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Performance Enhancement of the South Baghdad Thermal Station

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Abstract

Aim of the research is the study of improving the performance of the thermal station south Baghdad and the main reasons for reduced its efficiency. South Baghdad power planet comprises (6) steam turbine units and (18) gas turbine units .The gas turbine units are composed of two groups: the first group is made up of gas units (1,2), each of capacity (123) MW. The design efficiency of gas turbine units is 32%. The actual efficiency data of steam units is 18.3% instead of 45% which is the design efficiency. The main reason for efficiency reduction of gas units is the rejected thermal energy with the exhaust gases to atmosphere, that are (450-510) °C.The bad type of fuel used (heavy) fuel. Another reason for the low efficiency and has a negative impact on the steam and gas units. The actual efficiency that is calculated to set the first group gas unit (1) is (27%). Suppose the steam is passed through the (HRSG) and this (HRSG) passes the combustion products emerging from first group gas turbine unit (1). The temperature of exhaust gases (T_{ieg} =783k) entered (HRSG) and the temperature of gas out from the (HRSG) (T_{oeg} =374k). The thermal efficiency of combined -cycle plant is (98.3 %).the amount of fuel that can be available by using the plant compound in combined cycle, is (3603.88) tons per year. The relationship between the account of load and compression ratio during the three seasons of the year as where a large difference in the degree of heat between summer and winter .When the high temperature in summer less than the energy generated. As was the rate of energy produced is (99.8, 90.6, 70.6) MW in the (winter, autumn and summer), respectively.

***Key word**: steam turbine, gas turbine, combined cycle, South of Baghdad, the thermal station.*

1. Introduction

South Baghdad power planet, consists of (6) steam turbine units and two groups of gas turbine units. The first group units (1, and 2) are of design capacity (123) MW. Efficiency: is the percentage of the work (electric power) produced to the thermal energy from fuel consumed:

$$\text{Efficiency } (\eta) = \frac{\textit{Electric Power Output}}{\textit{Heat Input}} \qquad \ldots(1)$$

Overall efficiency is the sum of the efficiency of every component of the plant in regard of fuel consumption, thermal energy and mechanical energy transfer [1]. Fuel is the main ingredient used in the liberalization of the energy as an element or a compound capable of generating energy through a chemical reaction, oxidant as in common applications or the fragmentation of the nucleus or merge with a so-called nuclear fuel [2]. The aim of every steam turbine design is an optimum and efficient operation characterizing an optimal energy conversion. Overall efficiency of a steam turbine power plant, however, strongly depends on the turbine's performance. Thus any improvement, however slight, can increase power availability, decrease equipment and component costs, and generate sizeable operating savings. Today's highly competitive and deregulated market, optimizing steam turbine operation is no longer a goal but, rather, a necessity for power producers to remain competitive.

A thorough evaluation of a turbine's design and operating condition can help increase a plant's efficiency by identifying improvements in one or more of three areas:

1. Combustion to improve fuel utilization and minimize environmental impact.

2. Heat transfer and aerodynamics to improve turbine blade life and performance.
3. Materials to permit longer life and higher operating temperatures for more efficient systems [3] .To increase the overall efficiency of electric power plants, multiple processes can be combined to recover and utilize the residual heat energy in hot exhaust gases. In combined cycle mode, power plants can achieve electrical efficiencies up to 60 percent. The term “combined cycle” refers to the combining of multiple thermodynamic cycles to generate power. Combined cycle operation employs a Heat Recovery Steam Generator (HRSG) that captures heat from high temperature exhaust gases to produce steam, which is then supplied to a steam turbine to generate additional electric power. The process for creating steam to produce work using a steam turbine is based on the Rankine cycle [4]. Some of the proposed solutions to improve the efficiency of steam turbine and gas turbine units is taking advantage of thermal power rejected with exhaust gas, which is to benefit from a joint heat exchanger for two units of steam and gas to be combined thermal power plant which reduces fuel used and raise the efficiency.

The advantages of combined cycle gas turbines are high power-to-weight ratio, smaller, fewer moving parts and less vibration than a reciprocating engine. Other advantages include very low toxic emissions, runs on a wide variety of fuels, and high operating speeds. Disadvantages are higher cost, longer start-up, less responsive to power demands, and a shrill whining noise. Flexi cycle power plants combine the advantages of high efficiency in simple cycle and the modularity of multiple engines supplying the steam turbine. The use of appropriate fuel is another reason to raise efficiency. This is because using a Heavy Fuel Oil (HFO) in the gas and steam units, affects efficiency. The disadvantage of (HFO) decreases boiler and combustion chamber efficiency, need to be stored, and heated in addition to the soot deposited on the internal surfaces of the tubes as well as the reduction in boiler pollutants [5].

