Thermal and Economic Evaluation of Using a Single Stage LiBr-H_2O Absorption Chiller to Boost the Power Output of a Gas Turbine Generator

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Abstract

The exhaust gases of gas turbines carry a significant amount of thermal energy that is usually expelled to the atmosphere without taking any further part in the power generation process. This low grade thermal energy can however be put into beneficial use as a heat source to a vapor absorption chiller that serves as cooling system to be operated during hot months to cool inlet air to the gas turbine to raise its power generation design level.

This paper describes the thermal and economic advantages of using a Single Stage LiBr-H_2O absorption chiller to boost the power output of a gas turbine generator with application to Mosul gas turbine power plant. The results showed that maximum increase in power output when inlet cooling involved is approximately 17.5%, which occurs in July and August being the hottest month in the year. The economic results showed that maximum economic saving of $34.9 million dollar which represent 8% saving can be obtained at inflation rate of 6% and interest rate of 1%.

Key words : Gasturbine , Absorption system , Thermal analysis , Economic analysis.

التقييم الحراري والاقتصادي لاستخدام منظومة تبريد امتصاصي لرفع القدرة الناتجة من التوربينات الغازية

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الخلاصة

تحتوي الغازات العادمة الخارجة من الوحدات الغازية على كمية من الطاقة الحرارية والتي غالبا تطرح إلى المحيط الخارجي دون الاستفادة منها في عمليات توليد إضافية. هذه الطاقة الحرارية الواطئة نسبيا يمكن الاستفادة منها كمصدر حراري لتشغيل منظومة تبريد الهواء قبل دخوله إلى الوحدات الغازية وبذلك تعمل على رفع أداء الوحدة الغازية إلى القدرة التصميمية. هذا البحث يبين الفوائد الحرارية والاقتصادية المرجوة من استخدام منظومة تبريد امتصاصي مع الوحدات الغازية مع تطبيق على الوحدة الغازية غي الموصل. بينت النتائج إن أعظم زيادة في القدرة يمكن الحصول عليها في حالة استخدام التبريد الامتصاصي تقريبا 17.5% والتي يمكن الحصول عليها في شهر تموز وآب واللذان يتمتعان بأعلى درجات حرارة في السنة. كما بينت النتائج الاقتصادية إن هناك توفير ما مقداره 34.9$ مليون دولار والذي يمثل تقريبا نسبة توفير مقدارها 8% يمكن الحصول عليها عندما تكون نسبة التضخم 6% ونسبة الفائدة 1% .

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Nomenclature		**Subscripts**	
E_{ncAnu}	Annual energy cost with out cooling (Dollar)	abs	Absorption system
E_{sanc}	Annual energy cost for standby gas turbine (Dollar)	nc	No cooling
E_{wcAnu}	Annual energy cost with cooling (Dollar)	gt	Gas turbine
F_p	Fuel price (Dollar)	sgt	Standby gas turbine
f	Inflation rate	wc	With cooling
IC_{abs}	Cost of absorption unit (Dollar)		
IC_{gt}	Gas turbine unit cost (Dollar)		
IC_{sgt}	Standby gas turbine unit cost (Dollar)		
i	Interest rate		
LCC	Life cycle cost (Dollar)		

LCS	Life cycle saving (Dollar)
M_{abs}	Maintenance cost of absorption unit (Dollar)
M_{gt}	Maintenance cost of gas turbine unit (Dollar)
M_{sgt}	Maintenance cost of standby gas turbine unit (Dollar)
m	Life time of the absorption unit (years)
n	Life time of the gas turbine unit (years)
P	Power (MW)
P_{adt}	Additional power output (MW)
P_{rd}	Reduced power output (MW)
P_{ncm}	Monthly power output with no cooling (MW)
P_{stand}	Power output of standby gas turbine (MW)
PWF	Present worth factor
U_{price}	Unit power price (Dollar)
Sal	Salvage value (Dollar)

Introduction

Many countries, including Iraq, are turning to gas turbine generators for their power needs because gas turbine generators provides the highest efficiency and lowest emissions of all combustion generation technologies available today. In addition, they have short installation time and low maintenance cost[1]. However, a disadvantage that penalize the gas turbine peaking plant, is the inversely proportional effect of the ambient temperature on the gas turbine output. Most gas turbines typically produce 30% higher electric power output when the ambient temperature is 15 °C compared to 45 °C [2].

Cooling of the compressor intake air is expected to result in the boosting of power output of the gas turbine, and also create a noticeable improvement in efficiency. This is illustrated by the schematic temperature entropy diagram of figure (1) where dashed lines and primed numerals designate normal operation (uncooled cycle) and solid lines refer to operation with cooled inlet air (cooled cycle). Point 0 indicates the ambient temperature, point 1 temperature at inlet to the compressor, point 2 temperature at exit from the compressor, point 3 and 4 refer to temperatures at the inlet and exit of the turbine respectively. Figure (1) indicates that the cooled cycle require less compression work than uncooled cycle for the same mass flow rate of air. The cooled cycle requires more heat input than uncooled cycle to reach similar temperatures at turbine inlet and hence produce more shaft work. Consequently, the net power output of the cooled cycle is expected to be considerably higher relative to that of the uncooled cycle, while its thermal efficiency is marginally improved.

