Analysis of Power Cooling Cogeneration System Based on Combined Cycle Power Plant and Double Effect Absorption System

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Abstract- This studying of the Benghazi North Gas Cycle Power Plant (GCPP) in Libya consists of four simple cycle gas turbine units of 600 MW total capacity. The study performed the calculation of the basic thermal design of the units in order to determine the main parameters of the electric generation process.

The results of the study show low thermal efficiency (33%), high exhaust temperature (542°C), and high thermal losses in the exhaust (201.34) MW per unit The objectives are to solve these problems and to satisfy the future demand for electricity and to reduce the harmful emissions to protect the environment as a result of the geographical position of the station.

The effectiveness of using exhaust thermal energy to produce steam at high pressures in four HRSGs with four steam turbines has been studied. The results of the investigation of new solutions using mathematical models showed that on average, the power plant is produced using a gas turbine engine of about 4 * 148.6 megawatts of electricity and the amount of energy used by the waste temperature kettle is 85.16 megawatts each, which means that the total energy of the plant is reached About 4 * 233.77 MW, and the overall efficiency (51.9 %). In addition, we are supposed to use waste steam at low pressures from steam turbine cycles to provide an absorption system to supply the company accommodations with cold air. This suggestion indicated to increase in the overall cycle efficiency by up to (52.7%)

Index Terms - Gas Cycle Power Plant ((GCPP).

I. INTRODUCTION

Electric energy is the main motivator of the modern renaissance and the main source of different activities as nations' development is measured by their consumption of electric energy. Libya had found its way in the field of energy generally and in the field of electric energy especially. And the past few years witnessed an increase in the use of gas turbines for electricity production to cover the demand of the electrical network of Libya.

In recent years, most countries focused on decreasing the use of conventional energy sources with the increased feeling of the depletion of these sources besides the environmental interests. This motivated studies to try to find new ways to limit consumption by using secondary sources of energy for electricity production Recent energy studies show the effectiveness of using thermo-electric plants for electric generation and air conditioning systems. In these plants, both electric power and thermal energy are produced.

The Benghazi North Gas Cycle Power Plant (GCPP) is considered one of the main stations in the country; it started the operation with nominal power of 4x150 MW. Since the gas turbine units used in this station are able to be operated in combined cycles. In this station, both generation of electricity and thermal energy for some industrial uses or air conditioning systems take place. Taking into consideration the high consumption load of Libya, also the need for air conditioning at the site of the station

II. Problem Statement and Descriptions

To study the distribution of heat energy resulting from fuel combustion inside the gas turbine unit used in the station, and then the determination of heat quantity thrown to the surrounding with the exhaust gases and the electric energy produced from the unit, the thermal analysis of this unit must be made. Therefore, in the current study, the following method was used to conduct the thermal analysis of the gas turbine unit at the rated operating conditions, where this method relies on performing a relative thermal analysis for the main parts of the gas turbine unit (Per 1kg of the input air to the compressor) as well as treating the blades cooling system as a separate expansion cycle for the cooling air inside the gas turbine unit. So, the operation of conducting the thermal analysis of a gas turbine unit can be summarized according to the methods follows: -

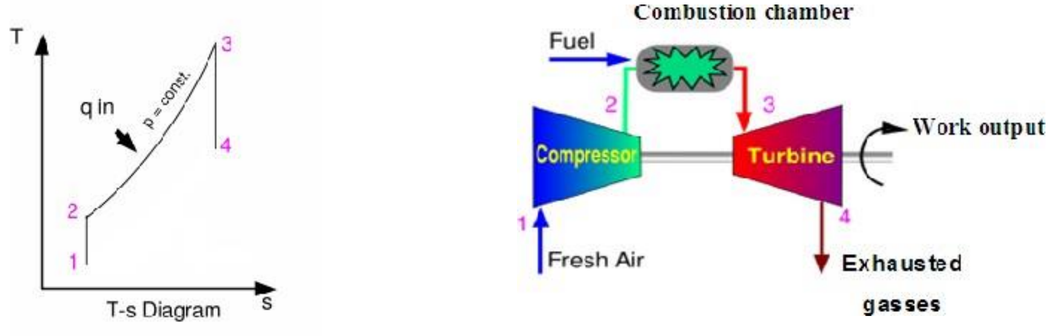

Fig. 1 Brayton Cycle

The netw ork available from the gas turbine plant (W_{NetGT}) can be calculated from thefollowing equation Where***:*** -