The quality of the heavy fuel oil is largely determined by the crude oil grade and the refining process applied. This is the reason why heavy fuel oil of the same viscosity may differ considerably in quality from one bunker place to another [6]. Heavy fuel oil normally is a mixture of residue oils and distillates. The components of the mixture often come from state of the art refining process such as vis-breaker of catalytic cracking plant. These processes may have a negative effect on the stability of the fuel and on its ignition and combustion properties. In this sense these factors also influence the heavy fuel oil treatment and the operating results of the engine. The properties of (HFO). are shown in table (1) [7].

Table 1,
The properties of H.F.O.[7].

S/N	Specification	Method	BPC limit
1	Density at 15°C Kg/L	ASTM D 1298	Max. 0.991
2	Viscosity at 50°C, cst	ASTM D 445	Max.180
3	Water & Sediment, % wt	ASTM D 1796	Max. 0.5
4	Total sediment Existent, %wt	IP 375	Max. 0.10
5	Sediment by Extraction, % wt.	ASTM D 473	Max. 0.10
6	Sulphur content, %wt	ASTM D 1552	Max. 3.5
7	Ash Content, %wt	ASTM D 482	Max. 0.10
8	V, ppm	IP 377	Max.50
9	Na, ppm	IP 288	Max. 16
10	Asphaltenes, %wt	IP 143	Max. 14
11	Flash Point, °C	ASTM D 93	Max. 60
12	Pour Point, °C	ASTM D 97	Max.24
13	Al, ppm	IP 377 mod	Max. 30
14	LHV, KJ/Kg	ASTM D 240	Min. 39000
15	Compatibility spot test	ASTM D 4740	Max. 2
16	Water by distillation, % Vol	ASTM D 95	Max. 0.50

As world energy demand recovers, it continues to drive power generation projects into ever expanding geographic regions and new areas of technology. The need to manage performance becomes increasingly more important. A comprehensive plan for efficiency improvements can typically yield multiple-percent output improvements at costs which are far lower than building new units. This helps the generation planning program for the fleet and can reduce or eliminate significant amounts of capital spending on new plant construction and all the issues and costs associated with bringing a new fossil-fired plant into the operating picture [8].

2. Calculations

2.1. Calculation of the Cycle Efficiency

The actual efficiency (η_{acu}) of the steam unit, is 18.3%. The actual efficiency (η_{acu}) calculated for unit number (1) for the first group type gas unit is 27%. The actual efficiency of gas turbine, is 66.8%. . Photos (1-1) taken from the control center for first group gas unit (1) showing its operating conditions, and .Table (2) presents readings of gas turbines units.

Table .2.
Readings were obtained for the first gas unit (1).

unit	rp	T_1 °C	T_2°C	T_3 °C	T_4 °C	$m°_f$ Kg/s	m°a Kg/s	Power
Unit1	10.23	25	338	946.064	510	8.03	636.4	93.8
Unit1	8.6	19	294	946.064	373	5.13	636.4	50.6

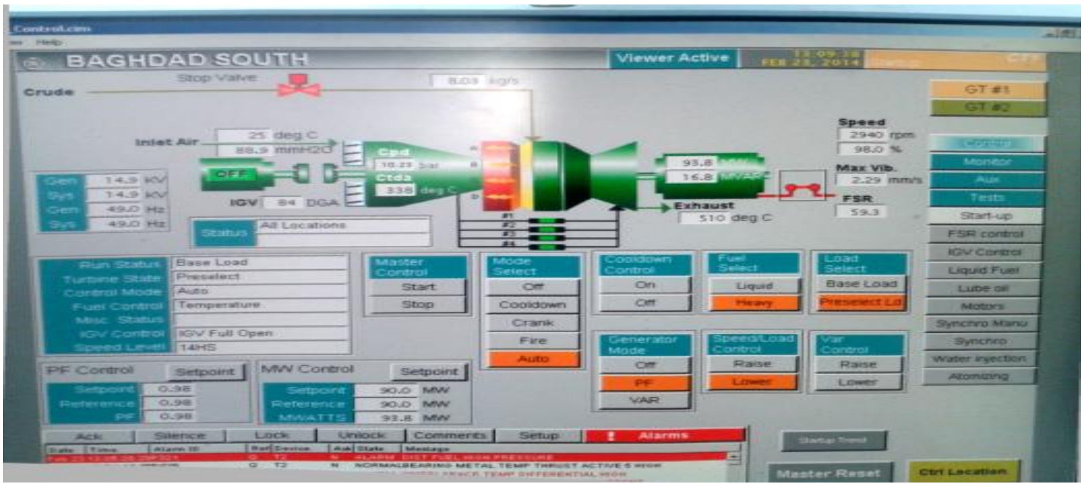


Photo .1.1. taken from the control center for first group gas unit (1) showing its operating condition.