In an effort to boost the performance of gas turbine generators, Johnson [3] suggested the use of evaporative coolers. Ondryas et al [4] investigated various options for cooling the inlet air, including vapor compression chillers and aqua-ammonia absorption chillers. Malewski and Holldorft, [5] analyzed the performance of a gas turbine generator fitted with aqua-ammonia absorption chiller to cool the inlet air. In their system, the generator received the required heat from the exhaust gases via a direct contact heat exchanger.

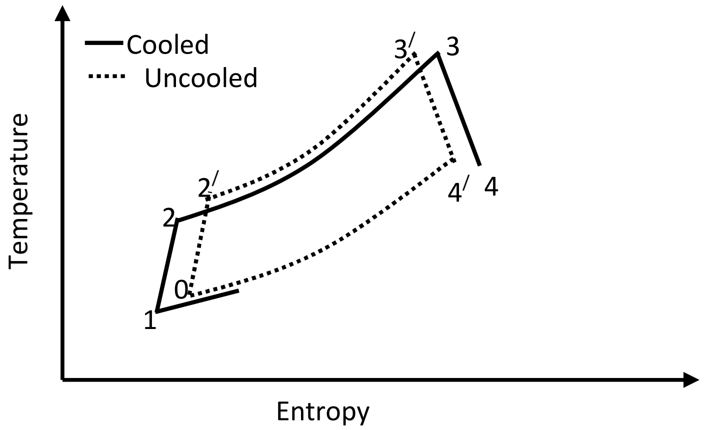


Figure (1): Temperature -entropy diagram for the original and proposed system

More recently, De Lucia et.al., [6] examined the operation of cogeneration gas turbine power plant with and without an air cooling system. Actual performances was examined according to Italy climate to evaluate the feasibility and cost effectiveness of the cooling system. The author concluded that, in the Italian climate, the turbine power output may increase by 18-19% if the compressor inlet air is cooled to 10 ˚C. Szargut, [7] studied the influence of ambient temperature on the operational indices of the gas turbine set. The author reported that lowering inlet air temperature leads to the increase of flow rate of combustion gases, which results in the increase of power output. Finally, McDonalds, [8], studied the turbine performance with optional power booster including mechanical chillers with thermal storage system. He recommended that a full size thermal storage would reduce the overall size of the peak cooling load profile and levelize the production of chilled water over the off-peak period. A significant improvement of power output by more than 20% is reported.

In this research the economic of adding Lithium bromide-water absorption chiller to a gas turbine generator is studied. The gas turbine unit is linked to the absorption system via a heat exchanger that transfer the thermal energy from the gas turbine exhaust to the absorption unit generator. The proposed system is arranged schematically as shown in figure (2). The thermal energy supplied to the absorption unit is obtained from the gas turbine exhaust gases that are confined to pass through a crossflow heat exchanger, before being passed to the environment. The output of the absorption unit is the production of chilled water that circulates in the evaporator and through a second crossflow heat exchanger, which cools the inlet air to the compressor. Basically, these two heat exchangers should be designed in a manner that will not alter the gas turbine performance due to excessive inlet and exhaust pressure losses.

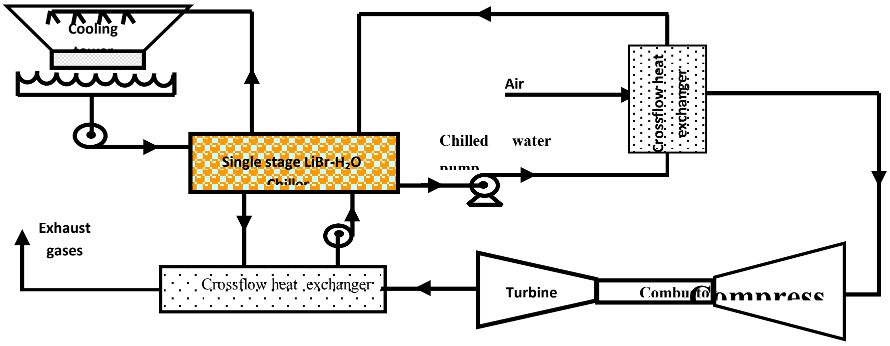


Figure (2): Gas turbine unit with single stage LiBr-H_2O absorption unit (proposed system)

Thermofluid models for the different components of the system under consideration are developed, including the compressor, the combustion unit and the turbine. The absorption refrigeration system, shown in figure (3), as well as the thermal coupling system that transfers energy between the power system and the inlet air cooling system are also modeled. The above mentioned models are combined to simulate the whole system and evaluate the impact of the cooling unit on the thermal performance of the entire system. The results were reported in a previous paper by the authors [9].

