Volume 1, Issue 12, pp. 1-7, 2017.
International Journal of Scientific Engineering and Science
ISSN (Online): 2456-7361

Design of Pre-Cooler for Gas Turbine at Garri (1and2) Power Station by Using Vapor Compression Refrigeration System

Jassim Salah Mohammed[1], Ali Mohamed Hamdan[2], Ramadan Mohmmed[3]
[1]Sudanese Thermal Power Generation Company, Khartoum, Garri, Sudan
[2, 3]Sudan University of Science and Technology, Khartoum, Khartoum North, Sudan

Abstract—*Gas-turbine inlet air cooling has been considered for boosting the power output during hot seasons, the gas turbine being a constant volume-flow machine, the power of the gas turbine is directly proportional to the mass flow rate of air passing through it, which is directly proportional to sucked air density. A high ambient temperature reduces the air density. Gas turbines designed to operate at standard conditions of 15°C therefore gas turbine loose a significant portion of their generating capacity when installed in hot climates. Reduce the temperature of inlet air by using chilled water to the design condition increase output power by 8 MW for each turbine in Garri power plant these amount of power equals 25% of the rate power of turbine. This research is the trial to calculate the increase in output power from gas turbine by designing pre cooler system to increase the efficiency and output power of the turbine*.

Keywords— *Gas turbine, Power augmentation, Evaporator cooling, Chiller cooling, ANSYS software*.

I. INTRODUCTION

Gas turbines are used for power electric generation, operating airplanes and for several industrial applications, The gas turbine engine consist of a compressor to raise combustion air pressure, a combustion chamber where the fuel/air mixing is burned, and a turbine that through expansion extracts energy from the combustion gases, These cycles operates according to the open Brayton thermodynamic cycle and present low thermal efficiency and are referred as combustion turbines. Usually, the rated capacities of combustion turbines are based on standard ambient air, and zero inlet and exhaust pressure drops, as specified by the International Standardization Organization (ISO) Therefore, the air inlet conditions are: air temperature 15 °C, relative humidity 60%, absolute pressure 101.325 k Pa at sea level. [1]

Discussed Power augmentation methods, which could be applied to existing gas turbines, can be divided into two main categories. The first category includes inlet air cooling techniques and the second involves techniques based on the injection of compressed air, steam, or water. [2]

There is research study the effect of using evaporative cooler at combined cycle (Garri)the power produced from gas turbine increased by 4 MW and steam turbine increased by 1 MW. [3]

Gas turbines have been used for power generation in several places in the world, and each region has different climatic conditions. Furthermore, the periods of the peak electricity demand occur during the summer, when the ambient temperature is high. For example, in Arabian Gulf region the average ambient temperature presents a variation by more than 30 °C from summer to winter and this factor generate a large drop in power output during the summer Due to these severe ambient conditions, the turbine inlet air cooling is one of many available technologies to improve the performance of the gas turbine power plants by cooling the air at the compressor entry. Thus, the interest in the intake air cooling techniques for gas turbines has augmented in the last years, due the increasing requirement for power to a low specific investment cost .[4]

Two different methods are frequently employed to obtain turbine inlet air cooling: the evaporative cooling and inlet chilling systems. Several works has been studied these cooling technologies as below detailed. Presented a comparison between two usual inlet air cooling methods, evaporative cooler and mechanical chiller, and one new technique that uses turbo-expanders to improve performance of a gas turbine located at the Khangiran refinery in Iran. [5]

Gas turbine plants are used for electricity production in many countries around the world because of their low capital cost, short synchronization time of 30 minutes (time required for gas turbine to reach the base load from zero speed), stability with regard to the electricity grid and availability in many countries, including in this case Egypt. Total electricity generated by gas turbine plants in Egypt is about 7001 MW, from deferent gas turbine models and capacities varying from 25 MW to 260 MW.[6]

An exergy economic and environment analysis for a 4900 kW absorption chiller integrated with a 159 MW gas turbine unit located at Bushr-Iran. The analysis shows that the gas turbine's power increases from 137 MW to 153 MW during the hottest month (August) when the inlet air was cooled from 37°C to 15°C. Moreover, efficiency rose from 33.4% to 43.2%. [7]

