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Transient modeling and performance analysis of site utilities and cogeneration systems: a case study for lubricant oil refinery utilization

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The heat and power demand are supplied by site utility systems. This paper aims to investigate transient modeling and performance analysis of lubricant oil refinery site utility systems. This model calculates the steam generated by boilers and CHP, steam flowrate of each header for site demand; shaft power generated by the GENSET and steam turbines with a constant isentropic efficiency, cogeneration efficiency with the objective function that maximizing total revenue. In addition, by the use of this model, the amounts of GENSET fuel consumption cogeneration efficiency and power generated by the GENSET will increase and boiler fuel consumption will decrease. Using heat recovery equipment to recover exhaust gas energy of GENSET, conformity of steam supply and steam demand and reduction the amount of steam letdown station are the reason that cause to reduce boiler fuel consumption and increase cogeneration efficacy. The reason for increased generator fuel consumption and power generation is power purchase price. Production and sale of electricity is affordable. In addition, total revenue of the site will increase. The resulting model provides a transient strategy for steam saving on total sites and modifications to the utility system as different operation conditions.

Keywords: Transient modeling, Optimization, Site utility, Total Cost, Total Revenue, Energy; Efficiency; Cogeneration

INTRODUCTION

Energy is one of the most essential commodities for sustaining people's livelihoods. Oil Refinery is one of the major energy consumers in industrial sector. Energy utilization in sites can be improved through [1]:

- Increasing energy efficiency by retrofit of site process
- Identifying the opportunities to improve utility system
- Operational optimization of existing processes or utility systems

Combined heat and power (CHP) systems, also known as cogeneration, generate electricity and useful thermal energy in a single, integrated system in different application. Varbanov *et al*. [2] studied about exergy analysis of the efficiency CHP systems in small scale utilization. Afanasyeva & Mingaleeva [3] described the detail of the Iterative Bottom-to-Top Model (IBTM) that is calculates the temperature of steam mains, steam flowrate and shaft power generated by the steam turbines. Ghannadzadeh *et al*. [4] developed the A new cogeneration targeting model that has been provided a consistent, general procedure for determining the mass flow rates and the efficiencies of the turbines. Optimizing the site utility systems is one of the most challenging topics. To analysis a utility system, it is first necessary to develop a simulation model. Such models have been developed in [5]. Also, for estimating cogeneration potential of site utility system, using the total site profile has been suggested. The total site profile is a most useful tool to obtain a better realizing of the systems. Total site profiles can be produced by combining the grand composite curve for individual process. Furthermore, several studies have been conducted to evaluated site utility and cogeneration systems. For this reasons, various methodologies and case studies have been investigated for different approaches [6].

Most processes operate in the context of an existing site in which a number of processes are linked to the same utility system. The analysis of utility systems in industrial process to determine the value of steam savings to obtain optimizing operational energy cost and identify the energy conservation opportunities is the main target of this study. This analysis is carried out for existing utility such as steam and power in sample lubricant oil refinery [7, 8, 9].

In this paper, after energy auditing of site utility system, and collect the information of the utility systems and measuring some important parameter, the energy conservation opportunities (ECOs) are

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founded and the current situation was simulated. Next, optimizing the plant operation under the current process steam demand was studied. Considering transient condition and maximizing total revenue (or minimizing total cost) with operation research technique are new innovation in this research.

METHODOLOGY

The heat and power demand are supplied by a site utility systems. Fuels (such as NG, coal etc.) are consumed in boiler by site utility system to supplies steam for operating the process and produce power with steam turbine. Steam turbines can be divided into two basic classes: condensing and back-pressure turbines. In condensing turbines, exhaust steam pressure must be less than atmospheric pressure. Back-pressure turbines decrease steam pressure from one header to another and produce power. The algorithm of the optimization procedure is shown in Fig. 1.

The site utility scheme in maximums demand situation is presented as Fig. 2. In this case, four steam levels that are feed the four main processes are existence. This site has 3 boiler that are produce steam at 360C and 20 bar and six gas engine generator which can be produce 3.7x6 MW. The boilers and gas engine generator specification are listed as table 1 and 2. Site contains 4 is a process in which steam is used. PR1 is referred to amount of steam demand in 370 C and 35 bar that is service to first and third process of the site. PR2 is steam demand at 260 C and 25 bar that is needed for process 1, 2 and 3. PR3 and PR4 represent the amount of saturated steam required in 10 bar and 2 bar that are services to process.

This study aims to investigate transient modeling and optimization of lubricant oil refinery site utility systems. For this purpose, the annual hourly power and steam demand are extracted from CCR logging software in 3 years and the site utility systems behavior are simulated and the best solution in operation and constitutional reform is applied on site.

ENERGY MODELING

Total heat supply rate by boiler to steam circuits is calculated as below:

$$\dot{Q}_{BOILER} = \dot{m}(h_{out} - h_{in})$$

Where $\dot{m}, h_{out}$ and h_{in} refer to flow rate of steam, enthalpy of outlet steam and boiler feed water. Total heat rate to the boiler is calculated as below:

$$\dot{Q}_{FUEL} = \dot{m}_{fuel} \times LHV$$

Where $\dot{m}_{fuel}$ and LHV refer to boiler fuel flow rate and low heat value of the fuel. Boiler energy efficiency is calculated as below formula.

$$\eta_{BOILER} = \frac{\dot{Q}_{BOILER}}{\dot{Q}_{FUEL} + \dot{m}_{AIR} \times (h_{AIR} - h_{AMB})}$$

Whereη_{BOILER}, $\dot{m}_{AIR}$, h_{AIR} and h_{AMB} are boiler efficiency, airflow rate, sensible specific enthalpy of supply air at the inlet to the boiler and sensible specific enthalpy of ambient air. Because of the difference of h_{AIR} and h_{AMB} is closed to zero, therefor the amount of this section is neglected.

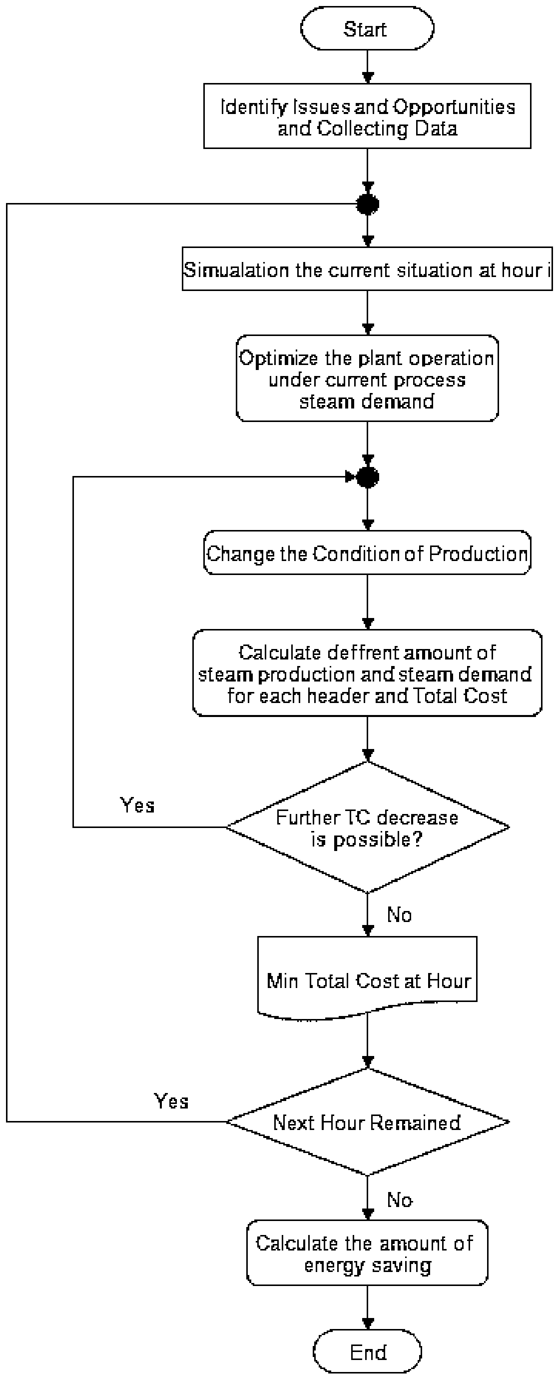

Fig. 1 The algorithm of the optimization procedure.