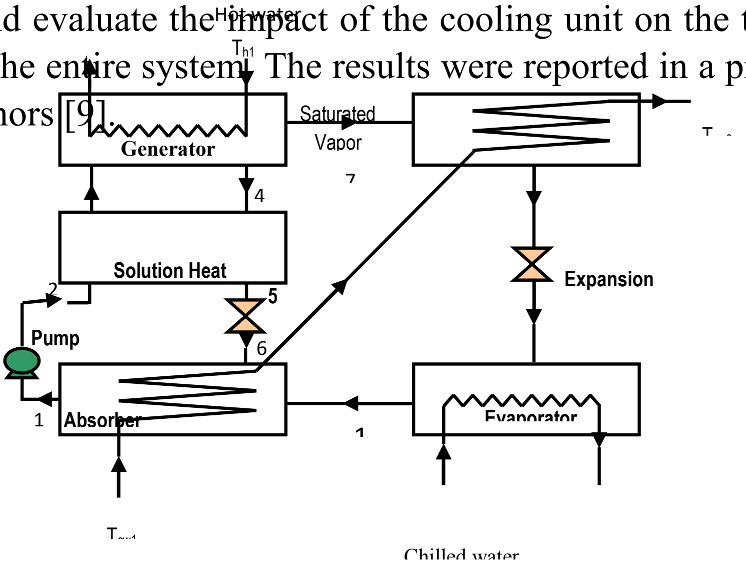


Figure (3): A single stage lithium-bromide absorption refrigeration unit

Economic Model

The life cycle cost analysis is adopted to reflect the economic benefit of applying the inlet air cooling system, (a single stage LiBr-H_2O absorption system) to boost the power out of the gas turbine in hot periods closer to its design value. Basically, three variation of the power system are studied in order to prove the benefit of the inlet cooling system, those are:

1- Gas turbine without cooling (conventional system)
2- Gas turbine with cooling (alternative 1)

3- Original system plus a small standby gas turbine to make up for the reduced power output, (alternative 2).

The life cycle cost for each the above mentioned systems is calculated based on the actual power output of the conventional system (gas turbine without cooling). i.e. comparison of the life cycle cost calculations are carried out taking into consideration that there is a reduction in the power output of the gas turbine during hot periods as a result of the high ambient temperature. The additional power output produced as a result of using the cooling system as well as in the case of installing the standby gas turbine is added in relevant places as a benefit. Therefore, the life cycle cost will be obtained by discounting all costs including the initial cost, fuel cost, and maintenance cost and the salvage value to their present value. Thereafter, the present values of all above costs will be added up together with the additional power output revenue to obtain the life cycle cost of each system. The system that yields the lowest life cycle cost is surely the one to be selected as the most cost effective one. As mentioned previously, the LCC for the conventional system will be based on the actual power output produced by the gas turbine through out the year. Thus, the life cycle cost can be written as follows:

$$LCC_{nc} = \{\text{Cost of gas turbine unit} + \text{Annual energy cost without cooling} + \text{Maintenance cost} - \text{salvation}\}_{\text{original}}$$

$$LCC_{nc} = \{IC_{gt} + [E_{ncAnu} * (PWF)] + [M_{gt} * (PWF)] - [Sal_{gt} * (SPW)]\}_{\text{original}} \qquad \textbf{(1)}$$

Or, in terms of the interest and inflation rates, equation 1 become:

$$LCC_{nc} = IC_{gt} + \sum_{1}^{12} \frac{P_{ncm} * F_p}{\eta_{gt}} * \left[\frac{1+f}{i-f} \left\{ 1 - \left(\frac{1+f}{1+i} \right)^n \right\} \right] + M_{gt} * \left[\frac{1+f}{i-f} \left\{ 1 - \left(\frac{1+f}{1+i} \right)^n \right\} \right] - Sal_{gt} * \left(\frac{1+f}{1+i} \right)^n \qquad (2)$$

In the absorption cooling assisted, a single stage LiBr absorption system is used to push the power output as close as possible to its design value by cooling the inlet air to a temperature of 15 ˚C which forces the gas turbine to operate at the (ISO) design conditions. The life cycle cost of the combined system can be written as:

$$LCC_{wc} = \{\text{Cost of gas turbine unit} + \text{Annual energy cost} + \text{Maintenance} - \text{salvation}\}_{\text{power generation}} + \{\text{Cost of absorption refrigeration system} - \text{additional power output Price} + \text{Maintenance} - \text{Salvation}\}_{\text{absorption}}$$

Or

$$LCC_{wc} = \left\{ IC_{gt} + E_{wcAnu} * (PWF) + M_{gt} * (PWF) - Sal_{gt} * (SPW) \right\}_{original}$$

$$+ \left\{ IC_{abs} - P_{adt} * U_{price} * (PWF) + M_{abs} * (PWF) - Sal_{abs} * (SPW) \right\}_{absorption} \qquad (3)$$

and in terms of the interest and inflation rates, it become:

$$LCC_{wc} = \left\{ IC_{gt} + \sum_{1}^{12} \frac{P_{wcm} * F_p}{\eta_{gt}} * PWF + M_{gt} * PWF - Sal_{gt} * \left(\frac{1+f}{1+i} \right)^n \right\}_{original}$$

$$+ \left\{ IC_{abs} - \frac{P_{adt} * F_p}{\eta_{gt}} * PWF + M_{abs} * PWF - Sal_{abs} * \left(\frac{1+f}{1+i} \right)^m \right\}_{absorption} \qquad (4)$$