Generally such system guaranties for certain dry inlet temperature and based on the maximum conditions of environmental design. These kinds of systems may have a secondary circulating cycle of Glycol-water in the fan-tubes and also the filter chamber, Thermal storage: For thermal storage, the chilling system is applied. However, a great amount of glycol-water the inlet air circulates into the fan-tubes or pipes in order to decrease the internal power consumption of chilling system during climate load periods. [8]

Volume 1, Issue 12, pp. 1-7, 2017.
ISSN (Online): 2456-7361

With the operation during summer season, the increase of ambient temperature leads to a decrease in gas turbine plants power output with25-35%, also leading to an average increase of the consumption of fuel 6%. The effect of intake air temperature over the performances differs from one gas turbine to another, but, generally, aero derivative gas turbines are more sensitive to this phenomenon than the industrial gas turbines. [9]

Some authors consider that air relative humidity even at temperatures higher than 10 °C has a neglect able influence over the gas turbine output power as the other performance parameters. This leads to the fact that in some calculus (especially when the results are presented in correlation to ISO conditions) the variations in atmospheric humidity and pressure to be neglected. Others consider that due to the fact that water content modifies thermodynamic properties of inlet air (density, specific heat), at certain gas turbines (depending on specific processes) the performances may increase when humidity rises and in the case of some gas turbines the performances may decrease in the same conditions. [10]

However, the increase in relative humidity leads to a significant reduction of NOx emissions, ambient pressure is defined by the conditions from plant location, altitude modification leading to air density modification and implicitly to power output variation. Thus, 3-4% losses occur for each 304.8 m (1000 ft) rise in altitude. [11]

II. ENVIRONMENT DESCRIPTIN

Garri power station is located 70 km north of Khartoum. The station consists of eight gas turbines. Four of them (located in Garri 1) are of type PG6581 (58khp design power), which are equipped with heat recovery and connected to two steam turbines as combined cycles (Fig. 1). Three of the other four turbines (located in Garri 2) are type PG6551 (55khp design power), which were commissioned in 2003 and used to work as open cycles. In 2007, a fourth gas turbine, type PG6581 was added together with two steam turbines to Garri 2 block so as to become similar to Garri 1.

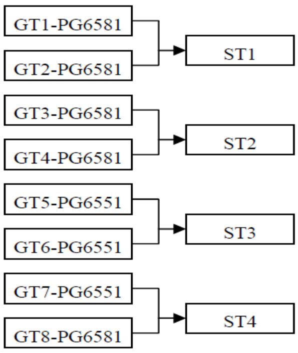

Fig. 1. Layout of Garri power plant.

The climate of the area is the semi desert climate influenced by the north-south movement of dry northerly winds and moist southerly winds that produce a wet summer and a dry winter. Fig. 2 shows the average maximum and minimum daily temperature and rainfall .Due to the high ambient temperature, there is a drop of 10 MW in each turbine of type PG6581 and 8 MW in each turbine of type PG6551. The total loss of power is 74MW in the eight gas turbines. This waste power could be recovered to the national grid, which suffers from power shortage. From Fig 2, there is a potential to reduce the inlet air temperature to 15 °C for the gas turbines at Garri power station. [3]

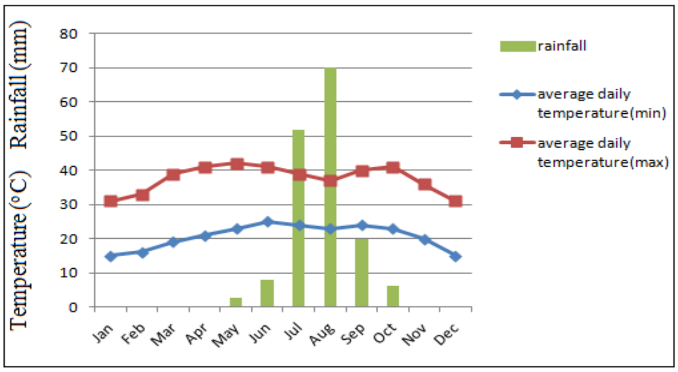

Fig. 2. Climatically data of Garri.