Therefore, the energy balance of b1, b2 and b3 are illustrated as Figure 3a,b,c. Thus the total amount of fuel that is needed to run the site utility systems is equal 8104 m^3/h.

Reciprocating engine generator sets can be used in cogeneration systems, with heat recovery from their exhaust gases and cooling water jackets. In current situation the gas engine generator only produce the power but it can be equipped with heat recovery steam generator.

For the current situation (PG=1250 Kw), the reciprocating engine is simulated and shown as Figure 3d. Thus the total natural gas consumption is about10270 m^3/h.

The value of heat recovery potential, fuel consumption and electrical energy efficiency of the gas engine generator with different power generation are simulated with software and presented as Table 3.

Heat recovery potential, fuel consumption and electrical energy efficiency are regression with power production of reciprocating engine. The results of regression are listed as Table.4.

Even though the steam demand is different in each time, the utility system is produced power and steam in current situation. The total site composite curve is plotted for the maximum situation. Process stream table of process 1 to 4 are shown as Table 1.

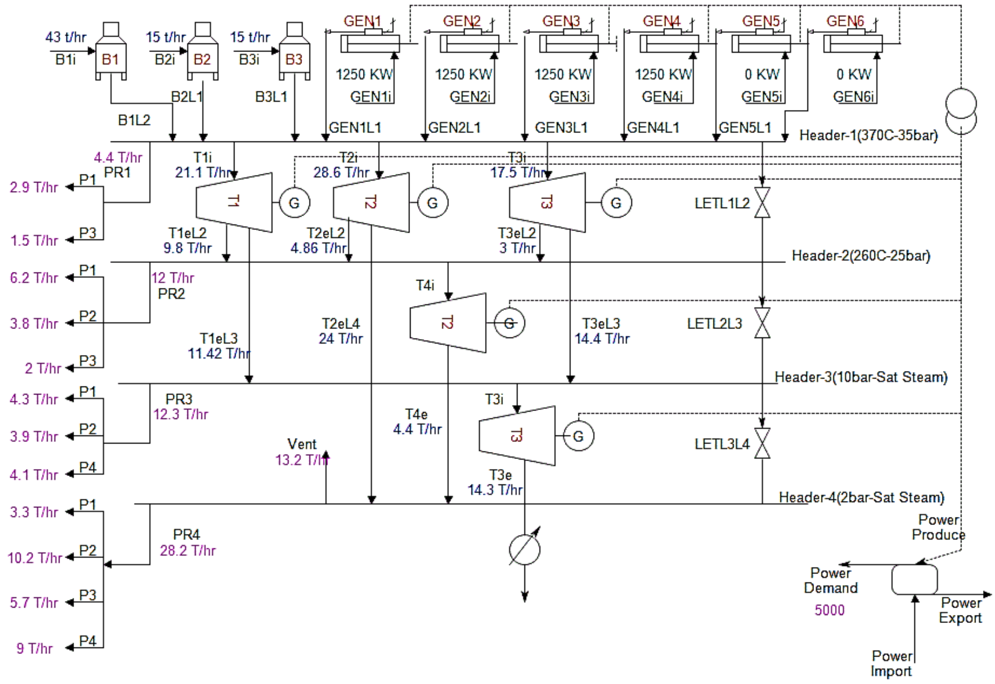

Fig. 2. The site utility scheme in maximums demand situation.

Table 1. Specifications of boilers.

	Parameter	Unit	B1		B2&B3	
			Design	Current	Design	Current
Boiler Feed Water	Flow Rate	T/hr	16~80	43.68	3~15	15.198
	Temperature	ºC	105	105	105	105
	Pressure	Bar	22.5	22.5	22.5	22.5
Steam Outlet	Flow Rate	T/hr	16~80	43	12500	15
	Temperature	ºC	360	360	360	360
	Pressure	Bar	20	20	20	20
Blowdown	Flow Rate	T/hr	-	0.68	-	0.198
Exhaust	Temperature	ºC	NA	189	NA	195
	Oxygen	%	-	4.695	-	5.719

Table 2. Specifications of gas engine generators.(at 3337 kW**)**

Fuel Type	Mode	RPM	Freq	Power	Texh	Exh. Flow	Elec Eff
NG	C	1000	50 Hz	3337 kW	490 C	19.48 t/hr	39.5 %

Table 3. Technical information of GENSET

	PG (KW)	Heat to exhaust (KW)	Fuel consumption (t/hr)	ELEC EFF (%)
1	3337	2832	0.657	39.49%
2	3250	2767.1	0.644	39.29%
3	3000	2581.7	0.604	38.66%
4	2750	2398.3	0.564	37.94%
5	2500	2217.3	0.524	37.11%
6	2250	2091.4	0.484	36.14%
7	2000	1958.5	0.444	35.01%
8	1750	1818.7	0.405	33.65%
9	1500	1659.6	0.365	31.99%
10	1250	1490.9	0.325	29.92%
11	1000	1319.1	0.285	27.28%
12	834.2	1203.5	0.259	25.08%

Table 4. Heat recovery potential, fuel consumption and electrical energy efficiency of GENSET**.**

Formula	Constraint	RValue
$\boldsymbol{\eta_{ELEC} = p_1 \times PG^4 + p_2 \times PG^3 + p_3 \times PG^2 + p_4 \times PG + p_5}$	$384.2 \leq PG \leq 3337$	$R = 0.99$
$\boldsymbol{M_{FUEL} = p_6 \times PG + p_7}$	$384.2 \leq PG \leq 3337$	$R = 0.99$
$\boldsymbol{HEP = p_8 \times PG + p_9}$	$384.2 \leq PG \leq 3337$	$R = 0.96$

Where the p_1 = -2.703e-013, p_2 = 2.987e-009, p_3 = -1.321e-005, p_4 = 0.03053, p_5 = 7.218, p_6 = 0.0001593, p_7 =0.1259,p_8 = 0.6332 and p_9 = 686.7

Table 5. Current situation mass balance

1	B1L1	43	T/hr.	14	T1eL2	9.8	T/hr.
2	B2L2	15	T/hr.	15	T1el3	11.2	T/hr.
3	B3L3	15	T/hr.	16	T2i	28.8	T/hr.
4	GEN1L1	0	T/hr.	17	T2eL2	4.8	T/hr.
5	GEN2L1	0	T/hr.	18	T2eL4	24	T/hr.
6	GEN3L1	0	T/hr.	19	T3i	17.4	T/hr.
7	GEN4L1	0	T/hr.	20	T3eL2	3	T/hr.
8	GEN5L1	0	T/hr.	21	T3eL3	14.4	T/hr.
9	GEN6L1	0	T/hr.	22	T4i	4.4	T/hr.
10	LETL1L2	1.4	T/hr.	23	T4e	44	T/hr.
11	LETL2L3	2.6	T/hr.	24	T5i	14.3	T/hr.
12	LETL3L4	1.6	T/hr.	25	T5e	14.3	T/hr.
13	T1i	21	T/hr.				

