Efficiency Increase and Fuel Save Benefits of Combined Cycle Operation (Garri Power Plant as a Case Study)

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ABSTRACT – Thermal power plants' overall efficiency increase and fuel consumption decrease draw worldwide researcher's attention due to the limited resources and high cost of fossil fuel. Considering Al-Jaily power plant, the so-called Garri power plants 1 and 2 in Sudan as the case study, this paper compares overall plant efficiency and fuel save with the combined cycle and open cycle operation in which both plants could run. Evaluation of plant's efficiency is based on the first law of thermodynamics. The results reveal advantage of the combined cycle operation mode in terms of efficiency increase, and on the other hand, in terms of fuel consumption decrease with the same amount of energy produced.

Keywords: *Combined cycle, Open cycle, Efficiency, Fuel save.*

المستخلص - تجذب زيادة الكفاءة الكلية لمحطات الطاقة الحرارية وتخفيض استهلاك الوقود انتباه الباحثين في جميع أنحاء العالم بسبب الموارد المحدودة والتكلفة العالية للوقود الأحفوري. بأخذ محطة الجيلي للطاقة، المسماة أيضاً بمحطة قري 1 و 2 في السودان كحالة دراسة، تقارن هذه الورقة الكفاءة الإجمالية للمحطة، واستهلاك الوقود لكل من وضعي تشغيل الدورة المركبة والدورة المفتوحة التي يمكن أن تعمل عليها كلتا المحطتين. يعتمد تقييم كفاءة المحطة على القانون الأول للديناميكا الحرارية. تكشف النتائج عن ميزة وضع تشغيل الدورة المركبة من حيث زيادة الكفاءة، ومن جهة أخرى، انخفاض استهلاك الوقود لإنتاج نفس كمية الطاقة.

INTRODUCTION

While the world is working hard to shift to renewable energy, yet, most of electricity generation depends on thermal power plants. Thermal generation up to 2021 represents over 70% of the world`s total electricity generation, with 86% of the thermal generation being fossil fuel fired [1]. Due to the high cost of fossil fuels, it is of paramount importance to ensure that thermal power plants extract as much energy as possible from this resource.

Operation of thermal power plants at highest possible efficiency is essential. Brayton cycle consists of four processes, which are compression, heat addition, expansion, and heat rejection. The exhaust gases from a gas turbine carry a large quantity of heat since their temperature is far above the ambient temperature [2]. Rankine cycle in the other hand, is a steam cycle which takes place at lower temperature; therefore, it is known as the bottoming cycle. In combined cycle operation mode, heat addition process of Rankine cycle is coupled with Brayton cycle's heat rejection process.

The combination 'gas-turbine-steam cycles' aims at utilizing the heat of exhaust gases from the gas turbine and thus, improve the overall plant efficiency [2]. This is done by means of *Heat Recovery Steam Generator* (HRSG) where a steam with high temperature is generated from low pressure hot gases at over 500°C [3].

Edgar *et. al*. [4] have performed a similar analysis, to this present one, for Tuxpan II combined cycle power plant in Mexico. Their work targeted study of generation and environmental differences between both cycles. Authors of [4] found that, open cycle thermal efficiency is 35.16% and combined cycle thermal efficiency is 43.79%. Khan and Tlili [5] conducted performance optimization of the combined cycle. Their study revealed an output growth of 45%, as an effect of increasing the turbine's inlet temperature of the topping cycle from 1000° K to 1400° K.

Several local analyses for thermal power plants were performed as in [6], where an analysis at Garri 2 power plant was carried out using second law of thermodynamics to locate the most exergy-destructive component in the thermodynamic cycle. Results revealed that, thermal and exegetic efficiency of the overall plant are 38% and 49% respectively.

Osman *et. al.* [7] had performed an exegetic analysis for a steam power plant at Garri 4 power plant. Their work disclosed a plant thermal efficiency of 21.12%. An alike procedure to [7] is found in [8], where an overall plant efficiency of 13.4% is found. This present paper aims at comparing Garri 1 and 2 power plants' open and combined cycle daily as well as three weeks efficiency. The paper also aims at investigating number of plants' open cycle and combined cycle fuel consumption while generating the same amount of energy for a period of three weeks.

PLANT DESCRIPTION

Garri power plants 1 and 2 are multi shaft combined gas and steam power plants. They implement two types of thermodynamic cycles, which are *Brayton* cycle as the topping cycle of the gas turbine, and *Rankine* cycle as the bottoming cycle of the steam turbine. Purpose of the combined operation is mainly to improve the plant efficiency and therefore reduce fuel cost. The plant basic principle is to use gas turbine's hot exhausts to generate steam in the heat recovery steam generator. Then, this steam is applied to a steam turbine. The plant could also run with the conventional open cycle and directly release the exhausts to the environment.