2.2. Gas Turbine Power Plants

The first group gas unit (1) (Fig 1). Efficiency calculation is as follows:

The heat supplied of the gas turbine (Q_{gt}):

Q_{gt} = m°a*C_P* ($T_3 - T_2$) ... (2)

$m°_f$*c.v= m°a*C_P* ($T_3 - T_2$) … (3)

If c.v = 43000 kJ/kg of H.F.O., cpg=1.1kJ/kg*K and cpa=1.005 kJ/kg*K

Then:

8.03*43000=m˚a*1.1*(T3-611)

$$m˚a = \frac{345290}{1.1\,T3-727.1} \quad \ldots (4)$$

Net power = W_T -W_C … (5)

Net power =cp_g*(T_3 -T_4) - cp_a*(T_2-T_1) … (6)

T3 = 1154.24 K …(7)

Subs. eq. (7 in 4) we get:

$$m°_a = \frac{345290}{1.1*1154.24-727.1} = 636.4 \text{ kg /S…}$$

$$T_2 = T_1 * \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = 298 * (10.23)^{0.285} = 578.12 \text{ K}$$

, $\gamma_a = 1.4$

$$T_4 = \frac{T3}{\left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}}$$

$$T_4 = \frac{1154.24}{(10.23)^{0.285}} = 594.96\ K$$

The first group gas unit (1) efficiency:

$$\eta_{ac} = \frac{Net\ power}{mf*c.v} = \frac{93800}{8.03*43000} = 27\% \quad \ldots (8)$$

The Efficiency of Gas Turbine:

η_{gt} = ($T_3 - T_4$) / ($T_3 - T_4$) …(9)

η_{gt} = (1154.24 – 783) / (1154.24 – 594.96) = 66.85%

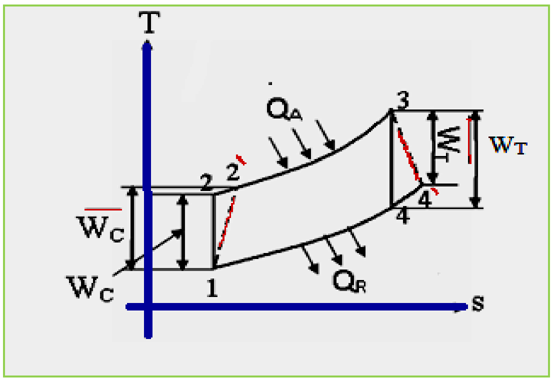


Fig. 1.T-S diagram for gas turbine [9].

2.3. Steam Unite Calculation

The Efficiency of steam turbine (Fig. 2):

$$\eta_{ac} = \frac{w_{st}}{Q_{ST}} \qquad \ldots(10)$$

Increase in enthalpy of steam = Q_{ST}

$$Q_{ST} = h_1 - h_3 \qquad \ldots(11)$$

= (3414.54 – 168.7) = 3245.77 KJ/Kg

$w_{st} = \eta_{ac} * Q_{ST} = 0.183 * 3245.77$

= 593.97 KJ/Kg

$$\eta_{st} = \frac{w_{sa}}{w_{si}} = \frac{593.97}{h_1 - h_2} = \frac{593.97}{593.97 + w_p}$$

$w_p = v * (p_2 - p_1) = 0.001 * (87.14 – 0.075) *100$

$w_p = 8.7\ KJ/Kg$ (The Compression Work)

$$\eta_{st} = \frac{593.97}{602.67} = 98.55\ \%$$

Combined – Cycle Plant:

The thermal Efficiency of Combined - Cycle plant:[10]

$$\eta_{cc} = \frac{\eta_{gt} * Q_{gt} + \eta_{st} * Q_{gt}(1 - \eta_{gt})}{\eta Q_{gt} + Q_{st}} \qquad \ldots(12)$$

$$\eta_{cc} = \frac{0.668 * 345290 + 0.985 * 345290(1 - 0.6680)}{345290 + 4245.77}$$

$$\eta_{cc} = 0.983 = 98.3\ \%$$

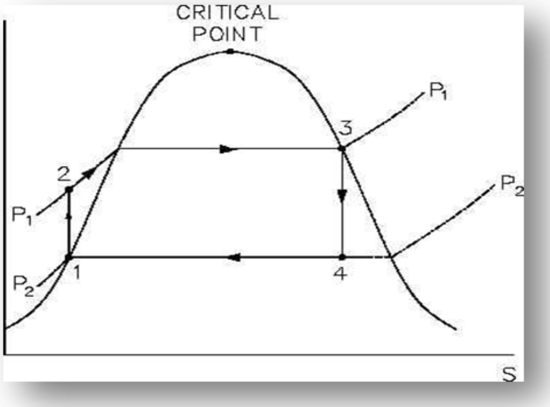


Fig. 2.T-S diagram for steam turbine.