III. WATER AVAILABILITY AT GARRI

The coolers used the service water available in the plant which is taken from the Nile and treated in the pretreatment plant of the power station. The pretreatment system consists of pre settler, clarifier, pumps and piping to transfer the water to the power stations. Mainly aluminum poly chloride is used to remove the mud and sodium hypocloride is used for the removal of algy. The water specification is shown on table I.

TABLE I. Specifications of Garri Service water.

No	Test	Unit	Value
1	PH	-	7.8
2	Conductivity	µs/cm	200
3	Total Hardness	ppm	70
4	Calcium Hardness	ppm	30
5	Chloride	ppm	5.2
6	TDS	ppm	110
7	Alkalinity	ppm	76
8	Silica	ppm	8.6
9	Iron	ppm	-
10	TSS	ppm	<1

IV. SOLVING METHODOLOGY

We will use ANSYS software to simulation before that we need to design of the heat exchanger. The thermodynamics specifications of fluids and heat exchanger specifications as shown in table II below

TABLE II.The Thermodynamics Specifications of Fluids and heat Exchanger.

Specifications	The value
Air flow rate (ma)	145(kg/sec)
Inlet chilled water temperature (T chi)	7 °C
outlet chilled water temperature (Tcho)	12°C
Inlet air temperature (Tai)	43°C
outlet air temperature (Tao)	15°C
Specific Heat of air (CPa)	1.007 (kJ/kg.K)
Specific Heat of chilled water(CPcw)	4.197(kJ/kg.K)
Outer, Inner Diameter of the large pipe (Do ,Di)	107.6-101.6 (mm)
Outer , Inner Diameter of the small pipe (do ,di)	10-8 (mm)
Length of the small pipe	7 (m)
d(both sides), space (both sides)	0.02-0.02 (m)
Fouling factor of chilled water, air (Rf,cw , Rf,a)	0.0001-0.0004 K/W
Density of chilled water , air	999.7-1.1694 kg/m3
Kcopper	401 W/m K

International Journal of Scientific Engineering and Science
Volume 1, Issue 12, pp. 1-7, 2017. ISSN (Online): 2456-7361

Calculate the quantity of heat transfer in heat exchanger by the following equation

$$Q_a = m_a * cp_a * (T_{ai} - T_{ao}) \quad (1)$$

Use10% as safety factor

$$Q_{design} = (1 + 0.10) * Q_a \quad (2)$$

Calculate the mass flow rate of chilled water by the following equation

$$m^{\cdot}_{ch} = \frac{Q_{design}}{cp_{ch} * (T_{cho} - T_{chi})} \quad (3)$$

Calculate the number of rows by the following equation

$$\text{Number of rows} = \frac{L}{d_{(\text{both sides})} + \text{space}_{(\text{both sides})}} \quad (4)$$

Calculate the log mean temperature difference by the following equation

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})} \quad (5)$$

Calculate the value of P, R by the following equation and then determine correction Factor (F) from Curve .[12]

$$P = \frac{t_2 - t_1}{T_1 - t_1}, R = \frac{T_{1-} T_2}{t_2 - t_1} \quad (6)$$

Calculate the flow rate of chilled water through the large pipe by the following equation

$$m^{\cdot}_{cw} = \rho_{cw} * A_{cw} * V_{cw} \quad (7)$$

Calculate the flow rate of chilled water through the small pipe by the following equation

$$q_{tube} = \frac{q_{supply}}{N_{row}} \quad (8)$$

Calculate the Velocity of chilled water through the small pipe by the following equation

$$v_{tube} = \frac{q_{tube}}{A_{tube}} \quad (9)$$

Calculate the Heat Resistance by conduction by the following equation

$$R_{wall} = \frac{\ln(\frac{d_o}{d_i})}{2 * \pi * k * l} \quad (10)$$

Calculate the convection heat transfer coefficient for chilled water (inside tube) by the following equation

$$h_{cw} = \frac{Nu_{cw} * K_{cw}}{d_i} \quad (11)$$

Calculate the convection heat transfer coefficient for air (outside tube) by the following equation

$$h_a = \frac{Nu_D * k_a}{d_o} \quad (12)$$

Calculate the overall heat transfer coefficient by the following equation

$$\frac{1}{U_o * a_o} = \frac{1}{h_i * a_i} + R_{wall} + \frac{1}{h_o * a_o} + \frac{R_{f,i}}{a_i} + \frac{R_{f,o}}{a_o} \quad (13)$$