This is possible because of the structure of gas turbine and HRSG which is provided with double chimney that allows operation in both cycles as can be seen in Figure 1. Garri plants 1 and 2 contain eight gas turbines, eight HRSGs and four steam turbines. Garri power plant could be divided into small blocks those perform the same functionality of the whole plant. Each block contains two GTs, two HRSGs and a single ST. Accordingly, each ST is fed from two HRSGs as represented in Figure 2.

The data which have been collected are the daily readings for whole April 2022 for gas turbine generation and steam turbine generation in MW, both steam and gas turbine operating hours, fuel consumption, fuel types and heat value of each type. Data are from the efficiency unit and central control room.

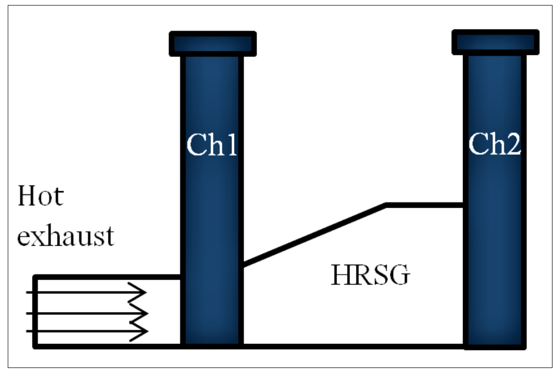

Figure 1: Double Chimney Structure

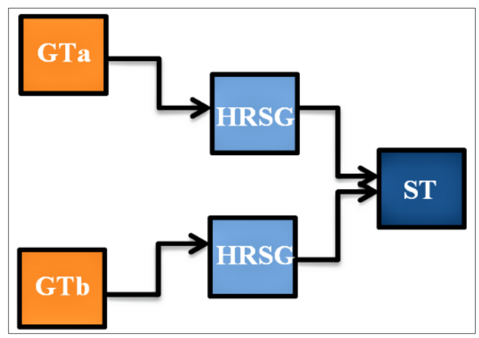

Figure 2: Combined Cycle Block

ANALYSIS

Two key analyses are performed in this work. These are determination of fuel consumption while generating same amount of power for each of open cycle and combined cycle operation modes, as well as determination of overall plant efficiency for each of open cycle and combined cycle operation modes.

- ***FUEL CONSUMPTION***

The thermal power plant uses two types of fuel, which are Light Diesel Oil (LDO) and Heavy Coked Gas Oil (HCGO), each has different heat value. Accordingly, in order to obtain the total input energy (kJ), calculations of each fuel type should be separated from the other.

- For the LDO:

$$E_{LDO}\,(kJ) = m_1\ (kg)\ \times H_1\ (\frac{kJ}{kg}) \qquad (1)$$

where,

E_{LDO} = *energy released by LDO(kJ).*

m_1 = LDO consumed mass (ton).
H_1 = LDO heat value(kJ/kg).

- For the HCGO:

$$E_{HCGO}\,(kJ) = m_2\,(kg) \times H_2\,(\frac{kJ}{kg}) \quad (2)$$

where,
E_{HCGO} = energy released by HCGO (kJ).
m_2 = HCGO consumed mass (ton).
H_2 = HCGO heat value(kJ/kg).

- ***OPEN CYCLE EFFICIENCY***

The term open cycle efficiency refers to the efficiency of the conventional cycle of plant which could be in both internal combustion and external combustion machines. In open cycle, fuel energy is released and exchanged in one stage. Taking gas turbine energy exchange process as an example, fuel is burned generating compressed hot gases which hit turbine's blades then these gases are released to the environment as exhausts. The efficiency (η) of this cycle could be determined by the following equations:

$$\eta = \frac{Eout}{Ein} \times 100\% \quad (3)$$

where,
E_{in} = input Energy(kJ).
E_{out} = output Energy(kJ).

$$E_{in}\,(kJ) = m\,(kg) \times H(\frac{kJ}{kg}) \quad (4)$$

where,
m = fuel consumed mass (ton).
H = low heat value of fuel (kJ/kg).

$$E_{out}\,(kJ) = p\,(MW) \times t\,(hr) \quad (5)$$

where,
p = turbine generation (MW).
t = turbine running hours (hours).

Table I demonstrates the daily efficiency of GTs for a period of month. Calculation is performed using data attached in Appendices I, II, and III.