2.4. Calculation of The Amount of Fuel That Can be provided in Combined Cycle

According to the previous reading of the south Baghdad station , the boiler efficiency reaches 43.2% ,the mass flow rate of steam ($m°_s$= 74.433 kg/s). This means that the efficiency of the boiler is very low. To impose. Merge of the two plants; the steam plant and the gas plant to obtain the combined station is shown figure (4) and the T-C diagram is shown fig (3). Suppose the steam is passed through the Heat Recover Steam Generator (HRSG) and this (HRSG) passes the combustion products emerging from first group gas turbine unit (1). The temperature of exhaust gases (T_{ieg} =783k) entered (HRSG) and Suppose the temperature of gas out from the (HRSG) (T_{oeg} =374k).The choice of the best gas efficiency of the unit, which operates on (93.8 MW), the amount of fuel that can be provided by using the plant compound in combined cycle, is according to the following equation:

The energy balance for (HRSG) gives:

$$m°_g * cp_g * (T_{ieg} - T_{oeg}) = m°_s \Delta h_s \qquad \ldots(13)$$

Where:

$m°_a$= 636.4 kg/s

T_{ieg}= 783 K

$m°_s$ =74.433 kg/s.

Change in energy of gas in the (HRSG)(fig.3,4) :

$= m°_g * cp_g * (T_{ieg} - T_{oeg})$

(635.6 + 8.03) *1.1*724 = 512586.9 kJ

$512586.9 = m°_s \Delta h_s = 74.4 * \Delta h_s$

$$\eta_B = \frac{ms.\Delta h}{mf.C.V} \qquad \ldots(14)$$

$43.2\% = \frac{74.433 * 6886.6}{mf * C.v}$ = 512590 29 / 183960

$\dot{m}_f$ = 2.78 Kg_f/s

$\dot{m}_f = 2.78 * 3600 * 30 * 12 = 360288\ 0 = 3602.88$ Ton in Year

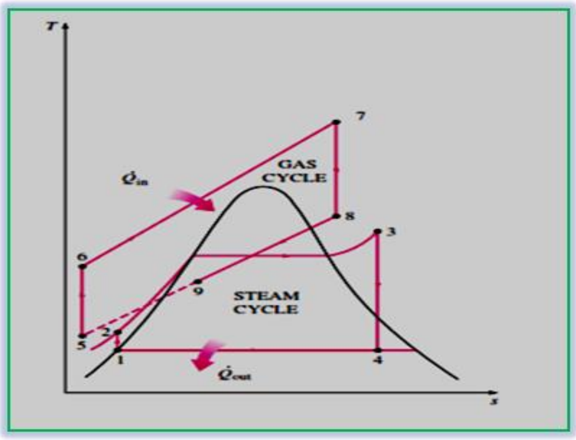


Fig.3.T-S diagram for combined cycle [11].

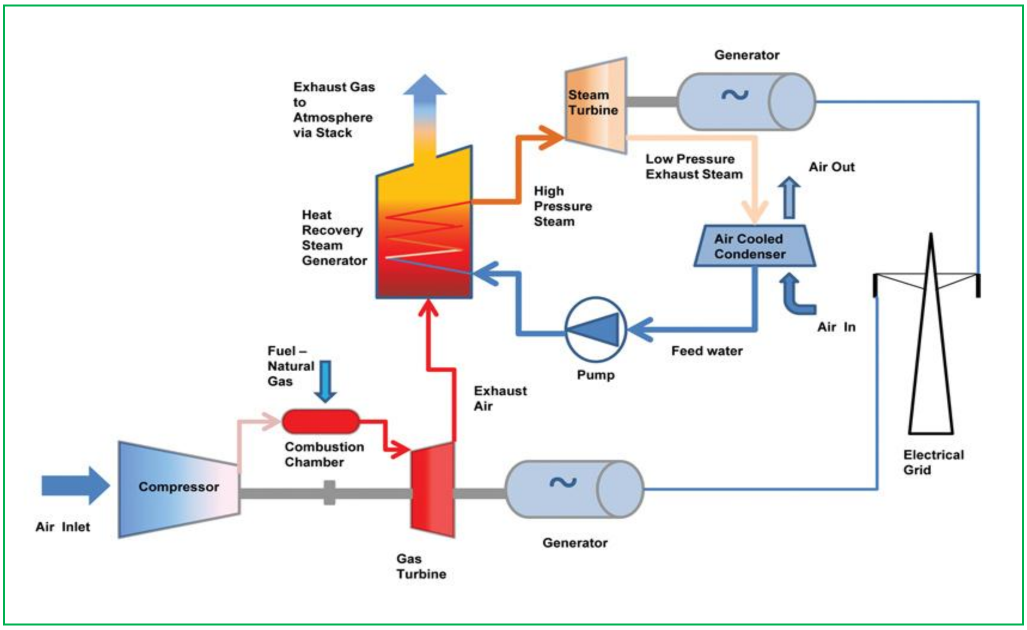


Fig. 4. Diagram of combined cycle.[12]