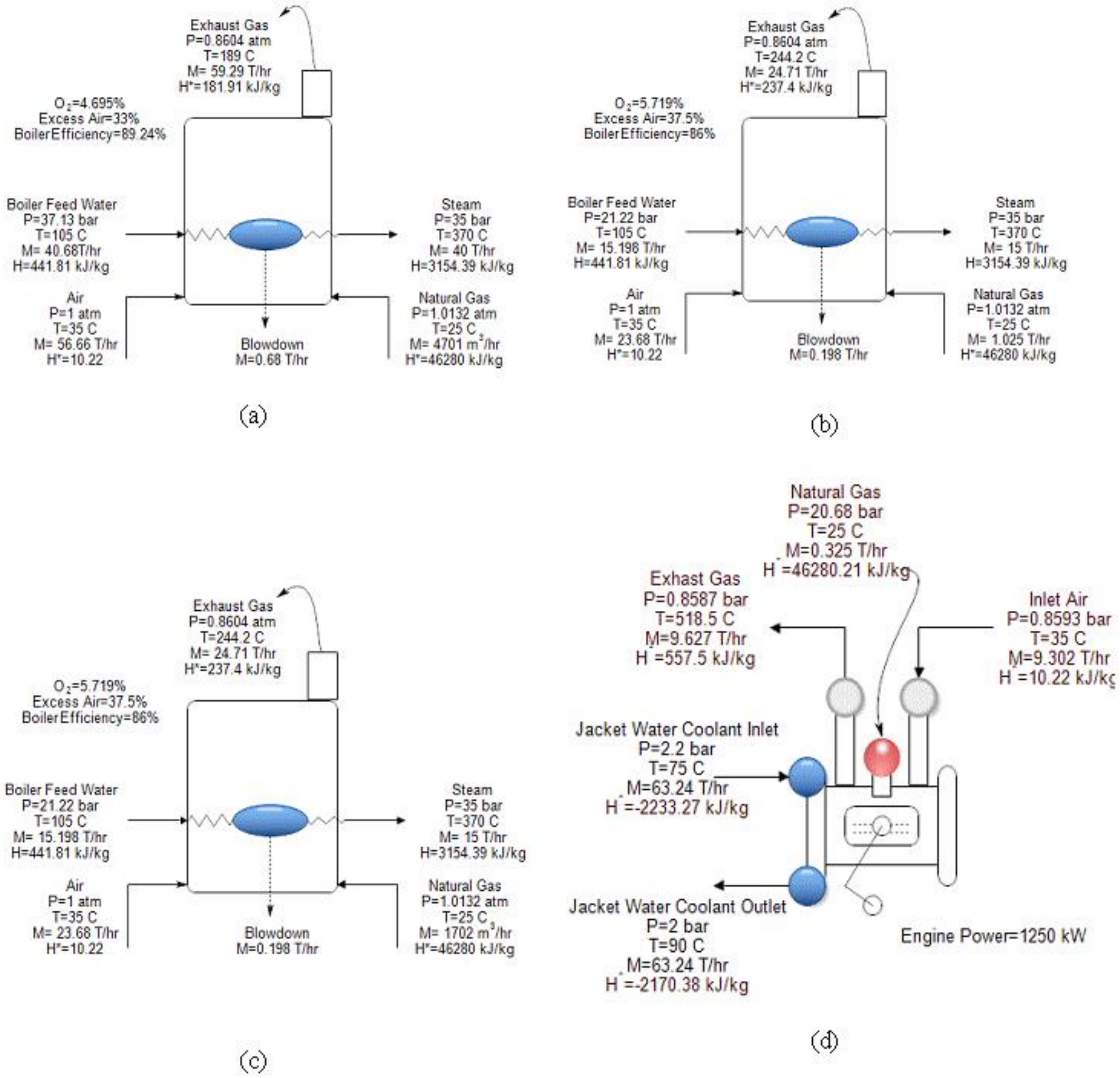

Fig. 3. Mass and energy balance of b1(a), b2(b), b3(c) and reciprocating engine(d).

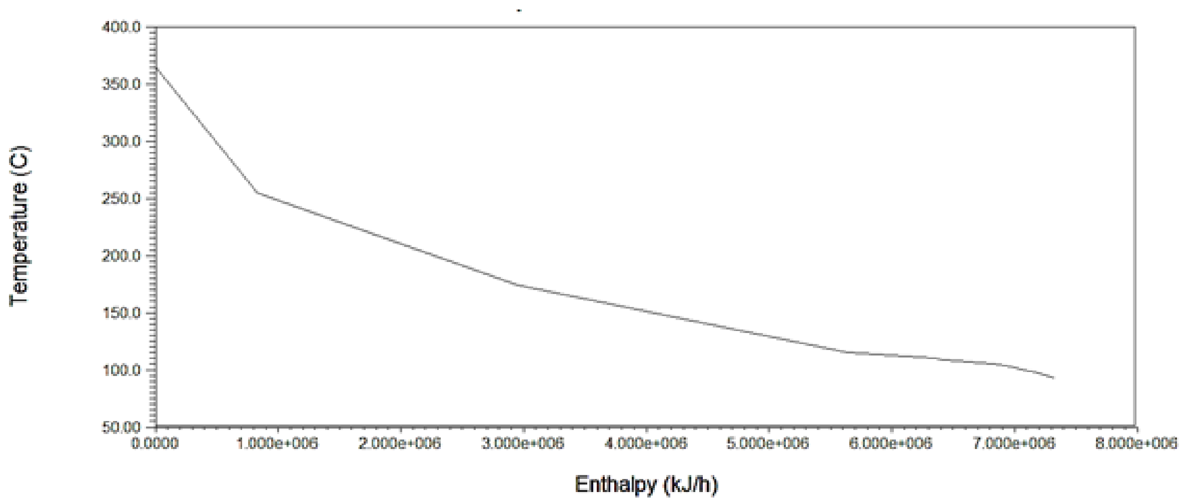

Fig. 4. Total site composite curve.

Table 6. Process stream table of total site

	Code	Flow rate	T_{in}	T_{out}	Duty
process 1	E101	2.9	370	110	1316430
	E103	6.2	260	114.3	1394864
	E104	4.3	179.9	112.4	441289.9
	E106	3.3	120.2	97.8	128145.3
process 2	E202	3.8	260	110	886131.7
	E203	3.9	179.9	113.2	394278.5
	E204	5.9	120.2	115	131282.8
	E205	4.3	120.2	108	418443.3
process 3	E301	1.5	370	105	695226
	E302	2	260	110	466385.1
	E304	5.7	120.2	98.3	215912.7
process 4	E401	4.1	179.9	103	494322.9
	E404	9	120.2	98	346058.2

As the statistical analysis, this site is operated as fixed condition during the year. The economic analysis is studied in this section. As thermal modeling of site utility, the boiler fuel consumption return to sum of fuel consumption of b1, b2 and b3. Similarly the fuel consumption of generators is equal to sum of fuel consumption of GEN1, GEN2, GEN3, GEN4, GEN5 and GEN6. Export power is calculated as different of power produce and power demand. The total cost (or total revenue) is different of fuel cost and power purchase. If the result is greater than zero total cost will be considered, else total revenue will be considered. Power and NG price are listed as below table.

The cogeneration efficiency is therefore more correctly defined as:

$$\eta_{COGEN} = \frac{W_{GEN} + Q_{SITE}}{Q_{SUPPLY}}$$

WhereW_{GEN},Q_{SITE} and Q_{SUPPLY} are total power production, total heat demand and total heat supply. Where Q_{SUPPLY}defined as:

$$Q_{SUPPLY} = Total\ fuel\ consumption \times LHV$$

The most appropriate cogeneration system for a site depends to a large extent on the site power-to-heat ratio, defined as

$$R_{SITE} = \frac{W_{SITE}}{Q_{SITE}}$$

Where R_{SITE}, W_{SITE} and Q_{SITE} are site power-to-heat ratio, power demand of the site and process heating demand for the site. R_{SITE} is equal to 0.131.

According to above discussion, economic evaluation of site utility existed condition is presented as Table 8.

For the proposed of this study, the average of hourly annual Steam and power demands in different header are extracted for 3 years from refinery's DCS and these data are plotted as fig 5,6,7,8.It should be noted that, unrealistic information (such as hot and cold maintenance, shutdown etc.) are excluded.

As shown in the figure, the amount of steam required in PR1, PR2, PR3 and conditions are equal 38509.7, 105026.7, 107652.1and 246811.8 Ton/hr. Although the boilers are working as constant condition, that is presented as Fig 2.

Hourly total revenue of incoming power purchase after shrinking of fuel consumption cost is plotted as below figure. Annual revenue is about of 1900878 $.This data should be used to simulate the different condition of site for optimization of operating site utility systems. For this simulation, it is assumed the efficiency of boiler is constant in different condition.