- ***COMBINED CYCLE EFFICIENCY***

Combined cycle could be defined as the thermodynamic cycle where two or more simple cycles are connected. It could be described as an ordinary gas turbine open cycle supplied with heat recovery system. The cycle begins in gas turbines where combustion happens. After hot gases rotate the turbine, it is directed to the Heat Recovery Steam Generator (HRSG). This is basically a boiler that generates steam using hot exhausts that generates power by rotating steam turbines.

The fuel consumption of each block is the total fuel consumption of the two gas turbines within the block. Then, calculations would be taken for each block to represent the combined cycle using Equations (6, 7, and 8):

$$E_{out}\,(MW.h) = (E_a + E_b + E_s) \quad (6)$$

where,
E_a= GTa output (MW.h).
E_b= GTb output (MW.h).
E_s= steam turbine output (MW.h).

$$E_{in}\,(KJ) = (E_a' + E_b') \quad (7)$$

where,
E_a' = energy released in GTa (kJ).
E_b' = energy released in GTb (kJ).

$$E_T(kJ) = m\,(g) \times H\,\left(\frac{kJ}{kg}\right) \quad (8)$$

where,
E_T = energy released in each turbine(kJ).
m= fuel consumed mass (ton).
H= low heat value of fuel (kJ/kg).

The daily efficiency of combined cycle blocks is calculated utilizing data in Appendices I, II, IV, and V, as presented in Table II.

- ***OVERALL PLANT EFFICIENCY***

Overall plant efficiency represents the ratio between produced electric energy and consumed fuel energy. Therefore, it indicates to plant capability of converting primary energy into electric energy, which directly affect plants running cost. Table III shows Garri 1 and 2 electricity generation and fuel consumption for operating period of a month. It also shows average generation rate calculated from the actual generation, and plant's efficiency.

TABLE I: DAILY EFFICIENCY OF GTS (%)

	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8
1 / 4	27.92	25.87	25.08	25.32	23.79	-	23.09	23.09
2 / 4	23.14	23.28	22.73	24.57	24.15	-	24.13	23.96
3 / 4	25.66	25.43	06.85	24.26	23.79	-	23.08	23.09
4 / 4	24.02	17.67	23.99	25.88	23.79	-	23.09	21.60
5 / 4	24.47	25.21	24.43	25.51	23.79	-	23.09	23.09
6 / 4	26.77	27.80	24.50	26.92	23.79	-	23.70	24.34
7 / 4	24.98	21.74	25.14	23.67	23.79	-	23.09	23.09
8 / 4	25.70	30.16	28.26	25.95	23.79	-	23.09	23.09
9 / 4	25.07	24.01	22.78	24.41	25.15	-	23.09	24.71
10 / 4	22.78	25.40	19.59	24.27	23.79	-	23.09	23.09
11 / 4	23.88	25.04	24.35	-	23.79	-	23.09	23.09
12 / 4	26.04	25.54	24.83	-	23.79	-	23.09	23.09
13 / 4	26.48	29.24	17.10	-	23.79	-	23.09	23.09
14 / 4	26.47	25.40	24.76	-	25.03	-	23.08	23.09
15 / 4	24.07	26.35	28.52	-	23.79	-	23.10	23.09
16 / 4	28.02	24.32	27.35	-	23.79	-	22.86	18.91
17 / 4	24.09	22.94	24.17	-	23.79	-	23.09	-
18 / 4	25.95	25.87	24.07	-	23.79	-	23.09	23.09
19 / 4	25.60	23.39	25.63	-	23.34	-	-	23.09
20 / 4	24.83	29.81	24.50	-	23.79	-	-	23.09
21 / 4	27.59	21.92	26.25	-	24.40	-	-	24.13
22 / 4	26.08	26.69	20.28	-	23.79	-	23.09	23.09
23 / 4	26.52	27.17	25.64	-	23.79	-	23.09	23.09
24 / 4	24.22	23.59	24.60	-	25.82	-	23.09	23.44
25 / 4	24.49	25.70	25.12	-	23.79	-	23.09	23.09
26 / 4	24.32	26.87	25.31	-	25.59	-	23.78	24.17
27 / 4	24.47	29.14	24.65	-	23.79	-	23.09	23.09
28 / 4	24.98	23.70	24.73	-	23.79	-	23.09	23.09
29 / 4	24.51	24.85	24.61	-	25.36	-	23.10	
30 / 4	24.19	-	23.87	-	23.79	-	23.09	23.09
31 / 4	-	-	-	-	-	-	-	-
Monthly efficiency	25.30	25.54	24.24	25.05	24.11	-	23.20	23.55

TABLE II: DAILY BLOCK EFFICIENCY (%)