If one presumes that no inlet air cooling system is used, and the utility company would like to install a standby gas turbine unit to be used only in hot periods to make up for the power reduction during the high temperature periods with constant power supply throughout the year, then the life cycle cost may be written in the following form:

LCC_{stg} = {Cost of main gas turbine unit +Annual energy cost + Maintenance - salvation}$_{\text{original}}$ + {Cost of standby gas turbine + Annual energy cost - Price of additional energy output + Maintenance - Salvation}$_{\text{standby}}$.

$$LCC_{Stg} = \left\{ IC_{gt} + E_{ncAnu} * (PWF) + M_{gt} * (PWF) - Sal_{gt} * (SPW \right\}_{original}$$

$$+ \left\{ \begin{array}{l} IC_{Stg} + E_{sanc} * (PWF) + P_{sadt} * U_{price} * (PWF) \\ + M_{sgt} * (PWF) - Sal_{sgt} * (SPW) \end{array} \right\}_{s\tan by} \qquad (5)$$

further substitution yields:

$$LCC_{Sgt} = \left\{ IC_{gt} + \sum_{1}^{12} \frac{P_{ncm} * F_p}{\eta_{gt}} * PWF + M_{gt} * PWF - Sal_{gt} * \left(\frac{1+f}{1+i} \right)^n \right\}_{original}$$

$$+ \left\{ \begin{array}{l} IC_{sgt} + \sum_{1}^{12} \frac{P_{rd} * F_p}{\eta_{sgt}} * PWF - P_{sadt} * U_{price} * PWF + M_{Sgt} * PWF \\ - Sal_{Sgt} * \left(\frac{1+f}{1+i} \right)^n \end{array} \right\}_{s\tan dby} \qquad (6)$$

The life cycle savings, LCS, of any system over an other one is the differences between their life cycle costs. Two comparisons are made in this study, the first is for the generation plant with and without the cooling system and the second is for the generation plant when equipped with either a cooling system or a stand by generator. In equation form they are:

$$LCS_1 = LCC_{nc} - LCC_{wc} \tag{7}$$

$$LCS_2 = LCC_{stg} - LCC_{wc} \tag{8}$$

Results and discussions.

1- Thermal results:-

Heat is recovered from exhaust gases of a gas turbine and used to drive a single-stage LiBr-H_2O absorption system to reduce the temperature of inlet air before admitting to gas turbine compressor in order to increase the power output to nearly design value. Cooling of the inlet air of a gas turbine in high ambient operation makes the air dense, giving the gas turbine a high mass flow rate of air, which results in an increase in the power output. A computer program is developed to investigate the influence of using a single-stage absorption chiller. Daily ambient temperature data for each months in the year is obtained from the National Weather Forecasting Agency in Mosul.

The results of thermal cycle simulation are shown in figure (4) to figure (13). Clearly the daily power output with and without cooling for the month of January, February and December is found to be constant and equal to the design value of 408 MWh as shown in figure (4), this is due to the low ambient temperature that persists during those months.

Figure (5) indicates the variation of the gas turbine generator daily power output with and without cooling for the month of March. It is obvious that during the night time and early morning, i.e. 18:00 P.M. to 6.00 P.M, the daily power output with and without cooling are identical and equals to the design value. While during the day time the ambient temperature is a little bit higher than that of 15 ˚C which affect the power production, hence the gas turbine generator produce power less than the design value. The daily power output was found to be nearly 405 MWh in the absence of the cooling system which represent an average daily reduction of 0.073% compared to the daily power design value of 408 MWh. Furthermore, the daily power output with cooling was assessed to be nearly 405.36 MWh instead of 408 MWh due to the inlet pressure losses caused by the heat exchanger, and the increase in the power was found to be nearly 0.1%. Therefore, it does not seem logical to operate the absorption system during the month of March and should be considered within the cold period.

Clearly, the reduction in power output was observed to happen during the hot months of April, May, June, July, August, September and October. Figure (6) shows the variation of power output for the month of April, it was found to be 401.5 MWh which represent an average 1.6% reduction in daily power out put compared to the design power output of 408 MWh. Figure (7) pictures the variation of daily power output of the month of May, which indicates that the reduction in the power output is high than that for the April month due to high temperature, the average reduction is nearly 6.7% and the maximum reduction was measured to be 11.9%. The power output with cooling is slightly lower than the design value by nearly 1.3% due to inlet pressure loss caused by the heat exchanger.