Table 7. Power and NG price

Power Export Price ($¢/kWh$)	NG Price of DG ($¢/m^3$)	NG Price ($¢/m^3$)
3.35	1.93	2.89

Table 8. Economic evaluation of site utility existed condition

TC (or TR) ($)	Power Produce (kWh)	Power Export (kWh)	Power Purchase ($/hr)	Boiler Fuel Consumptio n (m3/yr)	Generator Fuel Consumption (m3/yr)	Total Fuel Consumption (m3/yr)	Fuel Cost ($/hr)	Cogeneration Efficiency
-217.4	20185	15185	509.1	8367	2587	10954	291.7	41.38%

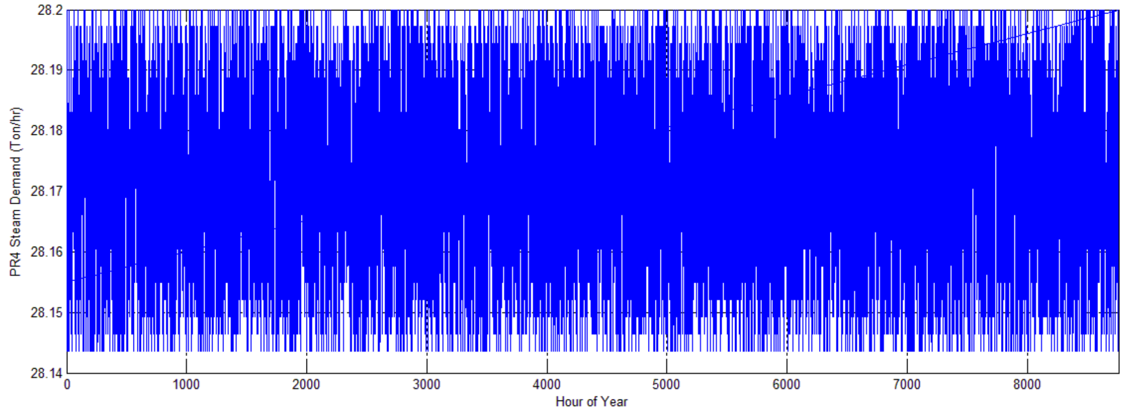

Fig. 5 Annual hourly PR4 steam demand.

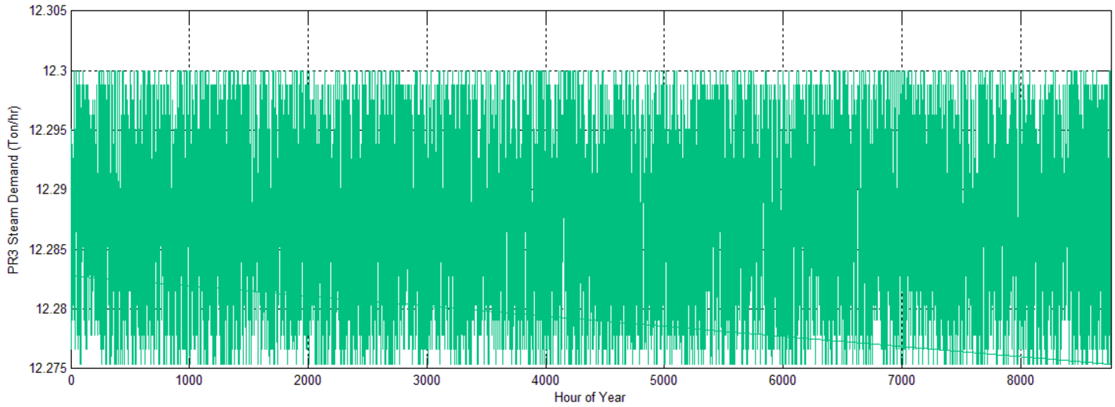

Fig. 6 Annual hourly PR3 steam demand.

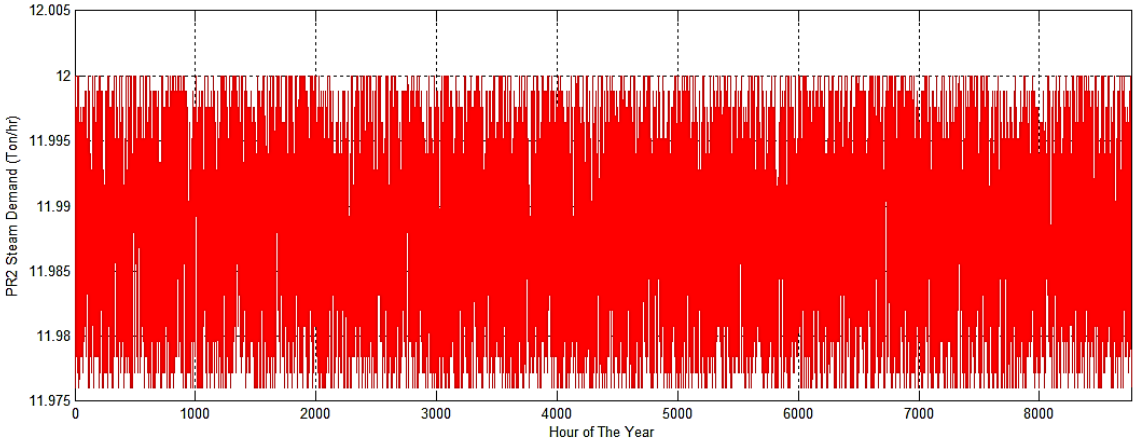

Fig. 7 Annual hourly PR2 steam demand.

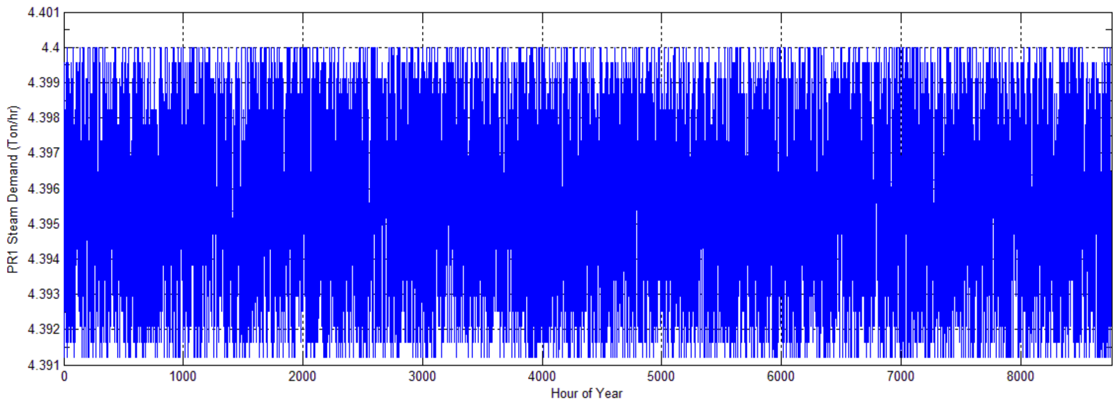

Fig. 8 Annual hourly PR1 steam demand.

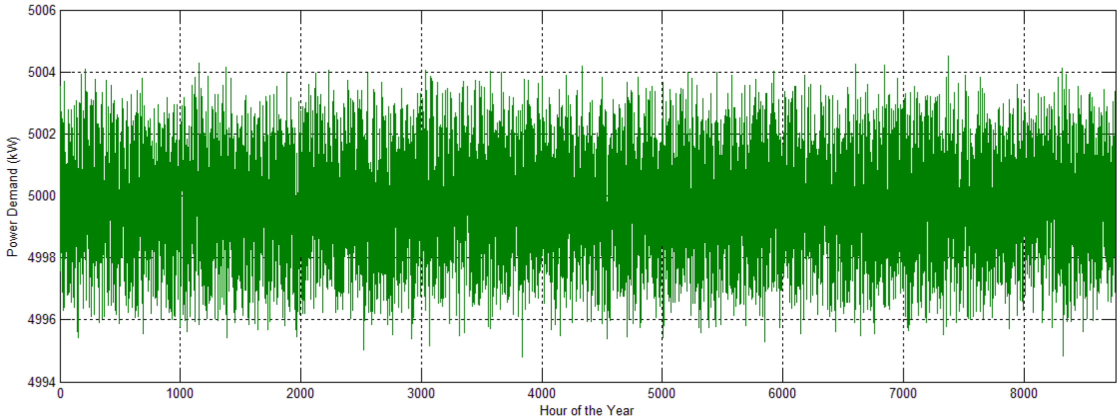

Fig. 9. Annual hourly power demand.