	Block1	Block2	Block3	Block4
1 / 4	27.22	34.74	23.79	23.09
2 / 4	23.19	30.43	24.15	24.05
3 / 4	25.54	22.66	25.72	39.55
4 / 4	20.89	29.68	34.06	33.36
5 / 4	24.76	35.04	34.60	33.48
6 / 4	27.20	34.81	23.79	35.12
7 / 4	22.85	33.29	27.03	34.03
8 / 4	27.48	33.58	32.75	33.82
9 / 4	24.56	32.71	34.39	34.18
10 / 4	23.93	30.29	32.86	33.61
11 / 4	24.41	29.02	32.86	34.22
12 / 4	25.81	24.83	32.86	33.85
13 / 4	27.73	17.10	31.34	31.40
14 / 4	25.94	24.76	25.03	23.09
15 / 4	25.14	28.52	23.79	23.09
16 / 4	26.29	28.71	23.87	21.31
17 / 4	23.41	24.17	23.79	23.26
18 / 4	25.91	26.01	23.79	23.09
19 / 4	24.57	35.31	23.34	23.09
20 / 4	26.82	25.76	31.15	23.09
21 / 4	24.87	26.25	34.00	24.13
22 / 4	26.34	20.28	33.52	23.09
23 / 4	26.80	25.64	33.21	23.09
24 / 4	23.92	24.60	36.12	28.07
25 / 4	25.00	25.12	33.46	28.38
26 / 4	25.48	25.31	35.77	28.97
27 / 4	26.45	24.65	33.76	30.18
28 / 4	24.62	24.73	28.49	31.05
29 / 4	24.62	24.61	30.58	28.95
30 / 4	27.83	23.87	34.71	29.35
31 / 4	-	-	-	-
Monthly efficiency	25.41	28.66	30.20	29.12

*The highlighted blocks refer to open cycle operation.

TABLE III: A MONTH OPERATING PERIOD DATA

Consumed resources (ton)	HCGO	2627.33
	LDO	28965.35
Actual generation (MW.h)	112884.90	
Average generation rate (MW)	156.78	
Monthly efficiency (%)	28.09	

RESULTS AND DISCUSSION

The study compared combined and open cycle operation in terms of efficiency and fuel consumption as shown in Table IV. In order to make a valid comparison for long period, each cycle should have full operation at this period. It is noticeable in Table II that there is full open cycle operation at block 1 for the whole month.

However, no data exists for a full month period with the combined cycle operation mode, due to faults that occurred at steam turbines, that made it out of service. For purpose of accurate comparison, the days that represent open cycle operation period at blocks 2, 3, and 4 are excluded. As it is found that block 3 had the longest operation period in combined cycle mode with 21 days period, the comparison is made for those 21 days.

TABLE IV: THREE WEEKS RESULTS

	Block1	Block3
LDO consumption (ton)	5509.81	3456.15
HCGO consumption (ton)	922.64	0.00
Output (MW.h)	20747.22	14356.00
Efficiency	25.38	32.61

From Figure 3, the comparison is made between block1 which operates in the open cycle mode, due to a fault that occurred in ST1 that made it out of service for the whole month, and block 3 in the other hand, when it operates in combined cycle mode. A remarkable rise in the efficiency is noticeable. The combined cycle operation has shown an efficiency range that varies between 25.72% to 36.12%.

For purpose of validation of the present paper's results, it is found that, analysis performed in [6] for Garri 2 power plant where block 3 is located, results in a thermal efficiency of 38% for the overall plant. Figure 4 illustrates the daily efficiency for three weeks, for block 3 and block 1 exemplifying the operation of the combined cycle and open cycle respectively.

In order to determine the fuel, save as a result of combined cycle operation mode, fuel consumption is determined in case of combined cycle as well as open cycle operation modes within a period of three weeks. In order to determine fuel, save, same output should be obtained from both cycles operating modes. From Table IV considering the output of combined cycle, assuming the same output is to be generated by open cycle operating mode, the respective fuel consumption is determined as follows:

$$fuel\ input\ (ton) = \frac{desired\ output\ (kJ)}{\eta \times heat\ value\left(\frac{kJ}{ton}\right)}$$

$$= \frac{(14356.00\ \times 3600)(kJ)}{(0.2538 \times 45859)\left(\frac{kJ}{ton}\right)}$$