$W_{NetGT} = W_T - W_C$ [1]

W_C: The work consumed by the compressor,

W_T: The work developed by the turbine.

$$W_{NetGT} = m_a \left[\left(1 + \frac{1}{A/F}\right) C_P T_3 \left(1 - r_{PT}^{\frac{K_{g-1}}{K_g}}\right) \xi_T - C_{Pa} T_1 \left(r_{Pc}^{\frac{K_{g-1}}{K_g}} - 1\right) \Big/ \xi_c \right] \quad [2]$$

Where:-(Input values)

rC: P_2 / P_1, rT: P_3 / P_4, $\dot{m}_a$: Air mass flow rate,

C_{Pa}: Air-specific heat at constant pressure,

Ka: Air-specific heat ratio,

Kg: gases specific heat ratio,

C_{Pg}: gases specific heat at constant pressure,

T_3: Temperature of gases after the combustion chamber,

A/F: Air to fuel ratio,

ξ_c: Compressor isentropic efficiency,

ξ_T: Gas turbine isentropic efficiency.

- The heat added by the combustion of fuel in the combustion chamber (Q_{add})can becalculated from the following equation: -

$\boldsymbol{Q_{add} = \dot{m}_f \times C_V \times \xi_{CC}}$ [3]

Where: -

CV: Fuel calorific value,

ξ CC: Combustion chamber efficiency,

m.f: Fuel mass flow rate.

- The thermodynamic efficiency of the gas turbine cycle can be calculated from thefollowing equation: -

$$\frac{W_{NetGT}}{Q_{add}} \quad [4]$$

The calculation of the thermal design of a gas turbine unit begins with entering the data necessary to perform this operation ions according to the approved method in the calculations, consequently, this data is: -Ambient air temperature and pressure, compressor pressure ratio, the initial temperature of gases before the turbine, isentropic efficiency of the turbine, isentropic efficiency of the compressor, coefficient of pressure loss at the compressor inlet, coefficient of pressure loss after the turbine, coefficient of pressure loss inside the combustion chamber, and the electric energy produced by the gas turbine unit.

Table .1 Rated specifications of the basic design for the gas turbine units (GT13E2) [1,2]: -

Statement	Symbol	Value	Unit
Produced electric energy	$P_{N.GT}$	150	MW
Fuel consumption	m_f	10.6	Kg/sec
Ambient air temperature	T_a	27	C^o
Ambient air pressure	P_a	1.013	Bar
pressure ratio	rp	14	----
Compressor isentropic efficiency	ξ_C	86	%
Combustion chamber efficiency	ξ_{CC}	98	%
Initial gas temperature before the turbine	T_3	1180	C^o
Turbine isentropic efficiency	ξ_T	90	%
Mechanical efficiency	ξ_M	99	%
Electric generator efficiency	ξ_G	99	%
gases specific heat at constant pressure	C_{Pg}	1.2	kJ/kg. k
Air-specific heat at constant pressure	C_{Pa}	1.005	kJ/kg. k
Exhaust specific heat at constant pressure	C_{exh}	1.13	kJ/kg. k
Air-specific heat ratio	ka	1.4	---
gases specific heat ratio	kg	1.33	---

Using the mathematical model of the gas turbine unit, the calculation of thermo-economic factors was done in accordance with the design and operating conditions of the station

Table .2 Results calculations of the basic design gas turbine unit: -

No.	Property	Value	Unit
1	Power output from the gas turbine	148.6	MW
2	The heat energy of fuel combustion	449.8	MW
3	Gas turbine efficiency	33	%
4	Exhaust temperature after the gas turbine	542	^oC
5	Exhaust flow rate	460.6	Kg/sec
6	Quantity of heat lost in the exhaust	201.34	MW
7	Reduction in the generated electric power	1.4	MW

By analyzing the results of studying the basic design of the gas turbine unit, the problems of the basic design of the gas turbine unit used in the station can be summarized as follows: -

- High exhaust gas temperature (542 C°), and thus high heat energy losses lead to the increase of losses of the station and the increase of thermal pollution of the surrounding area.