2.5. Calculation of the Relationship between Load and Compression Ratio with Time

The readings were taken from the first group gas unit (1) as shown in the Table (3) showing the relationship between load and compression ratio with time. Figure (5,6) shows the peak load (in summer) is (81 MW), on 02/08/2013. Figure (7,8) shows the peak load (in winter) is (102 MW), on 31/01/2014. Figure (9,10) shows the peak load (in autumn) is (102 MW), on 27/10/2013. Figure (5,6) shows that the high compression ratio of the first group gas units (1) rp = (9.92) when the temperature of primary $T = 25^{\circ}C$. The productive capacity was (79 MW).

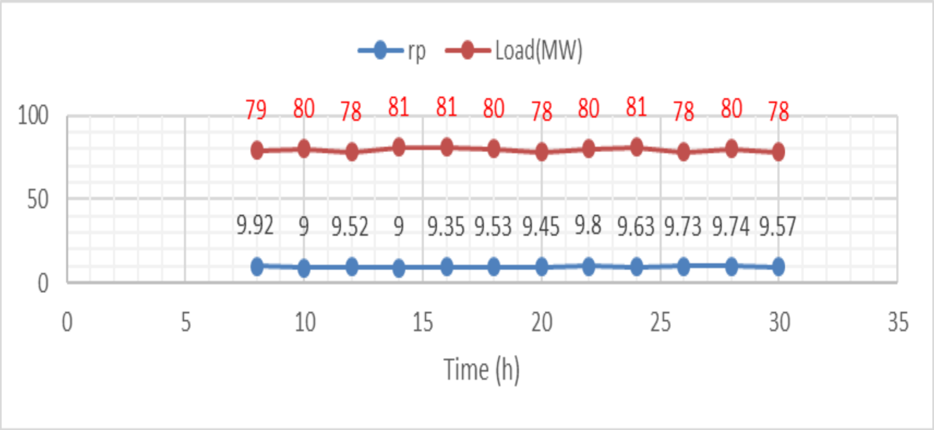
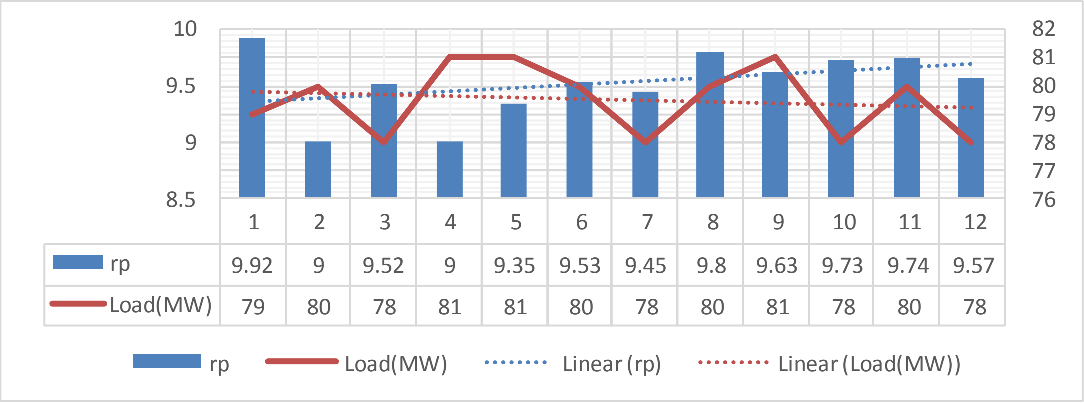


Fig. 5.The relationship between load and compression ratio with time on 02/08/2013.



	1	2	3	4	5	6	7	8	9	10	11	12
rp	9.92	9	9.52	9	9.35	9.53	9.45	9.8	9.63	9.73	9.74	9.57
Load(MW)	79	80	78	81	81	80	78	80	81	78	80	78

Fig. 6. the relationship between load and compression ratio peak load (in summer) on 02/08/2013.

Fig. (7,8). Where the compression ratio rp = 10.71 at the elementary grade temperature t = 18℃ was producing power (102MW). With rp = 11.11 and temperature t = 25℃ primary energy produced was (100MW).