$$= \quad 4440.38$$

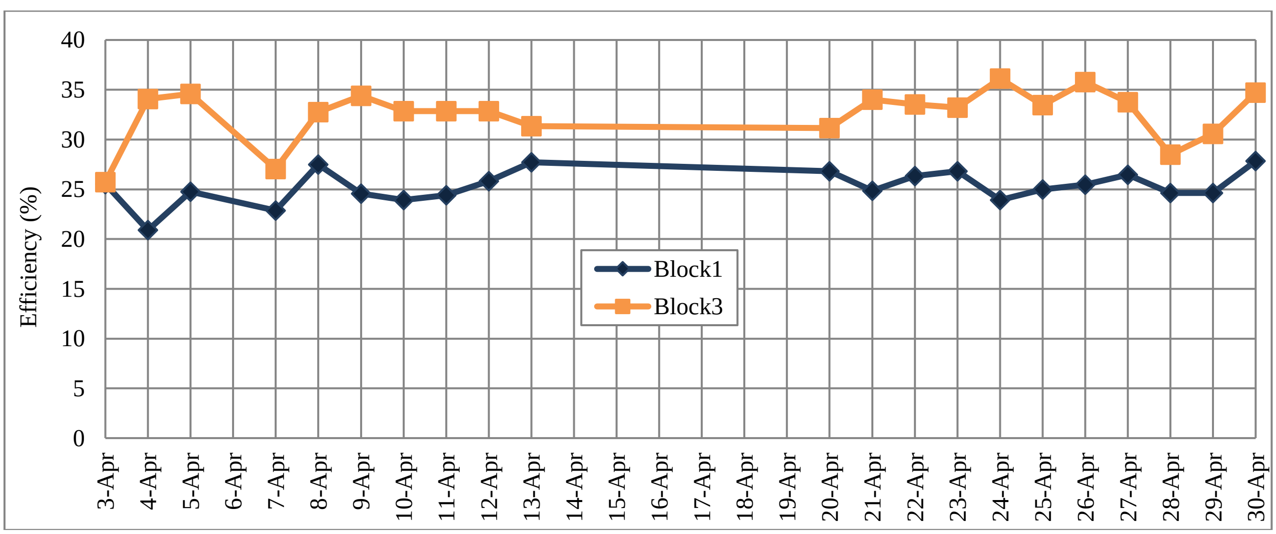

Figure 3: Block`s Daily Efficiency

The amount of fuel consumption in case of the combined cycle operation mode represented in block 3 in the same three weeks period is obtained from Table IV. Then, the amount of fuel save in result of the combined cycle operation mode is given by:

$$saved\ fuel\ (ton) = 4440.38 - 3456.15 = 984.23$$

Then, percentage fuel save is given by:

$$fuel\ \ save\ (\%)\ = \frac{984.23}{4440.38} = 22.17\%$$

It is noticeable that, for a specific amount of output electric energy of the plant, the combined cycle operation results in consumption of less fuel than open cycle operation, and the percentage fuel save is considerable.

CONCLUSION

Thermal power plant’s overall efficiency increases and fuel consumption decrease is of paramount importance owing to the limited resources and high cost of fossil fuel. This paper compared Al-Jaily power plant overall efficiency and fuel consumption in case of combined cycle and open cycle operation modes. Results showed that combined cycle operation mode improves plant’s efficiency by a considerable amount.

It is found that, when Al-Jaily power plant, the so-called Garri 1 and 2, is operated in the combined cycle mode, plant efficiency is 28.49% higher than when operated in the open cycle mode. On the other hand, while producing the same amount of energy, 22.17% fuel save is attained when operating the power plant in the combined cycle mode as compared to when operated in the open cycle mode.

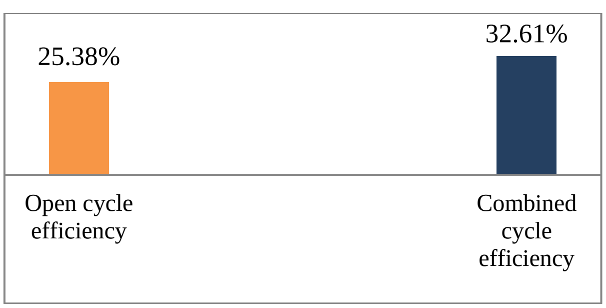

Figure 4: Combined vs. Open Cycle Efficiency

NOMENCLATURE

GT = Gas Turbine.
ST = Steam Turbine.
Ch1= Gas turbine outlet chimney.
Ch2 = HRSG outlet chimney.
η = efficiency.
E_{in} = input Energy(kJ).
E_{out} = output energy(kJ).
E_{LDO} = energy released by LDO (kJ).
E_{HCGO} = energy released by HCGO (kJ),
E_a= GTa output (MW.h).
E_b = GTb output (MW.h).
E_s = steam turbine output (MW.h).
E_a`= energy released in GTa (kJ).
E_b`= energy released in GTb (kJ).
E_T= energy released in each turbine(kJ).
p = turbine generation (MW).
t = turbine running hours (hours).
m_1 = LDO consumed mass (ton).
m_2 = HCGO consumed mass (ton).
H = low heat value of fuel (kJ/kg).
H_1 = LDO heat value(kJ/kg).
H_2= HCGO heat value(kJ/kg).
H_1= 45859 (kJ/kg).
H_2= 45125 (kJ/kg).