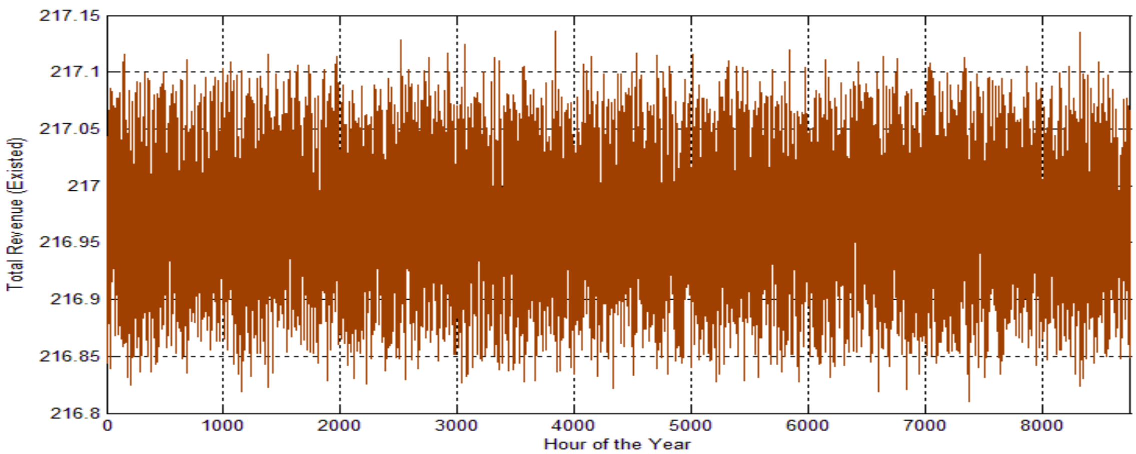

Fig. 10 Annual hourly site utility revenue

Table 9. Equal constraints of the model

$16 \leq B1L1 \leq 80$;	$3 \leq T2eL2 \leq 13.2$;
$3 \leq B2L1 \leq 15$;	$14 \leq T2eL4 \leq 37$;
$3 \leq B3L1 \leq 15$;	$8.36 \leq T3i \leq 23.3$;
$13.2 \leq Ti \leq 36.3$;	$1.4 \leq T3eL2 \leq 5.3$;
$4.2 \leq T1eL2 \leq 16.5$;	$6.96 \leq T3eL3 \leq 18$;
$9 \leq T1eL3 \leq 19.8$;	$8.8 \leq T5i \leq 16.5$;
$17 \leq T2i \leq 50.2$;	$382 \leq PG1{\sim}6 \leq 3337$;

The next step in this study is modeling of site utility system for transient situation of PR1, PR2, PR3 and PR4. Minimizing the total cost is the main target in this study. For this reason, the thermo-economic model is developed that finds the minimum of total cost and best solution for operation cost specified by

$$min_x f^t x such that \begin{cases} A.x \le b, \\ Aeq.x = beq \\ lb \le x \le ub \end{cases} ,(1)$$

f, x, b, beq, lb and ub are vectors and A and Aeq are matrices. The cost of energy is the sum of the costs of purchased natural gas used in the boilers and GENSET and the revenue is the sum of the power purchase. The profit is the different between the cost of energy and the revenue. Thus objective Function is presented as below formula.

$$\max Total\_Revenue\ (or \min Total\_Cost) = FPB \times (m\_FUEL\_B1 + m\_FUEL\_B2 + m\_FUEL\_B3) + (M\_FUEL\_GEN1 + M\_FUEL\_GEN2 + M\_FUEL\_GEN3 + M\_FUEL\_GEN4 + M\_FUEL\_GEN5 + M\_FUEL\_GEN6) \times FPGEN - PG1 + PG2 + PG3 + PG4 + PG5 + PG6 + WPT1 + WPT2 + WPT3 + WPT4 + WPT5 - PD) \times PP;\ (2)$$

In this section the subject to the restrictions are are discussed. The mass balance around the header 1 is presented as below formula:

$$\frac{GEN1L1}{1000} + \frac{GEN2L1}{1000} + \frac{GEN3L1}{1000} + \frac{GEN4L1}{1000} + \frac{GEN5L1}{1000} + \frac{GEN6L1}{1000} + B1L1 + B2L1 + B3L1 - T1i - T2i - T3i - LETL1L2 = PR1; \quad (3)$$

Where PR1 is the amount of steam demand at 370 C and 35 bar that is presented at Fig8. Also the mass balance of header NO2 is calculated from below formula:

$$T1eL2 + T2eL2 + T3eL2 - T4i + LETL1L2 - LETL2L3 = PR2;, \quad (4)$$

Where PR2 is the amount of steam demand at 260 C and 25 bar that is presented at Fig7. Then the mass balance of header NO3 is calculated from below formula:

$$T1eL3 + T3eL3 + LETL2L3 - LETL3L4 - T5i = PR3; \quad , \quad (5)$$

Where PR3 is the amount of saturated steam demand at 10 bar that is presented at Fig6. Also the mass balance of header NO4 is calculated from below formula:

$$-VENT + T4e + T2eL4 + LETL3L4 = PR4;,(6)$$

Where PR4 is the amount of saturated steam demand at 2 bar that is presented at Fig5. The amount of fuel consumption and steam production by three boilers is calculated from below formula.

$$Q\_B1 - B1L1 \times (HL1 - H\_FW) \times 1000 = 0;, (8)$$

$$m\_FUEL\_B1 - \frac{Q\_B1}{(LHV \times ETHAB1)/0.6} = 0; , \quad (9)$$

$$Q_{B2} - B2L1 \times (HL1 - H_{FW}) \times 1000 = 0;, \quad (10)$$

$$m\_FUEL\_B2 - \frac{Q\_B2}{(LHV \times ETHAB2)/0.6} = 0;, \quad (11)$$

$$Q_{B3} - B3L1 \times (HL1 - H\_FW) \times 1000 = 0;, \quad (12)$$

$$m\_FUEL\_B3 - \frac{Q\_B3}{(LHV \times ETHAB3)/0.6} = 0;,(13)$$

The mass balance and the amount of power generated by turbine No1 is calculated as below formula

$$-T1i + T1eL2 + T1eL3 = 0;,(14)$$

$$-HL1 \times T1i + Ha \times T1eL2 + Hb \times T1eL3 + \frac{WPT1}{0.000277778 \times 1000} = 0;,(15)$$

The mass balance and the amount of power generated by turbine No2 is calculated as below formula

$$-T2i + T2eL2 + T2eL4 = 0;, (16)$$

$$-HL1 \times T2i + Hc \times T2eL2 + Hd \times T2eL4 + \frac{WPT2}{0.000277778 \times 1000} = 0;, (17)$$

The mass balance and the amount of power generated by turbine No3 is calculated as below formula

$$-T3i + T3eL2 + T3eL3 = 0;,(18)$$

$$-HL1 \times T3i + He \times T3eL2 + Hf \times T3eL3 + \frac{WPT3}{0.277778} = 0;,(18)$$

The mass balance and the amount of power generated by turbine No4 is calculated as below formula.

$$T4i - T4e = 0;,(20)$$

$$-HL2 \times T4i + T4e \times Hg + \frac{WPT4}{0.277778} = 0;,(21)$$

The mass balance and the amount of power generated by turbine No5 is presented as below formula.

$$T5i - T5e = 0;,(22)$$

$$-HL3 \times T5i + T5e \times Hh + \frac{WPT5}{0.277778} = 0;,(23)$$

The amount of heating supplied and fuel consumption by the six GENSET is calculated as the below formula.