Calculate the area of heat exchanger by the following equation

$$A_o = \frac{Q}{U_o * LMTD * F} \quad (14)$$

Calculate the number of tubes to install inside the intake air filter house by the following equation

$$N_{tubes} = \frac{A_o}{\pi * d_o * l} \quad (15)$$

Calculate the number of cooling stages by the following equation

$$Nst = \frac{N_{tubes}}{N_{row}} \quad (16)$$

V. RESULTS AND DISCUSSION

A. Effect of Air Density

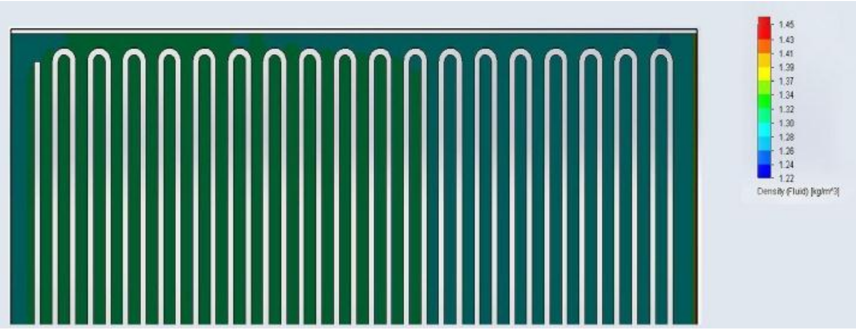

Fig. 3. Air density distributions in heat exchanger.

Volume 1, Issue 12, pp. 1-7, 2017. ISSN (Online): 2456-7361

B. Effect of Air Temperature

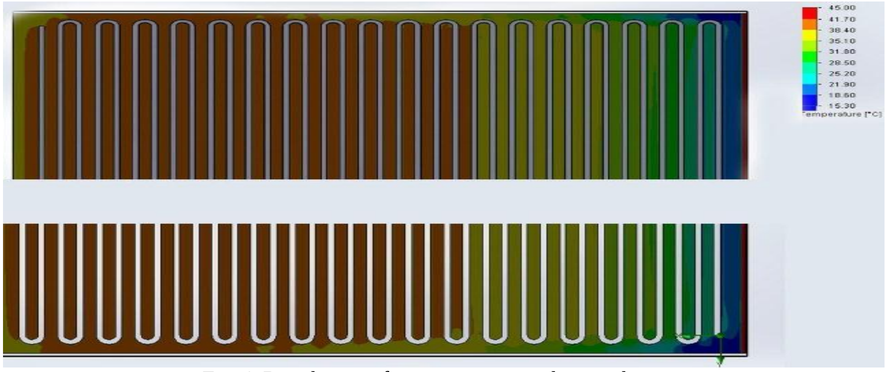

Fig. 4. Distribution of air temperature in heat exchanger.

C. Effect of Air Pressure

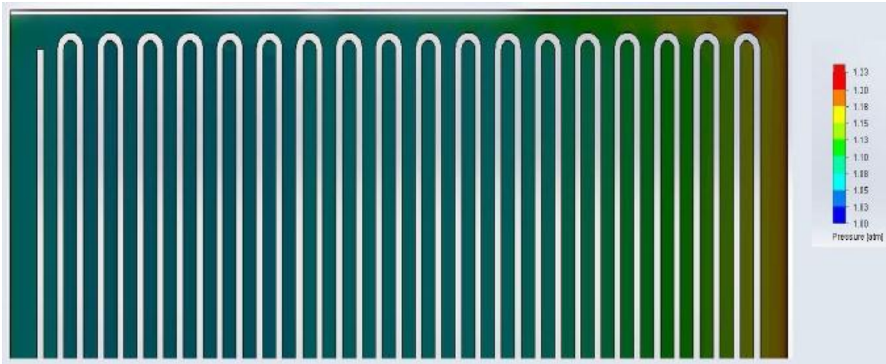

Fig. 5. Air pressure distributions in heat exchanger.