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APPENDICES

Appendix I

LDO CONSUMPTION (*ton*)

	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8
1 / 4	28.00	95.00	28.00	161.00	160.38	0.00	213.52	179.86
2 / 4	90.00	103.00	5.00	161.00	156.00	0.00	203.00	173.00
3 / 4	100.45	106.08	17.50	173.00	158.40	0.00	212.26	190.06
4 / 4	95.74	101.80	100.90	161.00	174.24	0.00	220.32	191.90
5 / 4	0.00	128.40	0.00	161.00	101.64	0.00	208.08	209.10
6 / 4	32.40	135.85	0.00	160.33	94.38	0.00	205.00	209.00
7 / 4	13.00	171.00	99.66	172.20	174.24	0.00	210.46	209.10
8 / 4	0.00	127.20	0.00	164.00	174.24	0.00	211.14	209.10
9 / 4	0.00	154.80	0.00	167.00	177.60	0.00	212.16	209.00
10/4	7.36	148.68	6.75	170.40	177.87	0.00	209.10	207.40
11/4	97.00	150.80	110.80	0.00	169.62	0.00	211.14	193.80
12/4	198.00	169.00	99.00	0.00	169.62	0.00	211.14	207.40
13/4	199.20	164.00	115.70	0.00	168.30	0.00	211.14	210.12
14/4	192.53	188.80	185.20	0.00	165.60	0.00	212.26	216.24
15/4	199.20	175.20	160.80	0.00	168.30	0.00	208.76	212.84
16/4	199.00	175.00	168.80	0.00	169.69	0.00	205.00	132.00
17/4	112.00	162.00	186.00	0.00	102.96	0.00	81.60	0.00
18/4	201.00	146.00	199.20	0.00	135.96	0.00	108.80	131.58
19/4	187.30	164.00	196.50	0.00	177.60	0.00	0.00	212.16
20/4	188.30	124.68	185.98	0.00	192.06	0.00	0.00	208.08
21/4	189.00	175.00	185.00	0.00	193.00	0.00	0.00	203.00
22/4	186.00	137.00	178.00	0.00	192.06	0.00	203.32	208.08
23/4	194.40	139.00	180.00	0.00	198.33	0.00	210.80	217.60
24/4	172.00	155.00	180.32	0.00	182.40	0.00	212.16	209.00
25/4	175.03	125.83	178.73	0.00	196.35	0.00	207.74	210.80
26/4	175.00	145.00	180.00	0.00	185.00	0.00	206.00	204.00
27/4	176.40	129.60	182.40	0.00	65.34	0.00	207.74	210.80
28/4	172.80	68.30	181.77	0.00	78.54	0.00	17.68	211.14
29/4	174.40	84.16	181.70	0.00	165.60	0.00	205.00	-
30/4	175.20	115.20	179.28	0.00	161.70	0.00	201.28	212.16
31/4	-	-	-	-	-	-	-	-
Total	3930.71	4165.38	3672.99	1650.93	4787.02	0.0	5226.6	5531.72

Appendix II

HCGO CONSUMPTION (ton)

	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8
1 / 4	157.00	0.00	144.00	0.00	-	-	-	-
2 / 4	106.00	0.00	78.00	0.00	-	-	-	-
3 / 4	0.00	0.00	0.00	0.00	-	-	-	-
4 / 4	9.23	0.00	80.30	0.00	-	-	-	-
5 / 4	199.20	0.00	184.56	0.00	-	-	-	-
6 / 4	160.48	0.00	184.00	0.00	-	-	-	-
7 / 4	77.04	0.00	72.00	0.00	-	-	-	-
8 / 4	194.40	0.00	160.80	0.00	-	-	-	-
9 / 4	172.53	0.00	157.80	0.00	-	-	-	-
10 / 4	185.10	0.00	179.75	0.00	-	-	-	-
11 / 4	85.14	0.00	40.00	0.00	-	-	-	-
12 / 4	0.00	0.00	0.00	0.00	-	-	-	-
13 / 4	0.00	0.00	0.00	0.00	-	-	-	-
14 / 4	0.00	0.00	0.00	0.00	-	-	-	-
15 / 4	0.00	0.00	0.00	0.00	-	-	-	-
16 / 4	0.00	0.00	0.00	0.00	-	-	-	-
17 / 4	0.00	0.00	0.00	0.00	-	-	-	-
18 / 4	0.00	0.00	0.00	0.00	-	-	-	-
19 / 4	0.00	0.00	0.00	0.00	-	-	-	-
20 / 4	0.00	0.00	0.00	0.00	-	-	-	-
21 / 4	0.00	0.00	0.00	0.00	-	-	-	-
22 / 4	0.00	0.00	0.00	0.00	-	-	-	-
23 / 4	0.00	0.00	0.00	0.00	-	-	-	-
24 / 4	0.00	0.00	0.00	0.00	-	-	-	-
25 / 4	0.00	0.00	0.00	0.00	-	-	-	-
26 / 4	0.00	0.00	0.00	0.00	-	-	-	-
27 / 4	0.00	0.00	0.00	0.00	-	-	-	-
28 / 4	0.00	0.00	0.00	0.00	-	-	-	-
29 / 4	0.00	0.00	0.00	0.00	-	-	-	-
30 / 4	0.00	0.00	0.00	0.00	-	-	-	-
31 / 4	0.00	0.00	0.00	0.00	-	-	-	-
Total	1346.12	0.0	1281.21	0.0	-	-	-	-