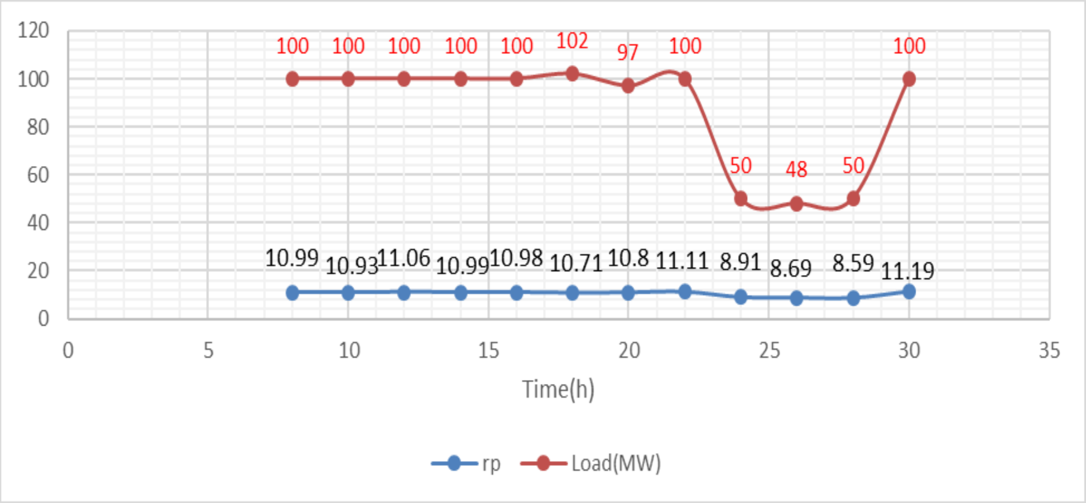
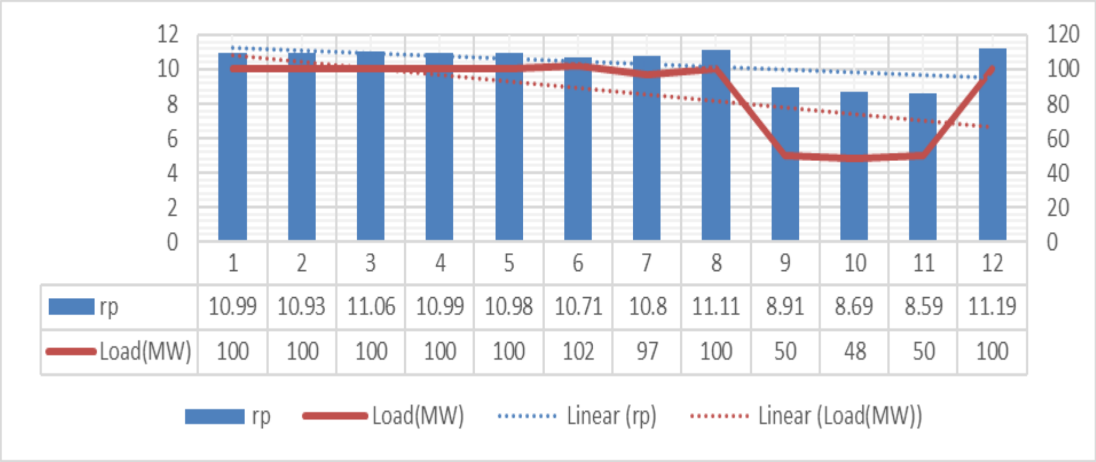


Fig. 7.The relationship between load and compression ratio with time on31/01/2014.



	1	2	3	4	5	6	7	8	9	10	11	12
rp	10.99	10.93	11.06	10.99	10.98	10.71	10.8	11.11	8.91	8.69	8.59	11.19
Load(MW)	100	100	100	100	100	102	97	100	50	48	50	100

Fig. 8. The relationship between load and compression ratio peak load (in winter), on31/01/2014.

In autumn when the temperature is moderate, we find that the highest amount of compression ratio is rp = 10.66 and the load is (94MW). Little reduction in the compression ratio leads to a small decrease in load. As in the figures (9and 10).