Figure (8), indicates in the daily power output with cooling and without cooling for the month of June. The daily power output when no cooling involved was found to be 363MWh which represent an average reduction in daily power out of 11%, while the maximum reduction in daily power output was obtained to be approximately 16.7%. Moreover, July and August are surely the hottest months in the year where the ambient temperature reaches over 40 ˚C. Therefore, the cooling system should operate at 100% capacity and 24 hours a day in order to boost the power production to near design value. Figure (9) shows the variation of power output for the month of July with and without cooling. The average daily reduction in power output was found to be 13.45% according to the obtained daily power output of 353 MWh. The maximum daily reduction in power output was found to be approximately 18.9% . Figure (10) shows the variation of daily power output of the month of August when no cooling and cooling system is used. The daily power output was found to be 354.8 MWh which indicates an average reduction in daily power out of 13% compared to the design value of 408 MWh. The maximum reduction in daily power output was obtained to be approximately 18.75%.

Figure (11) shows the daily power output profile for the month of September. The daily power output was found to be 369.5 MWh which indicates an average daily power reduction of 9.5%. Furthermore, the maximum reduction in power out was obtained to be nearly 16.4% . Again the absorption system should operate 24 hours to obtain a constant power production which is lower than the design value by nearly 1.3% due to the inlet losses.

In October, the ambient temperature is lower than that of September, but higher than 15˚C for most of day hours except for a short period of time which lies between midnight and early morning. Hence, the absorption system should operate overall the period of ambient temperature higher than 15˚C. The daily power output in this month was determined to be nearly 390 MWh which indicates an average daily reduction of 4.35% compared to the design value of 408 MWh, as shown in figure (12).

Figure (13) shows the variation of gas turbine daily power for the month of November. It is quite obvious that the reduction in daily power is very small and take place only for short period, i.e. 9.0 A.M to 3.0 P.M. The daily power was found to be nearly 404.5 MWh which represent an average daily reduction of 0.78%. While the maximum daily power output reduction was obtained to be 0.85%. the peak reduction in power was obtained in June to be 18.9% as well as the average daily reduction peak was found to be 13.6% as shown in figure (14). Moreover, the annual power output reduction on daily bases was found to be nearly 5.12% which indicate the necessity of using inlet cooling system to overcome such significant reduction. However, the use of a single stage LiBr-H_2O absorption chiller in conjunction with the gas turbine unit cause it to produce nearly constant power output through out the year irrespective of the increase in ambient temperature as shown in figure (15).

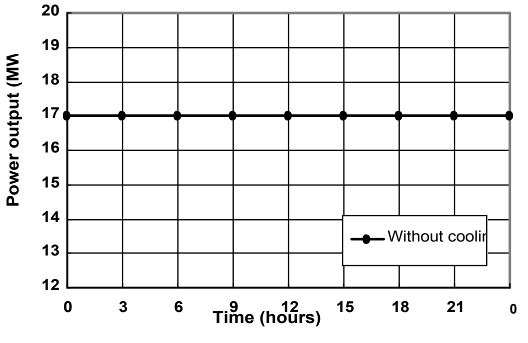


Figure (4): Simulation of the performance of Mosul gas turbine without cooling for January

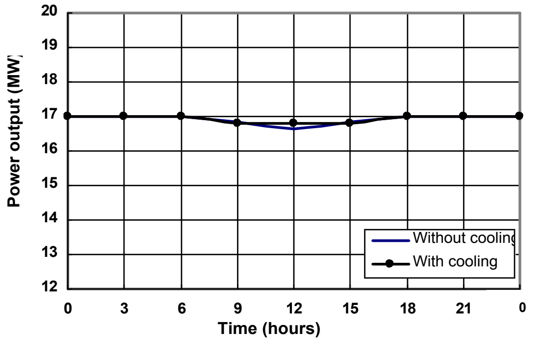


Figure (5): Simulation of the performance of Mosul gas turbine without cooling for March

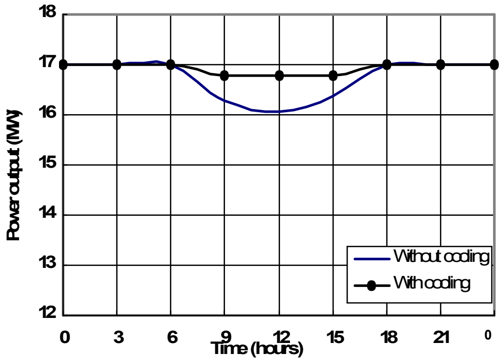


Figure (6): Simulation of the performance of Mosul gas turbine with and without cooling for the month of April

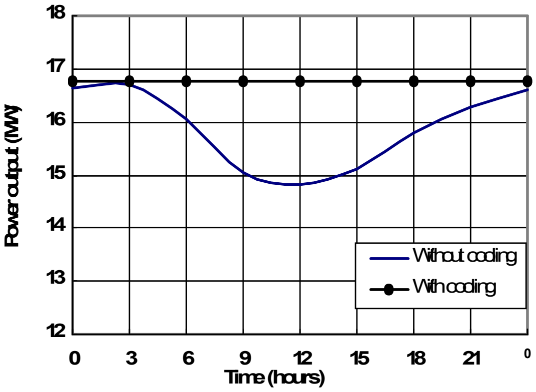


Figure (7): Simulation of the performance of Mosul gas turbine with and without cooling for the month of May