Appendix III

GT'S GENERATION (MW.h)

	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8
1 / 4	649.09	313.09	542.18	519.27	486.00	0.00	628.00	529.00

2 / 4	572.73	305.46	236.73	504.00	480.00	0.00	624.00	528.00
3 / 4	328.36	343.64	15.27	534.55	480.00	0.00	624.00	559.00
4 / 4	320.73	229.09	549.82	530.73	528.00	0.00	648.00	528.00
5 / 4	610.91	412.36	565.09	523.09	308.00	0.00	612.00	615.00
6 / 4	649.09	481.09	565.09	549.82	286.00	0.00	619.00	648.00
7 / 4	282.55	473.56	546.00	519.27	528.00	0.00	619.00	615.00
8 / 4	626.18	488.73	469.64	542.18	528.00	0.00	621.00	615.00
9 / 4	542.18	473.46	450.55	519.27	569.00	0.00	624.00	658.00
10 / 4	549.82	481.09	458.18	526.91	539.00	0.00	615.00	610.00
11 / 4	549.82	481.09	465.82	0.00	514.00	0.00	621.00	570.00
12 / 4	656.73	549.82	313.09	0.00	514.00	0.00	621.00	610.00
13 / 4	672.00	610.91	252.00	0.00	510.00	0.00	621.00	618.00
14 / 4	649.09	610.91	584.18	0.00	528.00	0.00	624.00	636.00
15 / 4	610.91	588.00	584.18	0.00	510.00	0.00	614.00	626.00
16 / 4	710.18	542.18	588.00	0.00	516.00	0.00	597.00	318.00
17 / 4	343.64	473.46	572.73	0.00	312.00	0.00	240.00	0.00
18 / 4	664.36	481.09	610.91	0.00	412.00	0.00	320.00	387.00
19 / 4	610.91	488.73	641.46	0.00	528.00	0.00	0.00	624.00
20 / 4	595.64	473.46	580.36	0.00	582.00	0.00	0.00	612.00
21 / 4	664.36	488.73	618.56	0.00	600.00	0.00	0.00	624.00
22 / 4	618.00	465.82	459.82	0.00	582.00	0.00	598.00	612.00
23 / 4	656.73	481.09	588.00	0.00	601.00	0.00	620.00	640.00
24 / 4	530.73	465.82	565.09	0.00	600.00	0.00	624.00	624.00
25 / 4	546.00	412.00	572.00	0.00	595.00	0.00	611.00	620.00
26 / 4	542.18	496.36	580.36	0.00	603.00	0.00	624.00	628.00
27 / 4	549.82	481.09	572.73	0.00	198.00	0.00	611.00	620.00
28 / 4	549.82	206.18	572.73	0.00	238.00	0.00	52.00	621.00
29 / 4	544.47	266.51	569.67	0.00	535.00	0.00	624.00	-
30 / 4	539.89	489.49	545.24	0.00	490.00	0.00	592.00	624.00
31 / 4	-	-	-	-	-	-	-	-
Total	16936.92	13554.31	15235.48	5269.09	14700	0.00	15448	16594

Appendix IV

BLOCKS OUTPUT (MW.h)

	Block1			Block2		
	GT1	GT2	ST1	GT3	GT4	ST2
1 / 4	649.09	313.09	0.00	542.18	519.27	401.80
2 / 4	572.73	305.46	0.00	236.73	504.00	200.22
3 / 4	328.36	343.64	0.00	15.27	534.55	0.00

