# TECHNICAL AND ECONOMICAL SIZING OF CHP SYSTEMS BASED ON OPTIMAL ALLOCATION OF HEAT AND POWER

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***ABSTRACT****-The growing worldwide demand for financial and environmental benefits of combined heat and power (CHP) system has led to promote and develop the optimal allocation of Heat and Power which is a complicated problem. In this paper the technical and economical sizing of CHP systems is carried out considering capital, investment, installation, operation, maintenance and replacement costs based on optimal heat and power dispatch. The model proposes an optimal CHP system capacity that customers could employ to defeat electricity and thermal requirements. A genetic algorithm (GA) was developed to solve the problem of heat and power allocation. Furthermore, a sensitivity analysis was implemented to show how the optimal solutions would vary due to changes of some key parameters. The simulation results demonstrate that the best solution for heat and power allocation will be achieved by using this proposed method.*

**Keywords:** Combined Heat and Power (CHP), Cost Function, Optimization, Net Present Cost, Genetic Algorithm (GA)

## 1 INTRODUCTION

The reduction of fossil energy resources and the pollution of the environment have forced governments and consumers to improve efficiency of energy systems in recent years [1].

Combined heat and power production (CHP) also known as Co-generation is a well known high efficient approach to generate electricity and thermal energy from a single fuel source. The importance of CHP in existing power systems has become more evident regarding lower fuel consumption; lower cost and more environmental friendly energy generation in recent years. Furthermore, co-generation can provide high quality and reliable electricity supply [2].

Cogeneration is playing an increasingly important role since it provides an economic solution to satisfy the demands on electric power and district heat simultaneously. Therefore, modeling of CHP systems plays a crucial role in assessing different CHP configurations, operational strategies, and novel technologies. In addition, models aide in the analysis of existing systems, allowing the system's performance to be gauged.

CHP schemes have been applied for over 100 yr and have been used to provide electric power from 15 kWe to 100 MWe [3]. In most applications, the main factor which determines the economic viability of the CHP scheme is a high simultaneous utilization of heat and power. As a rule of thumb, CHP plants must operate for about 5000 h per year to be economic, although this depends on the application[4] [5].

Any feasibility study should include assessing the economics of a range of CHP sizes, the overall unit performance, the maintenance costs, the control strategy, the possible changes in fuel and electricity prices, and the site demands [6].

The overall efficiency of energy use in CHP mode can be up to 80 per cent and above in some cases. The production of electricity being on-site, the burden on the utility network is reduced and the transmission line losses eliminated [7].

The cogeneration facility may be located in industrial estates or city centers.

Regarding to calculate the optimal operating point of CHP systems, the mathematical model shall be defined clearly. Various methods have been presented for different CHP systems by researchers. M.T.Tsay and et al have applied Evolutionary computing to find the system operating point [8] & [9]. E.Thorin and et al have developed linear programming to solve the problem but this method is not efficient for nonlinear systems and it needs many input data [10]. Particle swarm Optimization (PSO) is applied in [11] and [12] and is compared by Genetic Algorithm (GA) but the model is complicated and needs many input data.

Combined heat and power system efficiency depends on operating point and recovered heat of prime mover. The wrong operating point will cause either the lack of electricity or heat output power, or the extra produced electricity or heat output power, which in both conditions the system, will not be efficient. The aim of this paper is to develop a new feasibility model considering technical and economical sizing of CHP systems based on optimal allocation of heat and power. In this paper a new cost function is introduced and a new method is developed to solve it and find the system operating point using Genetic Algorithm. The proposed method is not as complex as previous methods and needs less input dada. The model is simulated in MATLAB and the results show the ability of the proposed method in different condition.

## 2 IMPRESSIVE FACTORS IN DETERMINING THE OPTIMAL STRATEGY

Set of influencing variables in determining the optimal strategy for combined heat and power system will be classified to three general categories.

1) Physical characteristic of system such as nominal capacity, unit efficiency, operating point;
2) Economical characteristic such as fuel cost, electrical energy price and its variations, annual, daily or hourly interest rate, capital cost, operation cost and maintenance and so on;
3) Features due to system loads such as electrical and thermal curve and peak demand.

Physical characteristic of system and economical parameters must be taken into consideration by CHP designer in optimal CHP system.