- Low station efficiency (33%) if compared with the new international standards for the efficiency of stations operating for the base load which leads to increasing the fuel consumption for electric generation, thus increasing the price of production cost per electric energy unit.

- The initial temperature of gases before the turbine is considered an average
- (T3 = 1180Co) compared with the modern designs of gas turbines (T3 >1250 Cº) which leads to the reduction of specific work done by gas turbines subsequently, increasing the air consumption of the compressor, thus increasing the pollution of the surrounding area with the exhaust from the station.

The thermal design of the gas turbine is not used suitably; where the gas turbine is designed with a simple cycle allowing transferring or directing of the exhaust to a boiler to make use of the thermal energy of exhaust gases

III. discussion and results

The results of studying the electric network load of Libya show an increase in electric energy consumption in summer compared to winter as well as during the day hours; this is beside the increase in water consumption and reduction of electric energy generated by the studied station. This leads to an increase in electric energy consumption in the network and the reduction of electric energy available for the network. Therefore, to solve the abovementioned problems in the thermal design of Benghazi North power station and to increase the economic effectiveness of the electric power generation in the network taking into consideration the geographic site of the station we suggest, in this study: -

- The necessity of studying the effectiveness of exploiting the thermal energy of exhaust gases of the gas turbine units as a secondary source of energy by improving the gas turbine units to operate with a combined system for producing both electric power and thermal energy,
- Studying the topen-aliveness of producing both electric power and this can be done by developing the station to a combined thermo-electric plant, where the thermal energy of the exhaust gases of the gas turbine units is exploited for electric generation and for the thermal consumer which can be in this case a Vapor Absorption Refrigeration System

Based on Rankin Cycle, we will calculate the efficiency of the steam cycle. As mentioned above the heat energy to produce the steam is got from the heat waste of the gas turbine. it's clear that the temperature of the exhaust gases is about 542 ºC.

The proposed design Fig. 2 in addition to the gas turbine unit in the basic design of the station consists of the following essential components.

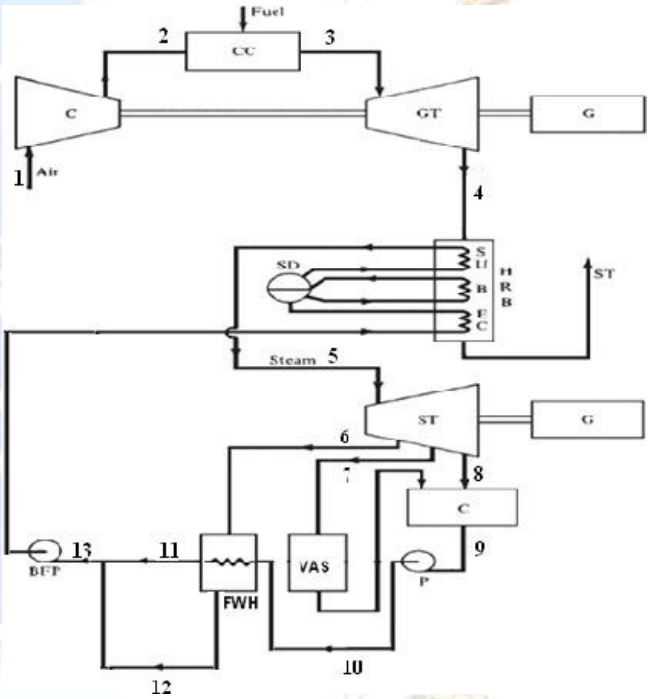

Fig .2 proposed design for the combined Cycle

Where: -

C:	Compressor
CC:	Combustion Chamber
G:	Electric Generator
GT:	Gas Turbine
HRB:	Heat Recovery Boiler
ST:	Steam Turbine
C:	Condenser
P:	Pump
VAS:	Vapor Absorption System
FWH:	Feed Heater Water

The calculation of the steam quantity generated in the boiler (m.s) in kg/sec.