D. Effect of Air Velocity

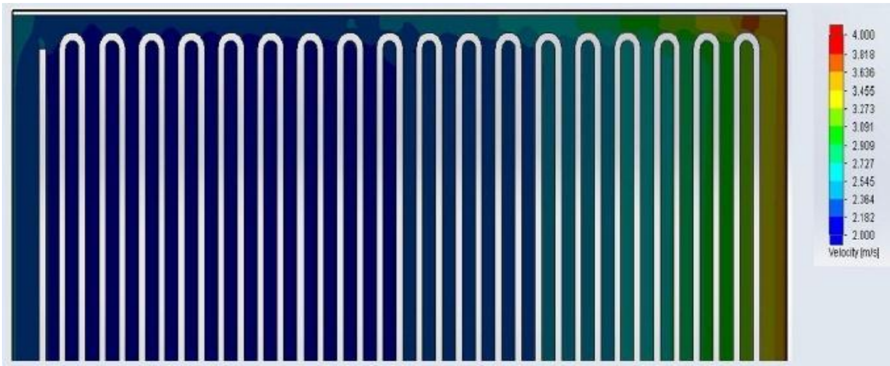

Fig. 6. Distribution of air velocity in heat exchanger.

The result compared before and after using chilling system, the comparison at power generated, Efficiency and heat rate. table III and table IV show the effect on the gas turbine, power generated, efficiency and heat rate Before installing the system and after installing chilling cooler as expected result to the unit design.

TABLE III. Power generated, efficiency and heat rate at gas turbine before and after install evaporator unit.

Before installing Evaporator system				After install Evaporator system				Saved
Unit	**Power generated at 5 July 2008**	**Efficiency%**	**heat rate kJ/kWh**	**Unit**	**Power generated at 5 May 2010**	**Efficiency%**	**heat rate kJ/kWh**	**Heat rate kJ/kWh**
Unit 1	**30**	**30**	**11909.0**	Unit 1	**34**	**31**	**11463.0**	**446**
Unit 2	**30**	**29.8**	**12048.7**	Unit 2	**34**	**31**	**11463.3**	**585.4**
Unit 3	**29**	**30**	**11886.7**	Unit 3	**32.5**	**31**	**11422.3**	**464.4**
Unit 4	**27.5**	**29**	**12353.7**	Unit 4	**31**	**31**	**11562.2**	**791.5**
Unit 5	**28**	**28**	**12772.1**	Unit 5	**31**	**29.4**	**12244.0**	**528.1**
Unit 6	**28**	**27**	**13287.0**	Unit 6	**31.5**	**28.5**	**12636.4**	**650.6**
Unit 7	**28**	**28.5**	**12630.8**	Unit 7	**31**	**29**	**12412.4**	**218.4**
Unit 8	**31**	**28**	**12767.0**	Unit 8	**35**	**29**	**12388.5**	**378.5**
Average								**507.8**

International Journal of Scientific Engineering and Science
Volume 1, Issue 12, pp. 1-7, 2017. ISSN (Online): 2456-7361

TABLE IV. Power generated efficiency and heat rate at gas turbine before and after install chilling unit.