$$M\_FUEL\_GEN - \frac{p\_6 \times 1000 \times PG1}{0.6} = \frac{p\_7 \times 1000}{0.6}, \quad (24)$$

$$(p_8 \times 3600) \times PG1 - (HL1 - H_{FW}) \times GEN1L1 = -p\_9 \times 3600;,(25)$$

$$M\_FUEL\_GEN2 - \frac{p\_6 \times PG2 \times 1000}{0.6} = \frac{p\_7 \times 1000}{0.6};, \quad (26)$$

$$(p_8 \times PG2) \times 3600 - GEN2L1 \times (HL1 - H\_FW) = -p\_9 \times 3600;,(27)$$

$$M\_FUEL\_GEN3 - \frac{p\_6 \times PG \times 1000}{0.6} = \frac{p\_7 \times 1000}{0.6}; \quad (28)$$

$$(p_8 \times PG3) \times 3600 - GEN3L1 \times (HL1 - H\_FW) = -p\_9 \times 3600;,(29)$$

$$M\_FUEL\_GEN4 - \frac{p\_6 \times PG4 \times 1000}{0.6} = \frac{p\_7 \times 1000}{0.6};,(30)$$

$$(p_8 \times PG4) \times 3600 - GEN4L1 \times (HL1 - H\_FW) = -p\_9 \times 3600;,(31)$$

$$M\_FUEL\_GEN5 - \frac{p\_6 \times PG5 \times 1000}{0.6} = \frac{p\_7 \times 1000}{0.6};,(32)$$

$$(p_8 \times PG5) \times 3600 - GEN5L1 \times (HL1 - H\_FW) = -p\_9 \times 3600;(33)$$

$$M\_FUEL\_GEN6 - \frac{p\_6 \times PG6 \times 1000}{0.6} = \frac{p\_7 \times 1000}{0.6};,(34)$$

$$(p_8 \times PG6) \times 3600 - GEN6L1 \times (HL1 - H\_FW) = -p\_9 \times 3600;,(35)$$

Additional constraints are extracted from technical catalogue of boiler, turbine and GENSET are listed as table 9.

Unequal restrictions values are extracted from technical catalogue of gas engine, boiler and turbine. Although,the constant Value are listed as table 10. In accordance with state law, the price of gas to DG power plants (FPGEN) and process plant are1.93 and 2.89$¢/m^3$. The power export price is equal to3.35 $¢/kWh$. Harry Taplin presented model to calculated combustion efficiency by measuring stack temperature and oxygen amount of exhaust gas and thermodynamic modeling [10-12]. ETHAB1, ETHAB2 and ETHAB3 are calculated by measuring and auditing. Enthalpies of header and turbine extraction are extracted from thermodynamic steam table.

RESULTS AND DISCUSSIONS

In the previous section, the optimal model for to achieve the best solution for operating site utility is presented. The optimum solutions of the model for boiler and turbine steam flowrate are presented as Fig. 11 to 15.

Table 10. Equal constraints of the model

$\boldsymbol{PD = 5000\ kW}$;	$\boldsymbol{PR2 = Variable}$;	$\boldsymbol{HL3 = 2584\ kJ/kg}$;	$\boldsymbol{Ha = 3121\ kJ/kg}$;
$\boldsymbol{FPGEN = 1.93(¢/m^3)}$;	PR3 = Variable;	HL4 = 2533 kJ/kg;	Hb = 2894 kJ/kg;
FPB = 2.89(¢/m^3);	PR4 = Variable;	H_{FW} = 441.81 kJ/kg;	Hc = 3121 kJ/kg;
PP = 3.35 (¢/kWh);	LHV = 46285.6 kJ/kg;	ETHAB1 = 0.8496%;	Hd = 2598 kJ/kg;
PR1 = Variable;	HL1 = 3217 kJ/kg;	ETHAB2 = 0.8015%;	He = 3121 kJ/kg;
p_6 = 0.0001593;	HL2 = 2996 kJ/kg;	ETHAB3 = 0.8015%;	Hf = 2894 kJ/kg;
p_7 = 0.1259;	p_8 = 0.6332 ;	p_9 = 686.7;	Hg = 2330 kJ/kg;
Hh = 491.3 kJ/kg;	$T4i$ = 4.4;		

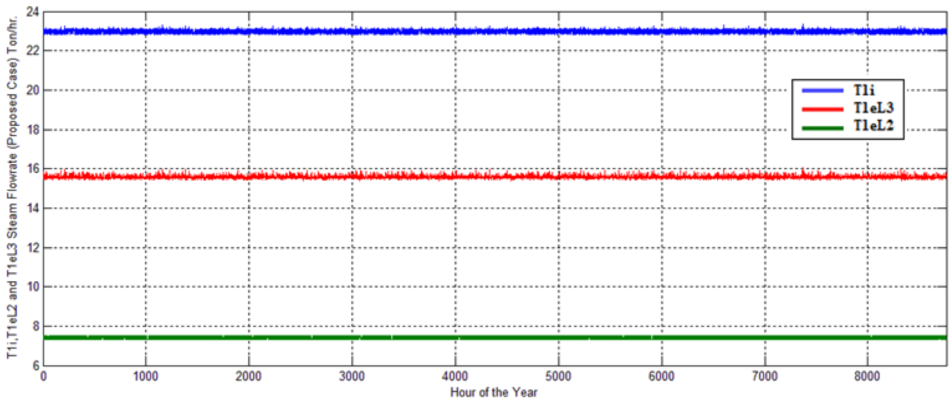

Fig. 11. Annual hourly T1i, T1eL2and T1eL3 flowrate.

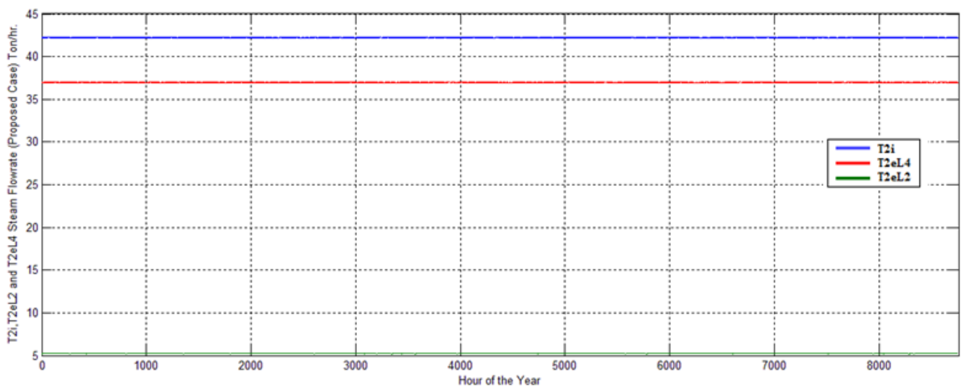

Fig. 12. Annual hourly T2i, T2eL2and T2eL4 flowrate

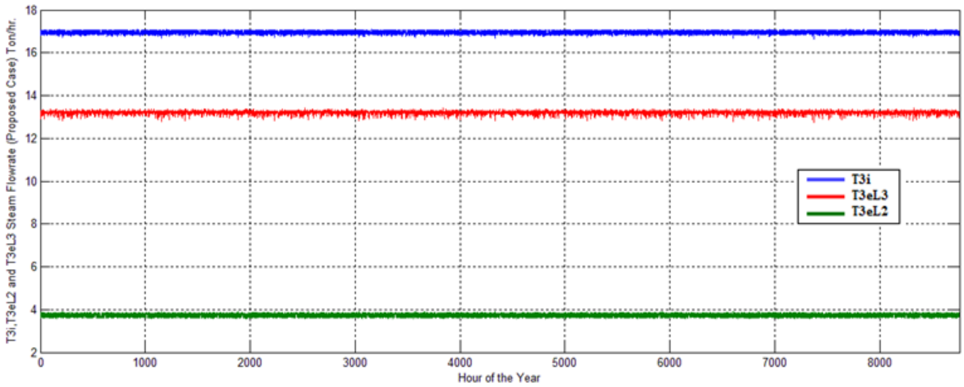

Fig. 13. Annual hourly T3i, T3eL2 and T3eL3flowrate.