Despite of the above factors, selecting the proper method to solve the optimization problem is important in determining the optimal strategy of CHP system.

## 3 PROBLEM FORMULATION

One of the differences between CHP optimization methods is the way that the heat parameter impresses the electrical generators cost function. The recovered heat of generators is not independent to produced electrical power, so the heat parameter might be modeled as a quadratic function of electrical power:

$$Q_i = A_i P_i^2 + B_i P_i + C_i \qquad (1)$$

Where;

$Q_i$: Recovered heat of a CHP or electrical generator

$P_i$: Output electrical power

$A_i$, $B_i$ and $C_i$ are constant coefficients which are defined by producer.

The considered CHP system is consisting of gas generator, diesel generator, micro turbine, fuel cell, DC/AC converter and battery system. The gas and diesel will be bought and the heat and electricity will be sold. The optimization method shall be capable of solving the problem whether the number of each generator increased or omitted. The schematic diagram of the CHP system is shown in Fig 1.

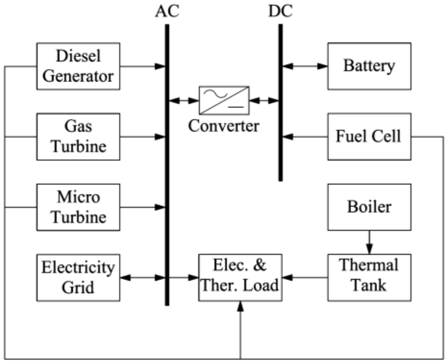

Fig.1 schematic diagram of the CHP system

The following indexes are used for each parameter:

$g$: Gas generator $d$: Diesel generator

$m$: Micro turbine $b$: Battery

$f$: Fuel cell $c$: DC/AC converter

$n$: Total for CHP system

Combined heat and power system costs are divided to three important parts; Initial capital cost, Operation and maintenance cost and Replacement cost.

**Initial capital cost**

The initial capital cost is the total installed cost of a component at the beginning of the project and might be presented as follows:

$$C_{in} = C_{ig} + C_{id} + C_{ib} + C_{im} + C_{if} + C_{ic} + C_o \qquad (2)$$

Where $C_i$ is initial capital cost and $C_o$ is equivalence cost.

The initial capital costs of component is significantly greater than other costs, though the investor tries to pay part of the capital cost at the year of Zero (installation year or at the beginning of system operation) and the remaining part including banking interest with uniform annual payments. In this condition $C_{in}(n)$ shall be used instead of $C_{in}$. So we have Equation (3).

Where;

$C_{in}(n)$: uniform annual payments

$i$: Interest rate (%) $T_L$: Loan payment time

$N$: System life cycle $f_0$: Coefficient between 0 & 1

$C_0$: part of the capital cost which will be paid at the Zero year

$$C_{in}(n) = \begin{cases} C_{in}(1-f_0)\left[\dfrac{i(1+i)^{T_L}}{(1+i)^{T_L}-1}\right] & i > 0 \\ \dfrac{C_{in}(1-f_0)}{T_L} & i = 0 \end{cases} \qquad n = 1,\ldots,T_L \le N \qquad (3)$$

$$f_0 = \frac{C_0}{C_{in}}$$

**Operation and maintenance cost**

The total O&M cost of the system is the sum of the O&M costs of each system component. For most components, you enter the O&M cost as an annual amount. This cost is dependant to general inflame rate and the amount of generated power of each production unit. The following equation describes the O&M cost;

$$\begin{aligned} C_m(n) &= (C_{mg} + C_{md} + C_{mb} + C_{mM} + C_{mf} + C_{mc}) \ldots. \\ &(1+g)^n + (1+f)^n \left(C_F\left[T_g\bar{F}_g + T_f\bar{F}_f + T_M\bar{F}_M\right] + C_F' T_d \bar{F}_d\right) \end{aligned} \qquad (4)$$

$$\begin{aligned} \bar{F}_g &= \eta_g P_g S_g & \bar{F}_f &= \eta_f P_f S_f \\ \bar{F}_M &= \eta_M P_M S_M & \bar{F}_d &= \eta_d P_d S_d \end{aligned} \qquad (5)$$

Where;

$C_m(n)$: Total operating and maintaining cost

$n$: year $g$: fuel inflation rate

$C_m$: Operating and maintaining cost

$C_F$: Cost of gas per unit $C_F'$: Cost of diesel per unit

$T$: Total hour operation of generator in studying period and the indexes defines the generators type.