Can be obtained by applying heat balance at the boiler using the following equation [3]:-

$$m^{\cdot}_{exh} \times C_{P_{exh}} \times (T_4 - T_{Cri}) \times \eta_{HRB} = m^{\cdot}_{s} \times (h_{st} - h_d) \quad [5]$$

Where: -

hst = Enthalpy of generated steam after the boiler or before the HP turbine,

hd = Enthalpy of feed water out from the condenser- neglecting the pump work, m.exh= Exhaust gas mass flow rate,

CPexh= Exhaust gases specific heat at constant pressure,

T4 = Temperature of exhaust gases output from the gas turbine,

Tcri = Temperature of exhaust gases output from the boiler (nearly 150 ºC).

In the most practical applications we can assume that,

$$m^{\cdot}_{sFWH} = 15\% m^{\cdot}_{s}$$

For 1.2 Double-effect for the vapor absorption system and cooling load of 3516 KW, Qh is obtained [4]: -

$$\text{COP} = \frac{Q_c}{Q_h}$$

Double-effet for the vapor absorption system which works at pressure of 900 KPa,

$$Q_h = m^{\cdot}_{abs} \times (\Delta h)_{abs}$$

The net work done by the steam turbine plant can be calculated from the following equation: -

$$W^{\cdot}_{ST} = M^{\cdot}_{S} \times (h_5 - h_6) + (m^{\cdot}_{S} - m^{\cdot}_{FWH})(h_6 - h_7) + (m^{\cdot}_{S} - m^{\cdot}_{FWH} - m^{\cdot}_{abs})(h_7 - h_8)$$

Now, we can calculate the total net power of CCPP as,

$$Net\ power_{(comb)} = Net\ power_{(G.T)} + Net\ power_{(S.T)}$$

And

$$Net\ power_{(comb)} = W^{\cdot}_{G.T} + W^{\cdot}_{S.T}$$

The power is required for feed water heater is,

$$W_{FWH} - m^{\cdot}_{sFWH} \times \Delta h_{(FWH)}$$

The net power that is required for the absorption system is [5] ,

$$W_{(abs)} = m^{\cdot}_{s(abs)} \times \Delta h_{(abs)}$$

The thermal efficiency of the combined cycle [6],

$$\zeta_{comb} = \frac{Net\ power_{(comb)}}{Rate of\ Heat\ added}.$$

Using the mathematical model, the following has been studied; the effect of the generated steam properties on the rate of steam generation, the amount of drop in the generated electric power compared to the basic design of the gas turbine unit, the Exhaust of thermal energy produced in the plant, the efficiency of thermal and electric production and the efficiency of the plant according to the second law of thermodynamics (Exhaust efficiency).

Table 3. Conclusion of the Case study results

No.	Property	Value
1	Total power production	233.76MW
2	Steam turbine power	85.16MW
3	Efficiency of the combined cycle	51.9%

Plant effectiveness study results summary

The effect of the pressure ratio of the air compressor or the different parameters in the gas turbine cycle also on the combined cycle