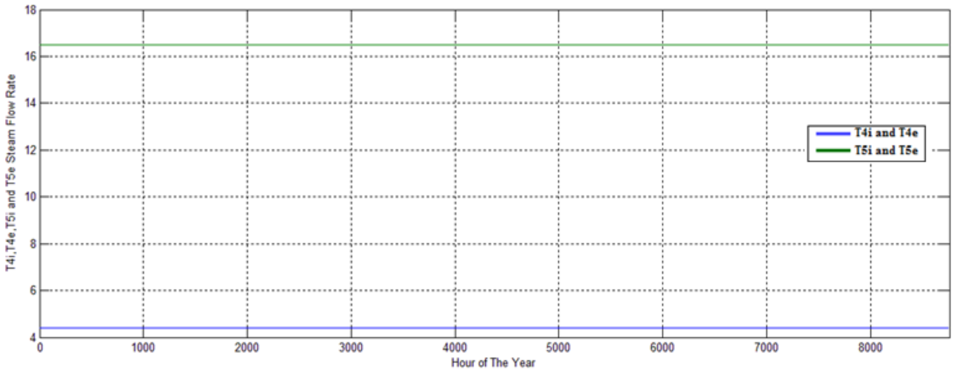

Fig. 14. Annual hourly T4i,, T4e, T5i and T5eflowrate.

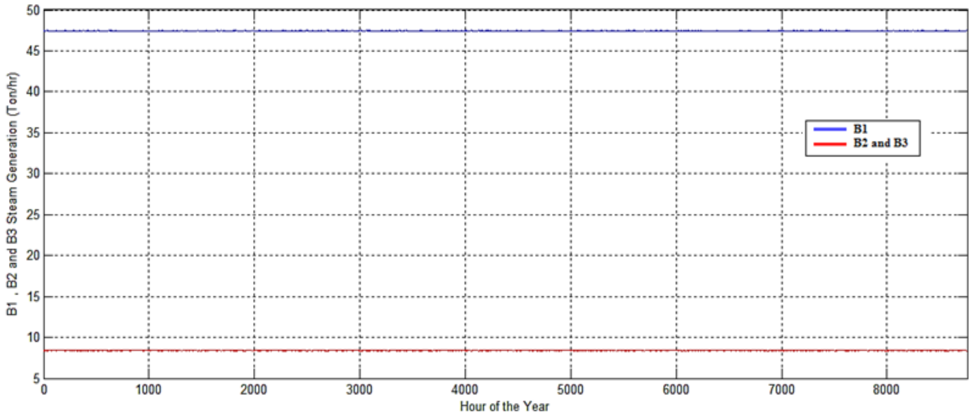

Fig. 15. Annual hourly B1, B2 and B3 steam generation.

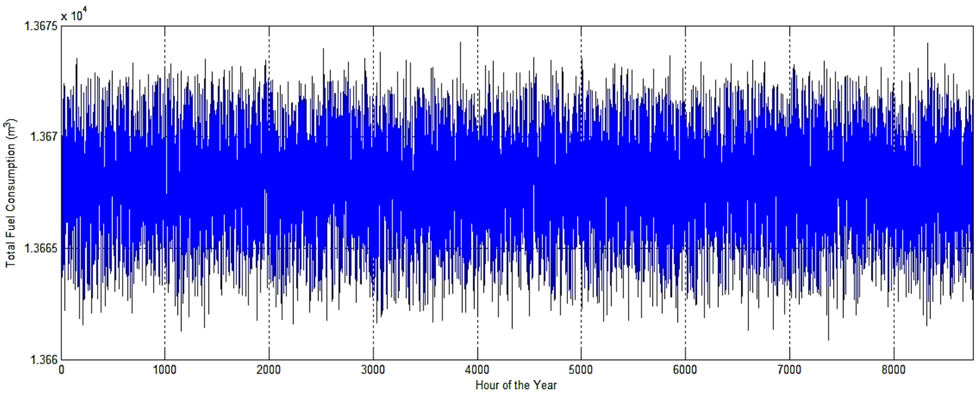

Fig. 16. Annual hourly total fuel consumption in proposed case.

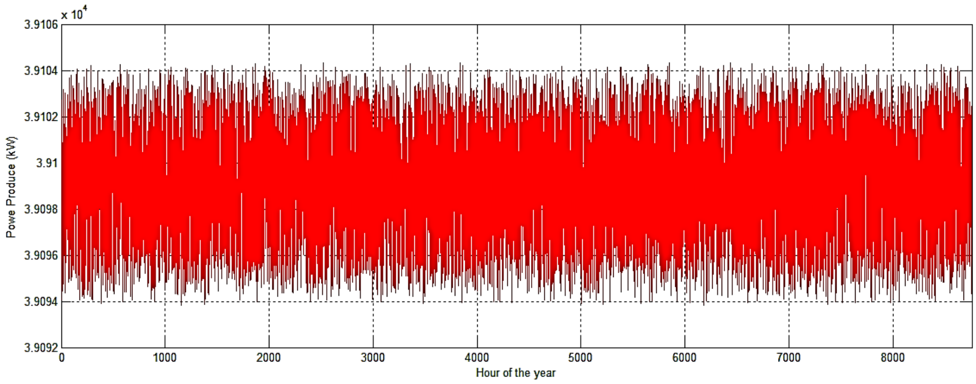

Fig. 17. Annual hourly power produces in proposed case.

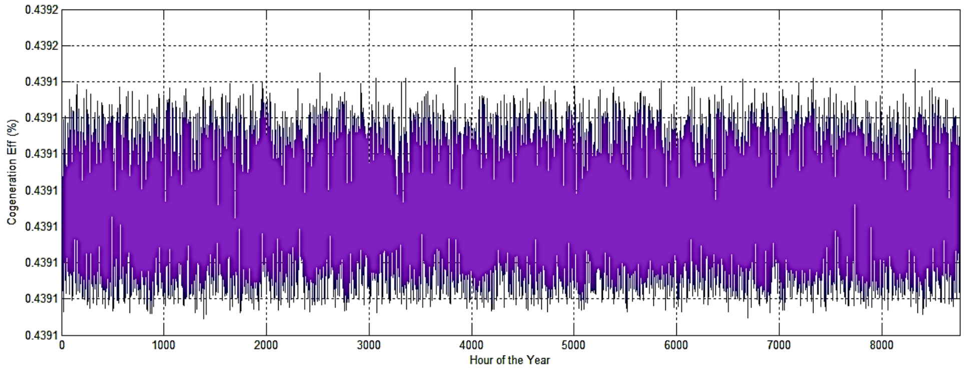

Fig. 18. Annual hourly cogeneration efficiency in proposed case.

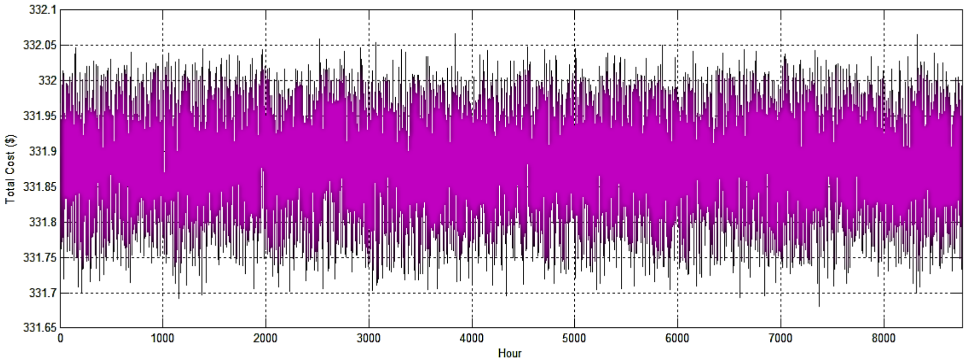

Fig. 19. Annual hourly total cost in proposed case.