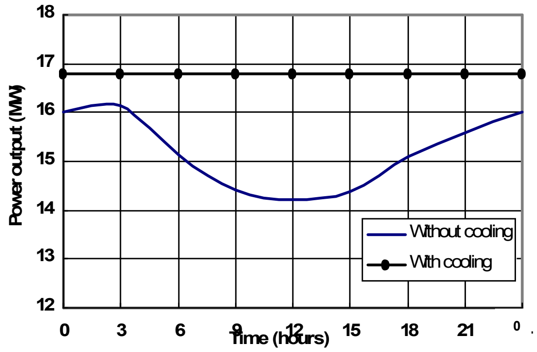


Figure (8): Simulation of the performance of Mosul gas turbine with and without cooling for the month of June

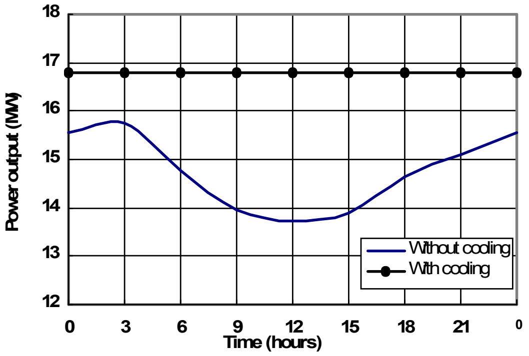


Figure (9): Simulation of the performance of Mosul gas turbine with and without cooling for the month of July

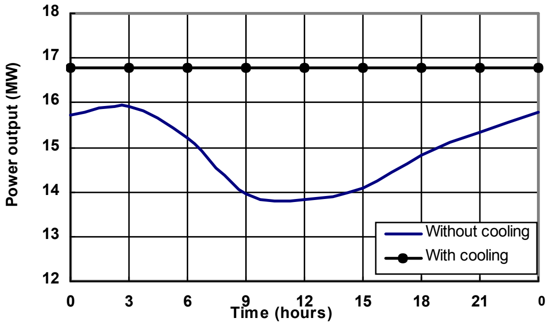


Figure (10): Simulation of the performance of Mosul gas turbine with and without cooling for the month of August

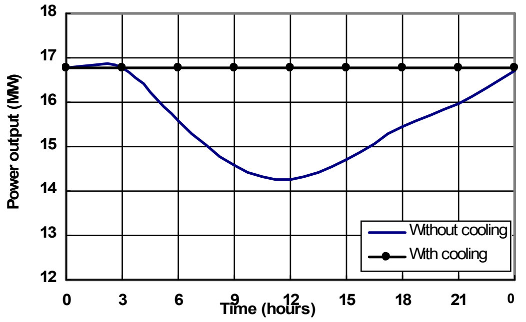


Figure (11): Simulation of the performance of Mosul gas turbine with and without cooling for the month of September

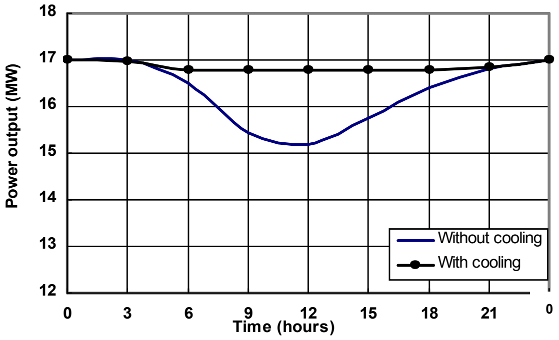


Figure (12): Simulation of the performance of Mosul gas turbine with and without cooling for the month of October

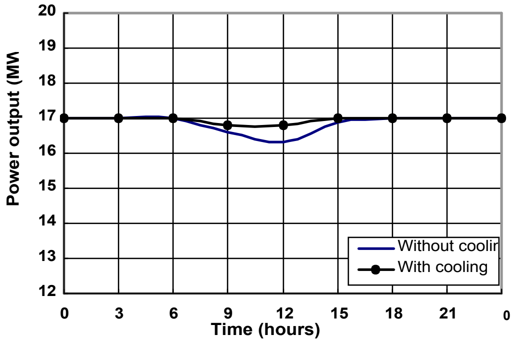
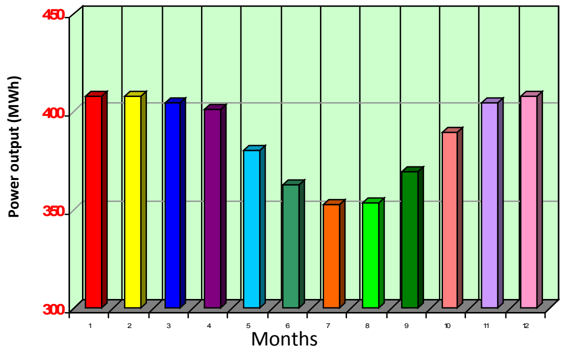


Figure (13): Simulation of the performance of Mosul gas turbine with and without cooling for the month of November



Figure(14): Daily power output without cooling for each month of Mosul gas turbine, unit12.