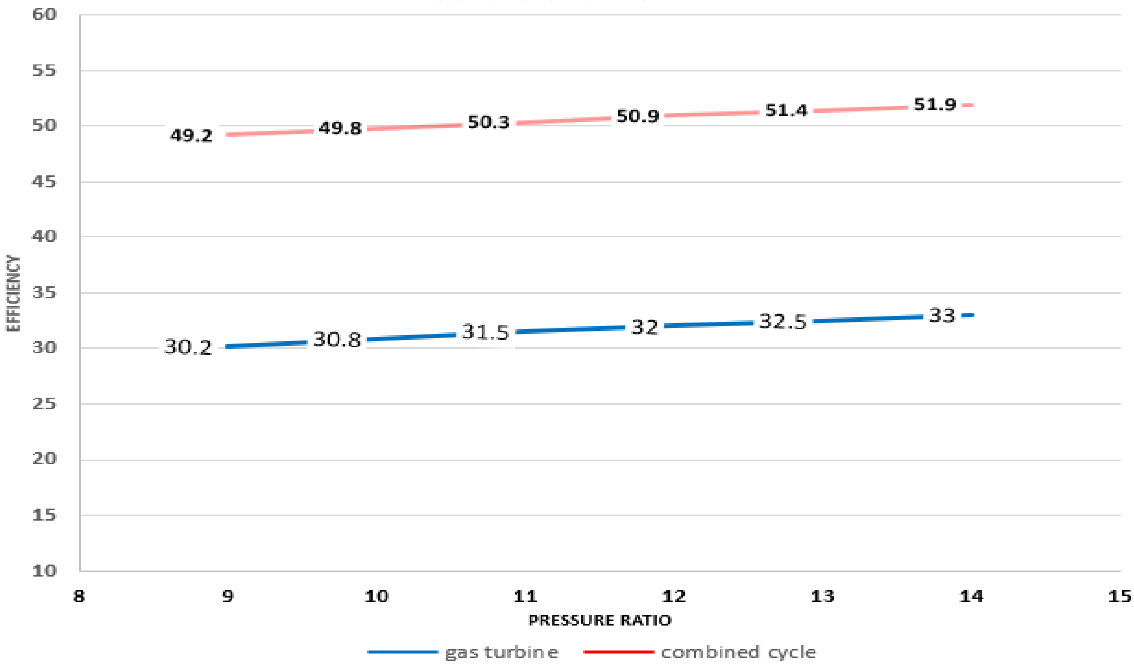

Fig.3 Relation between the pressure ratio and the gas turbine and combined Sycle efficiency
(As the pressure ratio increase the combined Sycle thermal efficiency increase)

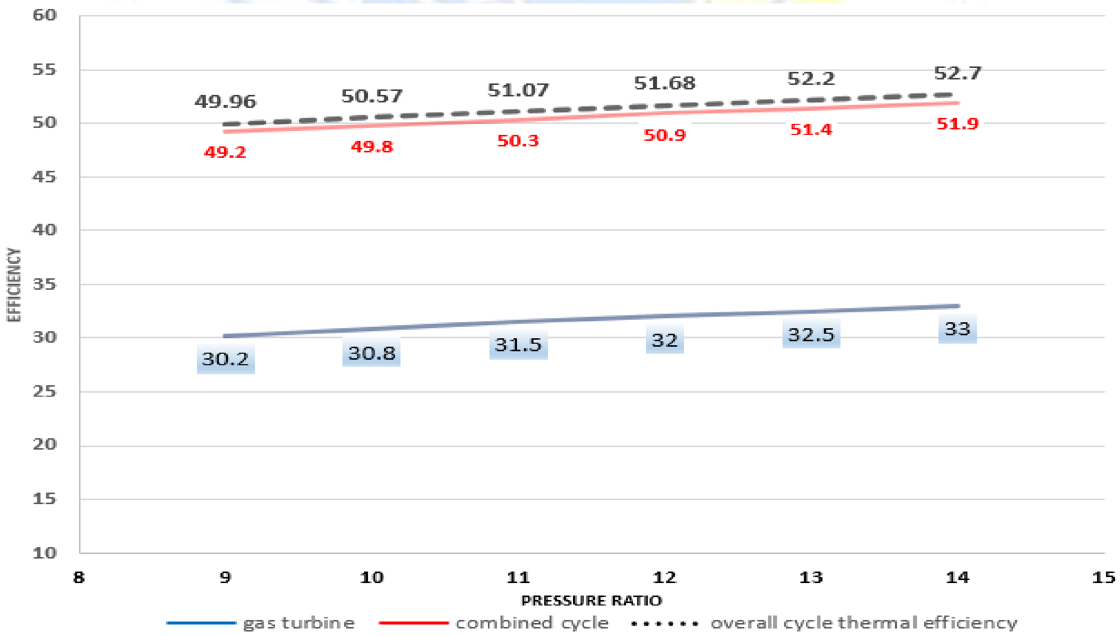

Fig .4 Relation between the pressure ratio and the overall cycle thermal Efficiency

(As the pressure ratio increase the overall cycle thermal efficiency increase)

IV. Conclusions

After studying the Benghazi North power plant, we will conclude some results that indicate to: -

- The efficiency and the different parameters of the gas turbine cycle have been studied and calculated numerically
- The overall efficiency of the gas turbine cycles has been calculated of 33%. Also, the average reduction in the generated electric energy in the proposed design (4 x1.4MW) Does not exceed (0.93%) of the original value of generated electric energy
- AS results of using HRSGS with steam turbine, the overall efficiency reached 51.9% and reduces the effects of the emissions.
- The Use of waste steam hot water at low pressures from steam turbines to provide an absorption system has obviously increased in the overall cycle efficiency from 51.9% to 52.7%.

V. *References*

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