Before installing chilling system				After install chilling system				Saved
Unit	**Power generated at 5 July 2008**	**Efficiency%**	**Heat rate kJ/kWh**	**Unit**	**Power designed**	**Efficiency%**	**heat rate kJ/kWh**	**Heat rate kJ/kWh**
Unit 1	**30**	**30**	**11909.0**	Unit 1	**42**	**32**	**11225.7**	**683.3**
Unit 2	**30**	**29.8**	**12048.7**	Unit 2	**42**	**32**	**11225.7**	**823**
Unit 3	**29**	**30**	**11886.7**	Unit 3	**42**	**32**	**11225.7**	**661**
Unit 4	**27.5**	**29**	**12353.7**	Unit 4	**42**	**32**	**11225.7**	**1128**
Unit 5	**28**	**28**	**12772.1**	Unit 5	**42**	**32**	**11225.7**	**1546.4**
Unit 6	**28**	**27**	**13287.0**	Unit 6	**42**	**32**	**11225.7**	**2061.3**
Unit 7	**28**	**28.5**	**12630.8**	Unit 7	**42**	**32**	**11225.7**	**1405.1**
Unit 8	**31**	**28**	**12767.0**	Unit 8	**42**	**32**	**11225.7**	**1541.3**
Average								**1231.17**

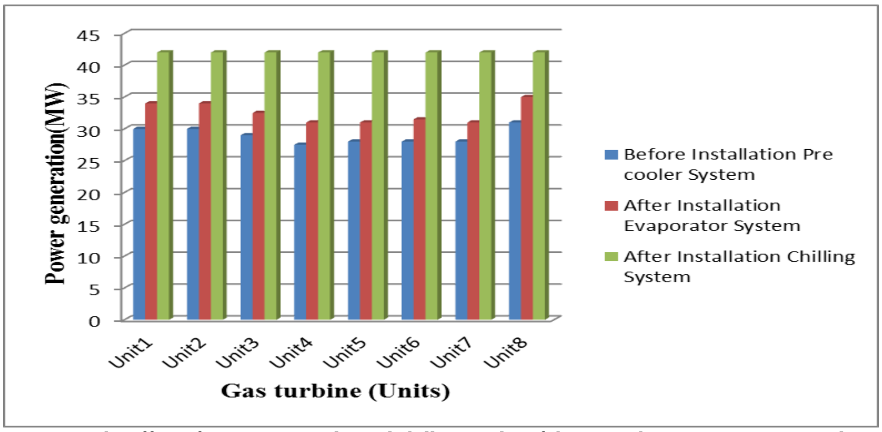

Fig. 7. The effect of evaporator cooler and chilling cooler of the gas turbine in power generated.

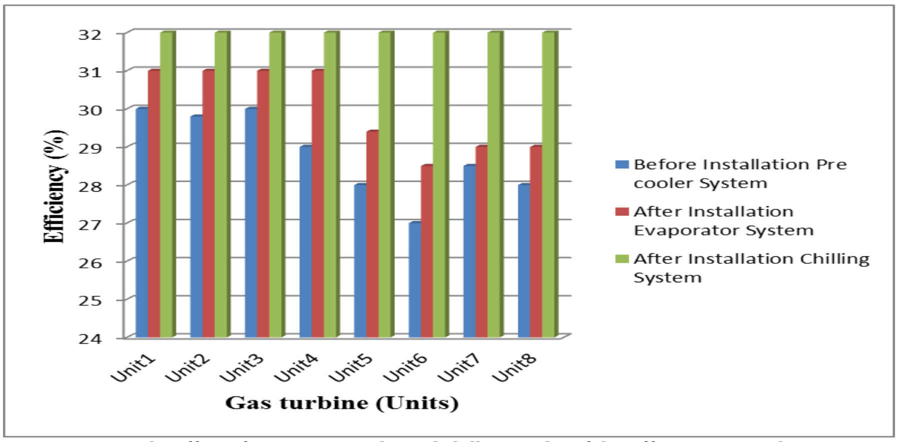

Fig. 8. The effect of evaporator cooler and chilling cooler of the Efficiency gas turbine.

