mass flow rate, kg/s**
P_e	**Electric power, MW**
T	**Temperature, C**
t	**Time, hr.**
Greek letters	
η	**Efficiency, %**
Subscripts	
amb	**ambient**
e	**electric**
WB	**Wet bulb**
DB	**Dry bulb**
Abbreviations	
C	**compressor**
CC	**Combustion chamber**
G	**generator**
IC	**Initial cost, $**
IRR	**Internal return rate, %**
L.C.V.	**Lower calorific value, kJ/kg**
NPV	**Net positive value, $**
O & M	**Operating and maintenance cost**
PLC	**Program logic control**
SFC	**Specific fuel consumption, kg /kW. hr.**
T	**turbine**
DF_i	**discount factor**

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