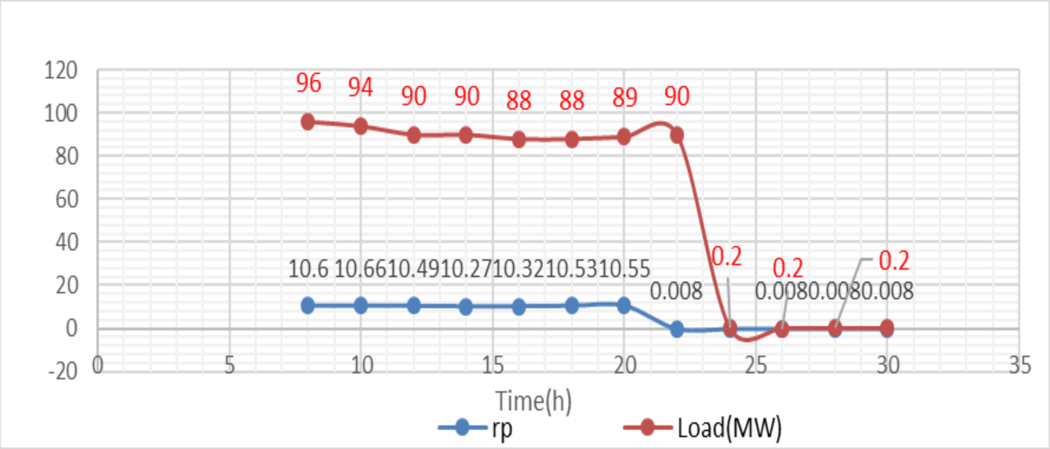
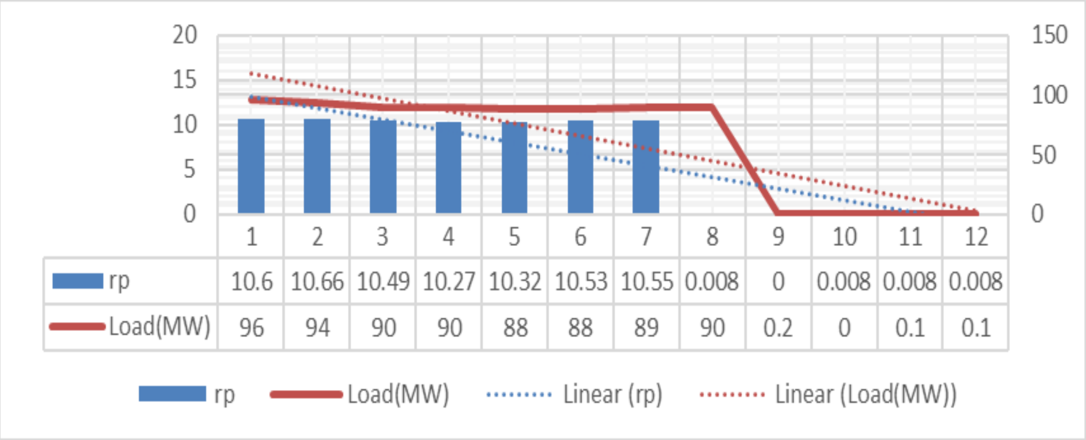


Fig. 9. The relationship between load and compression ratio with time in peak load (in autumn) on 27/10/2013.



	1	2	3	4	5	6	7	8	9	10	11	12
rp	10.6	10.66	10.49	10.27	10.32	10.53	10.55	0.008	0	0.008	0.008	0.008
Load(MW)	96	94	90	90	88	88	89	90	0.2	0	0.1	0.1

Fig. 10.The relationship between load and compression ratio in peak load (in autumn) on27/10/2013.

Table.3
The relationship between load and compression ratio with time.

One day	the summer 02/08/2013		the winter 31/01/2014		the autumn 0/10/2013	
Time(h)	**Rp**	**Load(MW)**	**rp**	**Load(MW)**	**rp**	**Load(MW)**
8	9.92	79	10.99	100	10.6	96
10	9	80	10.93	100	10.66	94
12	9.52	78	11.06	100	10.49	90
14	9	81	10.99	100	10.27	90
16	9.35	81	10.98	100	10.32	88
18	9.53	80	10.71	102	10.53	88
20	9.45	78	10.8	97	10.55	89
22	9.8	80	11.11	100	0.008	90
24	9.63	81	8.91	50	0	0.2
26	9.73	78	8.69	48	0.008	0
28	9.74	80	8.59	50	0.008	0.1
30	9.57	78	11.19	100	0.008	0.1

Calculations were made for the first group gas unit (1) to find the relationship between load and compression ratio in different months of the year , in (January, August, and October) where there is a difference between the atmospheric temperatures during the months, Table (3),we found that the Compression ratio is inversely proportional to the air temperature .At high air temperature, less compression ratio as the density of air becomes less and therefore less air into the compressor and that contribute to combustion. And the energy generated will be less, which calls for adding cooling system at high temperatures in the summer to increase the efficiency of the gas units.

3. Results and Discussion

1- The actual efficiency (η_{acu}) calculated for unit number (1) for the first group type gas unit is 27% . The actual efficiency of gas turbine, is 66.85% .

2- The efficiency of the combined cycle is (98.3)% by the station data available can be considered high, which means the possibility of improving the steam unit and gas unit efficiency.

3- The amount of fuel that can be saved by using plant compound plant is estimated to be 3602.88 tons per year. This show the reduction in operating cost.