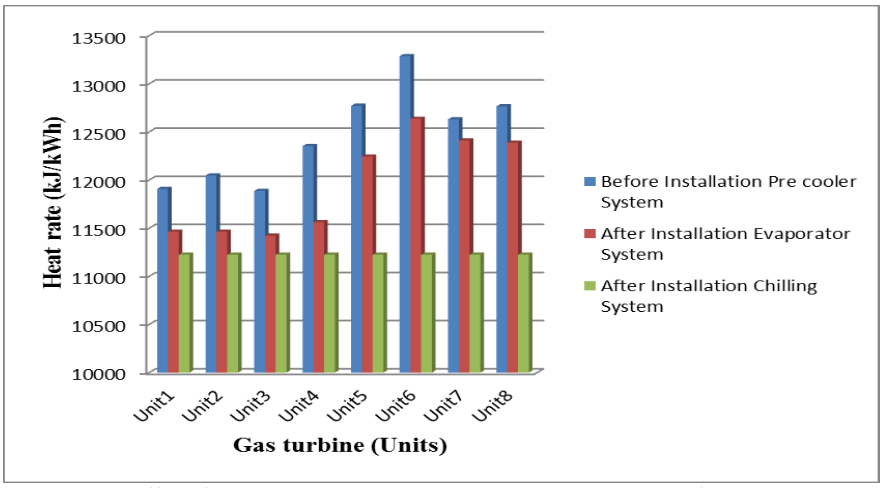

Fig. 9.The effect of using evaporator cooler and chilling cooler in heat rate of the gas turbine.

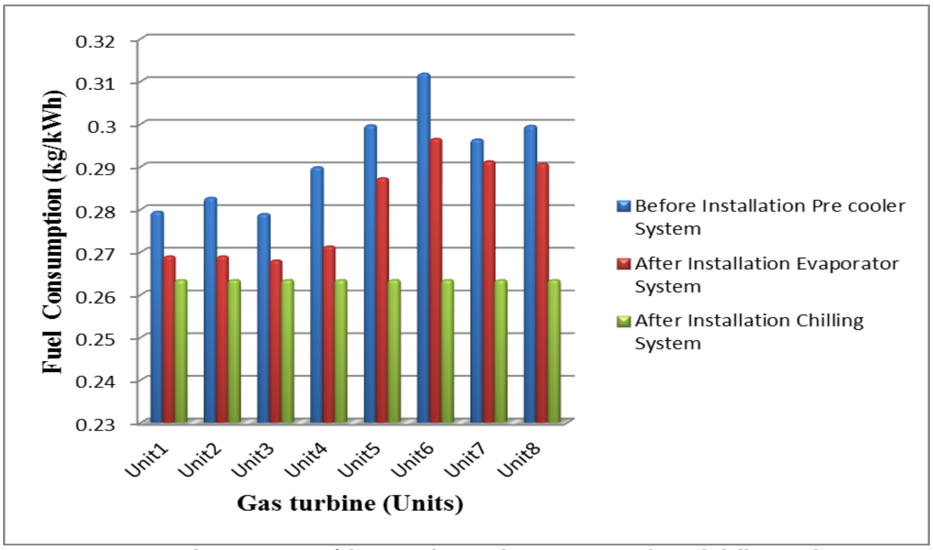

Fig. 10. Fuel consumption of the gas turbine with Evaporator cooler and chilling cooler.

1. Evaporator Cooler

The system gave a total power increase of 32.5 MW. NEC sells electricity at a rate of 0.1 SG/kWh for residential consumers and at a rate of 0.26 SG/kWh for industry. Assuming full capacity operation at an average rate of 0.23 SG/kWh (0.072 Euro/kWh), the additional megawatts give NEC 7475 SG (2336 Euro) per hour of operation. From this revenue alone, the system could pay back its initial cost of 1,310,000 Euro in 561 hours, or 24 days of full-capacity operation. The initial cost of one unit is163, 750 Euro (524000SDG). [3]

2. Chiller Cooler

The cost of purchasing and installation single chiller = 2000000 SDG.

The cost of purchasing and installation three chillers=3*2000000=6000000SDG.

The cost of purchasing and installation Heat Exchanger = 2750000 SDG.

Total cost of chiller system =6000000+2750000=8750000SDG.

KWh price =0.17 SDG/ KWh.

The increase in output power after pre cooler per hour=8 MWh.

The price of the increased power output per day=8*1000*24*0.17 =32640SDG/day.