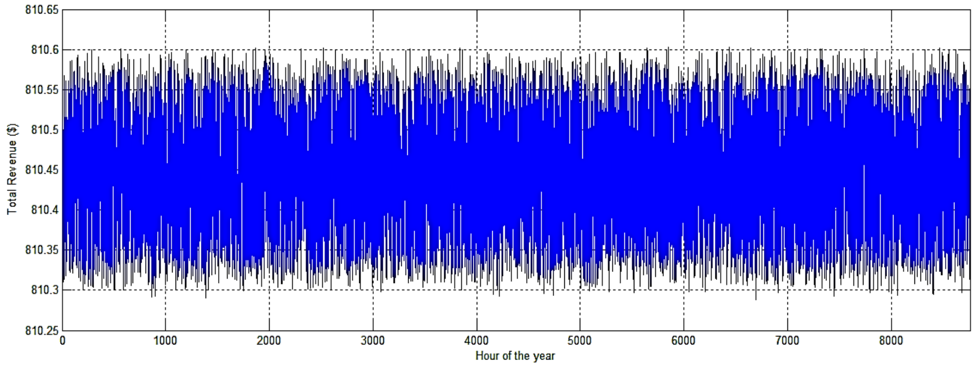

Fig. 20. Annual hourly total revenue in proposed case.

Table 11. Fuel consumption of existed and proposed case.

	Total Fuel Consumption (m^3/yr.)	Boiler Fuel Consumption (m^3/yr.)	GEN Fuel Consumption (m^3/yr.)
Existed Case	95967994	73303287	22664707

Proposed Case	119744227	62142045	57602182

Table 12. Power Produce, Power Demand and Power Purchase in existed and proposed case.

	Power Produce (kWh/yr.)	Power Demand (kWh/yr.)	Power Purchase (kWh/yr.)
Existed Case	176840785	43802795	133037989
Proposed Case	342546981	43802795	298744185

y the use of this model, total fuel consumption in boilers and gas engine are shown as Fig16. According to the model the annual fuel consumption is equal to 119744227 m^3.In existed condition the amount of fuel consumption is about 95967994 m^3. By the use of proposed condition, the fuel consumption is increased about 23776233 m^3, which, due to increased generators power production.

Total power produce is shown as Fig 17. The area under the power produce and time's curve is equal annual electrical energy production. The power purchase is different between total power produce and total power demand. As result, the amount of power produces and power purchase in proposed case is equal to 342546981 and298744185 kWh and existed case is equal to 176840785 and 133037989 kWh. The power produce and purchase are increased about 165706196 kWh.

Cogeneration efficiency is calculated by the transient model. Hourly cogeneration efficiency of the site is shown as fig18. By the averaging, the mean annual cogeneration efficiency is about 43.91%. By the use of this model and compared result with existed efficiency are shown that the cogeneration efficacy increased 2.5%.

The next important parameter that should be considered is total cost. The hourly cost of the site in optimal condition is shown as Fig. 19. By the use of this model, total cost increase about351733$ $.

Finally, total revenue is another parameter that is very important to recognize economical characteristic of site utility systems. Total revenue is different between total cost and power purchase income. Hourly total revenue for optimal model is presented as Fig. 20. The amount of total revenue of site for optimal model is equal to 7100303 $. The total revenue in existed case is about 1900878 $.

Comparison between existed and proposed case are listed as below table. With an annual review of the above information, the following results are obtained.

- The boilers fuel consumptions are decreased and GENSET fuel consumptions are decrease in proposed case.
- Power produce and power purchase are increased in proposed case.
- Total cost and total revenue is increased in proposed case.

Table 13. Total variable cost and total revenue of site in existed and proposed case.

	Total Variable Cost ($/yr.)	Total Revenue ($/yr.)
Existed Case	2555893	1900878
Proposed Case	2907627	7100303

CONCLUSION

One of the most important achievements of this study is, considering the transient condition for initial assumptions of site utility to make better decisions. In the absence of consideration of this issue, the supply must be utilized in highest amount of demand. If demand decrease and supply remains constant, steam passes through the letdown stations and it cause to decrease cogeneration efficiency. If transient decisions are possible, demand and supply will compatible together and cogeneration efficiency will remain constant.

Next, the performance analysis and parameters on site utility systems has been carried. The result of different between existed and proposed case is studied. The results show that the boiler fuel consumption is reduced; generator fuel consumption, total fuel consumption, total variable cost, total revenue and cogeneration efficiency are increased. The reasons for reduced boiler fuel consumption are listed as below:

- Using heat recovery equipment to recover exhaust gas energy of DG
- Conformity of steam supply and steam demand
- Reduction the amount of steam letdown station

The reason for increased generator fuel consumption is power purchase price. Production and sale of electricity is affordable with the governmental energy price. Thus the total variable cost and total increased. There for cogeneration efficiency is increased.

It is suggested that future studies develop the exergetic analysis and consider the ambient circumstances condition in the site utility and focus more on total site grand composite curve technique.

NOMENCLATURE

B1L1 Boiler No.1 Existed Steam Flowrate
B2L2 Boiler No.2 Existed Steam Flowrate
B3L3 Boiler No.3 Existed Steam Flowrate
GEN1L1 CHP No.1 Existed Steam Flowrate
GEN2L1 CHP No.2 Existed Steam Flowrate
GEN3L1 CHP No.3 Existed Steam Flowrate
GEN4L1 CHP No.4 Existed Steam Flowrate
GEN5L1 CHP No.5 Existed Steam Flowrate
GEN6L1 CHP No.6 Existed Steam Flowrate
LETL1L2 Letdown Station from Header 1 to Header 2
LETL2L3 Letdown Station from Header 2 to Header 3
LETL3L4 Letdown Station from Header 3 to Header 4
T1i Turbine No1. Steam Inlet
T1eL2 Turbine No1. Steam Outlet to Header 2
T1el3 Turbine No1. Steam Outlet to Header 3
T2i Turbine No2. Steam Inlet
T2eL2 Turbine No2. Steam Outlet to Header 2
T2eL4 Turbine No2. Steam Outlet to Header 3
T3i Turbine No3. Steam Inlet
T3eL2 Turbine No3. Steam Outlet to Header 2
T3eL3 Turbine No3. Steam Outlet to Header 3
T4i Turbine No4. Steam Inlet
T4e Turbine No4. Steam Outlet
T5i Turbine No5. Steam Inlet
T5e Turbine No5. Steam Outlet
PG CHP No1~6. Power Produce
m_FUEL_B Boiler Fuel Consumption
LHV Lower Heating Value of Fuel
ETHAB Boiler Fuel Consumption
WPT Power Production bye Steam Turbine
M_FUEL_GEN CHP Fuel Consumption

REFERENCES

1. R. Smith, Chemical Process Design and Integration. John Wiley, West Sussex, 2005.
2. P. Varbanov, S.Perry, Y. Makawana, X.X. Zhup, R.Smith, *Chemical Engineering Research and Design*, **82**, 34 (2004).
3. O.V. Afanasyeva, G. R. Mingaleeva, *Energy Efficiency*, **8**, 56 (2015).
4. A. Ghannadzadeh, S. Perry, R. Smith, *Applied Thermal Engineering*, **43**, 60 (2012).
5. M.H. Khoshgoftar Manesh, M. Amidpour, S. Khamis Abadi, M.H. Hamedi, *Appl. Thermal Eng.*, **54**, 12 (2013).
6. V.R. Dhole, B. Linnhoff, *Computers & Chemical Engineering*, **17,** 101 (1993).
7. S. Perry, J. Klemes, I. Bulatov, *Energy*, **33**, 1489 (2008).
8. P.S. Varbanov, J. Klemes, *Computers and Chemical Engineering*, **10,** 44 (2010).
9. J. Klemes, V.R. Dhole, K. Raissi, S.J. Perry, L. Puigjaner, *Appl. Thermal Eng.*, **17**, 993 (1997).
10. W.F. Kenney, Energy Conservation in the Process Industries. Academic Press, Orlando, 1984.
11. K. Raissi Total Site Integration، PhD Thesis، UMIST،UK, 1994.
12. H. Taplin, Combustion Efficiency Tables, Fairmont Press, Inc., 1991.