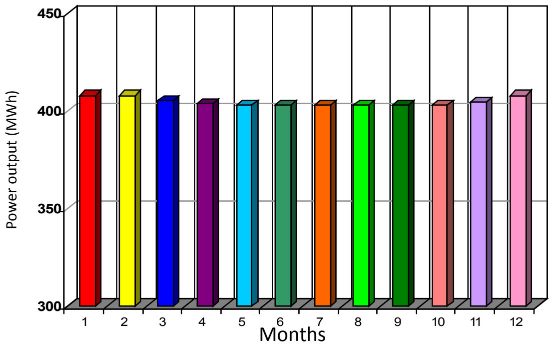


Figure (15): Daily power output with cooling for each month of Mosul gas turbine, unit12.

2- Economic results

An economic analysis has been performed for both cooling and no cooling. The life cycle cost has been adopted as convenient criteria to explore the economic benefit of using the single stage LiBr absorption system. The costs of the gas turbine generator as well as the single stage LiBr absorption system were obtained. The annual energy cost was assessed on the basis of natural gas cost of $6/MMBtu [10,11], as well as the unit power cost, maintenance costs for both the power and the cooling system are obtained [12].

Obviously, the key figure in economic analysis is the present worth factor (PWF), because it contains information about the interest and inflation rates. These two variables control the success of any conservation technique in reducing the life cycle cost, LCC, of the complete energy system.

In the present study the lifetime of the gas turbine generator as well as the single stage absorption system is considered to be 25 years. The values for interest rate, i, was varied in the range of 0% to 10%, while the inflation rate is considered to be in the range of 0% to 6%. Two main cases were considered, those are: 1) gas turbine with and without cooling and, 2) when a small standby gas turbine is used.

In this case the life cycle cost is based on the annual power output produced by the gas turbine generator in absence of the cooling system and then is calculated when the cooling system is added, thereafter, a comparison can be made between them.

Figure (16) shows the variation of the life cycle costs with and without cooling for various interest rates at an inflation rate of 0%. It was found that the life cycle cost of gas turbine with the cooling system is lower than that of no cooling by approximately 8%. The life cycle saving also plotted for various value of interest rate at inflation rate of 0 %, which indicates that nearly 15 millions dollars saving occurs for interest rate of 1%, then decreases as the interest rate increases as shown in figure (16).

Figure (17) shows the variation of the life cycle costs for both cooling and no cooling for inflation rate of 1%. Again the life cycle costs indicate that the use of the absorption system resulted in energy saving by nearly 8%. However, it was observed that the life cycle costs increase as the inflation rate increase.

Examining these figures, two main characteristic features can be identified, first , for a given inflation rate, the life cycle cost decreases as the interest rate increases and, second, for a given interest rate the life cycle cost increases as the inflation increase. Because all costs are discounted to present worth using the present worth factor (PWF) which is function of interest and inflation rate. Furthermore, in all cases it was found that the life cycle cost for the cooling case is lower than that of using standby gas turbine generator by nearly 8%. This consistent differences is undoubtedly due to the present worth value (PWF) that effects the life cycle costs for both cases, cooling and no cooling.

Therefore, a conclusion can be made that the life cycle cost is inversely proportional to the present worth factor (PWF), this means, as the inflation rate increase or the interest rate decrease the life cycle cost increase and the necessity of applying energy conservation increase

In the second case if it presume no absorption system is used, the reduced power during hot periods can be made up by a small standby gas turbine to be operated only when a reduction in power output occurs due to high ambient temperatures. This is a practical method that is often used by utility companies to keep their daily production of electricity nearly unchanged throughout the year.

Figure (18) shows the variation of life cycle costs for various interest rates at an inflation rate of 0 % when an absorption system and when a small standby gas turbine is used. It was found that the life cycle cost with cooling is lower than that of using standby gas turbine by approximately 10 %. The capacity of the small standby gas turbine generator in this study was found to be 3.5 MWh to meet the peak daily reduction in power for the month of July.

Figure (19) shows the variation of life cycle cost at various interest rates at an inflation rate of 1%. Similar results was found with higher life cycle cost for given interest rate, however, the life cycle cost with cooling was observed to be lower that of using standby gas turbine by nearly 10%. Similar profile of the life cycle costs with cooling and when small standby gas turbine is used for various interest rates at inflation rates 2, 3, 4, and 6 % respectively. Again examining these figures, two main characteristic features can be identified, first, for a given interest rate, the life cycle cost increases as the inflation rate increases and, second, for a given inflation rate the life cycle cost

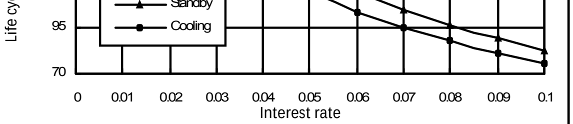


Figure (18): Life cycle costs for gas turbine with cooling and when a standby gas turbine is used for various interest rates at inflation rate of 0%