4 / 4	320.73	229.09	0.00	549.82	530.73	208.48
5 / 4	610.91	412.36	0.00	565.09	523.09	441.00
6 / 4	649.09	481.09	0.00	565.09	549.82	398.80
7 / 4	282.55	473.56	0.00	546.00	519.27	388.00
8 / 4	626.18	488.73	0.00	469.64	542.18	366.50
9 / 4	542.18	473.46	0.00	450.55	519.27	373.20
10 / 4	549.82	481.09	0.00	458.18	526.91	380.90
11 / 4	549.82	481.09	0.00	465.82	0.00	89.20
12 / 4	656.73	549.82	0.00	313.09	0.00	0.00
13 / 4	672.00	610.91	0.00	252.00	0.00	0.00
14 / 4	649.09	610.91	0.00	584.18	0.00	0.00
15 / 4	610.91	588.00	0.00	584.18	0.00	0.00
16 / 4	710.18	542.18	0.00	588.00	0.00	0.00
17 / 4	343.64	473.46	0.00	572.73	0.00	0.00
18 / 4	664.36	481.09	0.00	610.91	0.00	49.00
19 / 4	610.91	488.73	0.00	641.46	0.00	242.50
20 / 4	595.64	473.46	0.00	580.36	0.00	30.00
21 / 4	664.36	488.73	0.00	618.56	0.00	0.00
22 / 4	618.00	465.82	0.00	459.82	0.00	0.00
23 / 4	656.73	481.09	0.00	588.00	0.00	0.00
24 / 4	530.73	465.82	0.00	565.09	0.00	0.00
25 / 4	546.00	412.00	0.00	572.00	0.00	0.00
26 / 4	542.18	496.36	0.00	580.36	0.00	0.00
27 / 4	549.82	481.09	0.00	572.73	0.00	0.00
28 / 4	549.82	206.18	0.00	572.73	0.00	0.00
29 / 4	544.47	266.51	0.00	569.67	0.00	0.00
30 / 4	539.89	489.49	0.00	545.24	0.00	0.00
31 / 4	-	-	-	-	-	-
total	16936.92	13554.31	0.0	15235.48	5269.09	3569.60
Block output	30491.23			24074.17		

Appendix V

BLOCKS OUTPUT (MW.h)

	Block3			Block4		
	GT5	GT6	ST3	GT7	GT8	ST4
1 / 4	486.00	0.00	0.00	628.00	529.00	0.00
2 / 4	480.00	0.00	0.00	624.00	528.00	0.00
3 / 4	480.00	0.00	39.00	624.00	559.00	436.00
4 / 4	528.00	0.00	228.00	648.00	528.00	576.00

5 / 4	308.00	0.00	140.00	612.00	615.00	552.00
6 / 4	286.00	0.00	0.00	619.00	648.00	585.00
7 / 4	528.00	0.00	72.00	619.00	615.00	585.00
8 / 4	528.00	0.00	199.00	621.00	615.00	574.50
9 / 4	569.00	0.00	209.00	624.00	658.00	552.00
10 / 4	539.00	0.00	195.00	615.00	610.00	558.00
11 / 4	514.00	0.00	196.00	621.00	570.00	574.00
12 / 4	514.00	0.00	196.00	621.00	610.00	574.00
13 / 4	510.00	0.00	162.00	621.00	618.00	446.00
14 / 4	528.00	0.00	0.00	624.00	636.00	0.00
15 / 4	510.00	0.00	0.00	614.00	626.00	0.00
16 / 4	516.00	0.00	0.00	597.00	318.00	0.00
17 / 4	312.00	0.00	0.00	240.00	0.00	0.00
18 / 4	412.00	0.00	0.00	320.00	387.00	0.00
19 / 4	528.00	0.00	0.00	0.00	624.00	0.00
20 / 4	582.00	0.00	180.00	0.00	612.00	0.00
21 / 4	600.00	0.00	236.00	0.00	624.00	0.00
22 / 4	582.00	0.00	238.00	598.00	612.00	0.00
23 / 4	601.00	0.00	238.00	620.00	640.00	0.00
24 / 4	600.00	0.00	239.00	624.00	624.00	258.00
25 / 4	595.00	0.00	242.00	611.00	620.00	282.00
26 / 4	603.00	0.00	240.00	624.00	628.00	261.00
27 / 4	198.00	0.00	83.00	611.00	620.00	378.00
28 / 4	238.00	0.00	47.00	52.00	621.00	232.00
29 / 4	535.00	0.00	110.00	624.00	75.00	110.00
30 / 4	490.00	0.00	225.00	592.00	624.00	330.00
31 / 4	-	-	-	-	-	-
total	14700	0.0	3714	15448	16594	7863.5
Block output	18414			39905.5		