The payback period

$$= \frac{\text{Total cost for chiller system}}{\text{The price of the increased power output per day}}$$

= 8750000/32640 =268.0759

VI. Conclusion

The compressor use 1.6944 MW on the other hand the net available power after using this system is 8MW from one unit, the total power from the plant is 64MW equal to one and half gas turbine. Considering that the installation of new gas turbine units takes more time and high cost of the cooling system also finding energy sources for these new stations is a problem In addition to the environmental pollution. The new power plant can be delayed by enhancing the production capacity of existing power stations. In this research the maximum output power from the plant and cooling load calculated on the maximum temperature of surrounding air of Garri 43 °C and the inlet air to the compressor cooled to design inlet temperature 15oC by using chilling system.

Acknowledgment

First of all I would like to submit my best greeting to my supervisor Dr. Ali Mohammed Hamdan for his acceptance to supervise my research and for his directions during preparing this research. Also my full respect and appreciation to my all friends, colleagues and co-worker enhanced me in this research and helped me in data collection stage. Finally, a lot of thanks to Garri Power Station Directorate which gave me permeations to apply this research and analysis in the station and has been supplying me by all data I needed throughout the research.

References

[1] Ibrahim T. K, Rahman M. M and Abdalla A. N., "Improvement of gas turbine performance based on inlet air cooling systems: A technical review," *International Journal of Physical Sciences*, vol. 6 issue 4, pp. 620-627, 2011.

[2] *Gas Turbine Engineering Handbook*, 2nd ed, United States: Gulf Professional Publishing, Boyce MP, pp. 30-34, 2002.

[3] O.H.M. El-Hassan, M.M.E-Awad, "The experience with media-type evaporative cooling for gas-turbine power augmentation at garri powerstation," Garri power plant, Khartoum North, (2-4-5-6), 2009.

[4] Nasser A.E.M, El-Kalay M.A, "A heat-recovery cooling system to conserve energy in gas-turbine power stations in the Arabian Gulf," Applied Energy, vol. 38, issue 2, pp. 133–142, 1991.

[5] Ana Paula P. dos Santos, Claudia R. Andrade, and Edson L. Zaparoli. "Comparison of different gas turbine inlet air cooling methods," *International Journal of Mechanical Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, vol. 6, issue 1, pp. 40-45, 2012.

[6] Ali Marzouk, Abdalla Hanafi, "Thermo-Economic Analysis of Inlet Air Cooling In Gas Turbine Plants," *Journal of Power Technologies*, vol. 93, issue 2 , pp. 90-99, 2013.

[7] M. A. Ehyaei, S. Hakimzadeh, N. Enadi, and P. Ahmadi, "Exergy, economic and environment (3e) analysis of absorption chiller inlet air cooler used in gas turbine power plants," *International Journal of Energy Research*, vol. 36, issue 4, pp. 486–498, 2012.

Volume 1, Issue 12, pp. 1-7, 2017. ISSN (Online): 2456-7361

[8] Seyed Ali Sakhaei and Mahbod Safari, "Study and comparison of inlet air cooling technique of gas turbines and their effects on increase of the efficiency and outlet power," *International Journal of Materials, Mechanics and Manufacturing*, vol. 2, issue 4, pp. 329-334, 2014.

[9] Abam F., Ugot I., and Igbong D, "Performance analysis and components irreversibilities of a (25 MW) gas turbine power plant modeled with a spray cooler," *American Journal of Engineering and Applied Sciences*, vol. 5, issue 1, pp. 35-41, 2012

[10] Rainer Kurz, "Gas turbine performance. Procedings of the thirthyfourth turbomachinery Symposium," Solar Turbines Incorporated, San Diego, California, pp. 131-132, 2005.

[11] Roointon Pavri, Gerald D. Moore, "Gas Turbine Emissions and Control," GE Power System, Atlanta, GA, PP. 13-27, 2014.

[12] Yunus A.Cengel and Michael A. Boles, *Heat Exchange, Thermodynamics an Engineering Approach*, 5th ed, United States, McGraw-Hill, pp. 305-307, 2006.