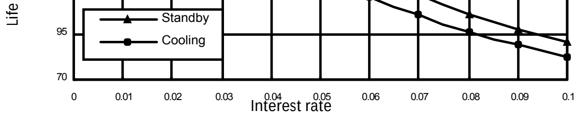


Figure (19): Life cycle costs for gas turbine with cooling and when a standby gas turbine is used for various interest rates at inflation rate of 1%

decrease as the interest rate increases. Moreover, in all cases it was obtained that the life cycle cost for the absorption refrigeration case is lower than that of using standby gas turbine generator by nearly 10%. This consistent differences is undoubtedly due to the present worth value (PWF) that effects the life cycle costs for both cases, cooling and no cooling. The life cycle cost differences in this case is relatively higher than that of case 1, this is due to high initial cost and operating cost of the standby gas turbine in comparison to that of the absorption refrigeration system.

Finally, economic analysis indicated that applying a single stage LiBr to boost the gas turbine power output in hot period is a valuable technique and should be considered.

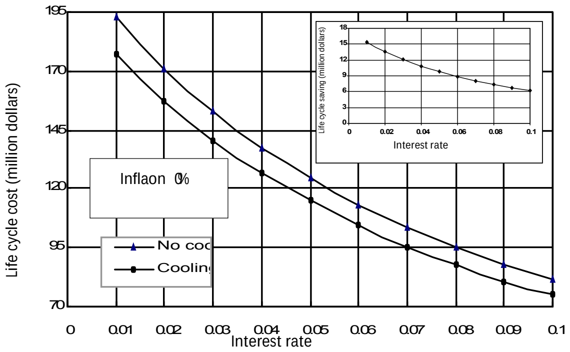


Figure (16): Life cycle costs for gas turbine with and without cooling for various interest rates at inflation rate of 0%

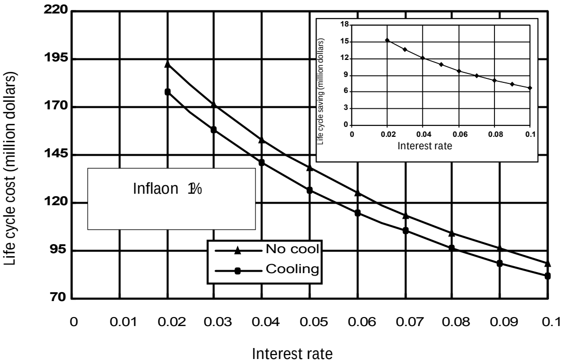


Figure (17): Life cycle costs for gas turbine with and without cooling for various interest rates at inflation rate of 1%

References

1- Frank J.Brooks, GE Gas Turbine Performance Characteristics, GE Power system, Oct.2001. www.mullerenvironmental

2- Jack D. Mattingly, Element of Gas Turbine Propulsion, McGraw-Hill Book Co., 1996.

3- Johnson R. S., The theory and Operation of Evaporative Cooler for Industrial Gas Turbine, Journal of Engineering for Gas Turbine and Power, Vol. 111, pp.327-334, April 1989.

4- Ondryas I. S., Haub G. L., Option in Gas Turbine Power Augmentation Using Inlet Air Chilling, Journal of Engineering for Gas Turbines and Power, Vol.113, No.2, pp. 203-211, 1991.

5- Malewski W. F., and Holldorft, G. M., Power Increase of Gas turbine by Inlet Air Precooling with Absorption Refrigeration Utilizing Exhaust Waste Heat, ASME International Gas Turbine Conference, Paper No 86-GT-67, Duseldorf June 1986.

6- De Lucia M., Bronconi, R., and Carneval, E., Performance and Economic Enhancement of Cogeneration Gas Turbine Through Compressor Inlet Air Cooling, ASME Journal of Engineering for Gas Turbine and Power, Vol. 116, pp.360-365, 1994.

7- Jan Szargut, Influence of the Ambient Temperature on the Operational Indices of the Gas Turbine Set, International Journal of Energy Research, Vol. 24, pp. 821-830, 1999.

8- MacDonald, J. A, Turbine Performance Enhancement Option Boost Power Plant Output, Energy Tech., pp.18-27, June 2003.

9- Kahwaji.Y.Ghalib, Habbo Mohammed A.R, Computer Simulation of the Performance of Industrail Gas Turbine with Application to Mosul Power Station, Alrafiden Vol 4 2005.

10- Henry Manczyk, CPE, CEM, Economic Analysis for an Energy Management System in a Commercial Type Office Building, ManCzyk Energy Consulting, 2003. www.energy.rochester.edu/energy/economic-analysis

11- Henry Manczyk, CPE, CEM, Life Cycle Cost Analysis Selection of Heating Equipment, ManCzyk Henry Manczyk, CPE, CEM, Economic Analysis for an Energy Management System in a Commercial Type Office Building, ManCzyk Energy Consulting, 2003 www.energy.rochester.edu/efficiency/life-cycle-analysis.

12- Oregon Department of Energy Report, Estimating the Cost of Generating Electricity 2002.