4- Table (2) shows that the high compression ratio of the first group gas units (1) rp = 10.23 when the temperature of primary t = 25 °C. The productive capacity Is 93.8 MW. When, the compression ratio rp = 8.6 and the degree of primary temperature t = 19 °C, then the produced energy be P = 50.6 MW. This means that the increase in compression ratio(rp) lead to increased energy despite the relatively high temperature.

5- Table (3), shown that the Compression ratio is inversely proportional to the air temperature .At high air temperature, less compression ratio as the density of air becomes less and therefore less air into the compressor and that contribute to combustion. And the energy generated will be less, which calls for adding cooling system at high temperatures in the summer.

4. Nomenclature

Symbol	Definition	Units
c_p-	heat capacity at constant pressure	KJ/Kg.K
Cp_a	heat capacity of air at constant pressure	KJ/Kg.K
cp_g	heat capacity of gas at constant pressure	KJ/Kg.K
C.V	calorie values of fuel	KJ/Kg.K
h_s	Specific enthalpy of steam	KJ/Kg
$\dot{m}_a$	mass flow rat of air	Kg/S
$\dot{m}_f$	mass flow rat of fuel	Kg/S
m_s	mass flow rat of steam	Kg/S
Q_A, Q_{add}	rate of added heat	KJ/Kg
Q_R	rate of heat reject	KJ/Kg
Q_{gt}, Q_{st}	rate of heat of gas turbine , rate of heat of steam turbine	KJ/Kg
T	isentropic temperature at points (1, 2, 3, 4)	K
$T_{\bar{2}}$	actual temperature at points (2)	K
$T_{\bar{4}}$	actual temperature at points (4)	K
T_{ieg}	temperature of gas inlet in the (HRSG)	K
T_{oeg}	temperature of gas out from the (HRSG)	K
W_c	specific compressor work.	KJ/Kg
$\bar{W}_{gt}$	specific actual gas turbine work.	KJ/Kg
W_T	specific turbine work	KJ/Kg
$\bar{W}_{st}$	specific actual steam turbine work.	KJ/Kg
η_{ac}	actual efficiency	%
η_{B} -	boiler efficiency	%
η_{cc}	thermal efficiency of combined - Cycle	%
η_{iso}	isothermal efficiency	%
η_{th}	thermal efficiency	%
γ_a	Specific heat ratio of air	
HRSG	Heat Recover Steam Generator	
Δ	difference	

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الخلاصة

هدف البحث هو دراسة تحسين اداء محطة جنوب بغداد الحرارية واهم اسباب انخفاض كفائتها . محطة جنوب بغداد تتألف من (٦) وحدات بخارية و (١٨) وحدة غازية. الوحدات الغازية تتكون من مجموعتين : المجموعة الغازية الأولى تتكون من وحدتين (١،٢) قدرة كل واحد (١٢٣) ميغاواط، الكفاءة التصميمة للوحدات الغازية ٣٢٪. بيانات الكفاءة الفعلية للوحدات البخارية هي ١٨.٣٪ بدلا من ٤٥٪ التي هي الكفاءة التصميمية. الاسباب الرئيسة للحد من كفاءة الوحدات الغازية الطاقة الحرارية المطروحة مع غازات العادم إلى الغلاف الجوي التي تكون (٤٥٠-٥١٠) °C، النوع السيء من الوقود المستخدم (وقود ثقيل). سبب اخر في انخفاض الكفاءة وله تاثير سلبي على الوحدات البخارية والغازية. الكفاءة الفعلية التي تم حسابها للمجموعة الغاز الأولى الوحدة (١) هي (٢٧) % . نفترض أن يتم تمرير البخار الخارج من المرجل خلال مبادل حراري الذي تقطعه نواتج الاحتراق الخارجة من الوحدة (١) من المجموعة الغازية الاولى. درجة حرارة غازات العادم الداخله الى المبادل الحراري (٧٨٣) كلفن وعند تركها المبادل الحراري (٣٨٤) كلفن، الكفاءة الحرارية للوحدة المركبة (٩٨.٣%)، تكون كمية الوقود المتوافرة باستخدام الدورة المركبة هي (٣٦٠٣.٨٨) طن في السنة . تم حساب العلاقة بين الحمل ونسبة الانضغاط خلال ثلاثة فصول من السنة للوحدة الغازية الاولى (١) حيث الفارق في درجات الحرارة كبير بين الصيف والشتاء،عند ارتفاع درجات الحرارة صيفا تقل الطاقة المتولدة اذ ان معدل الطاقة المنتج (٩٩.٨,٦٠.٩٠، ٧٠.٦) ميغاواط في الشتاء والخريف والصيف على التوالي