$F$: Consumed fuel of generator per hour (e.g. L/hr)

$\eta$: Efficiency $P$: Nominal power

$S$: Consumed fuel rate for production of 1 kWh output energy of each generator and the indexes defines the generators type.

**Replacement Cost**

The replacement cost is the cost of replacing a component at the end of its lifetime. This may be different from the initial capital cost. The replacement cost is used to calculate the annualized replacement cost.

$$C_R(n) = C_{Rg}(n) + C_{Rd}(n) + C_{RM}(n) + C_{Rf}(n) + C_{Rb}(n) + C_{Rc}(n) \qquad (6)$$

Where;

$C_R(n)$: Total replacement cost of component at year of $n^{th}$ and the indexes defines the kinds of each component.

Unlike the lifetime inputs for most other components, the generator lifetime is specified not in years but in hours of operation.

**Total cost function for CHP system**

The total cost function of CHP system might be formed by adding the above specified parts; Initial capital cost, Operation and maintenance cost and Replacement cost.

$$C_T(n) = C_{in}(n) + C_m(n) + C_R(n) \qquad (7)$$

Where $C_T(n)$ is the summation of all costs that shall be paid at the end of each year ($1 \le n \le$ end of system lifetime).

In order to form a cost function that calculates all the cost at year of $0^{th}$ a discount rate shall be taken in to consideration. In this paper the Net Present Value (NPV) is used [12] to shift the total costs of each year to the year of $0^{th}$ or the starting year of project therefor the projects can be comparable with each other. The schematic diagram of NPV is shown in Fig 2.

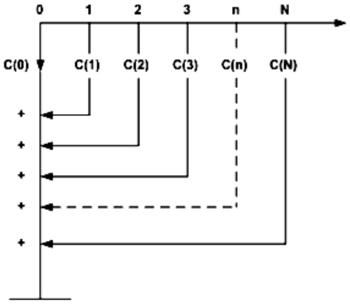

Fig.2 system cost at year $0^{th}$

*C(0)* is the paid cost at year $0^{th}$ and *C(1)* to *C(n)* are system costs which will be paid at each year till lifecycle of system. According to Net Present Value (NPV) method the Total cost function or life cycle cost can be formulated as bellows:

$$C_T = C_T(1)[\frac{1}{(1+i)}] + C_T(2)[\frac{1}{(1+i)^2}] + ... + C_T(n)[\frac{1}{(1+i)^n}] + C_0 \quad (8)$$

If the yearly payments are equal we have

$$C_T = C_0 + \frac{(1+i)^N - 1}{i \times (1+i)^N} C_T(n) \quad (9)$$

If the produced power is lower than the amount of electrical demand power the rest of needed power shall be purchased from grid and wise versa.

## 4 OPTIMIZATION METHOD

The proposed method uses a perfect and simple mechanism to optimize the CHP systems. In this method all costs such as initial capital cost, operation and maintenance cost and replacement cost are defined separately or will be taken from user if necessary. A genetic algorithm is used to solve the cost function optimization problem. The proposed optimization algorithm is shown in Fig 3.

## 5 SIMULATION RESULTS AND DISCUSSION

The CHP system is consisting of gas generator, diesel generator, micro turbine, fuel cell, DC/AC converter, battery system, boiler, thermal tank and electrical and thermal loads. The gas and diesel will be bought and it is also possible to buy or sell the electricity on grid. In order to validate the optimization method, simulation is implemented in MATLAB.

In this paper an industrial factory is used as a test sample. The electrical and thermal loads which shall be supplied by cogeneration system. The demand AC primary load and thermal load for one week is shown in Fig 4.

It is assumed that the factory is 20 km far from the nearest distribution network and due to experiences the price of overhead line is considered 15150 \$/km. The energy sources are chosen according to the loads and the producers. The diesel generators, micro turbine, gas generator, battery pack and fuel cell are chosen from the production of Cummins Power, Capstone, MTU, Trojan battery and Fuel cell Energy companies respectively. The ranges of generators are 100, 200, 400, 600, 800, 1000 and 1100 kW and the range of fuel cell package and converter are 100, 300 and 1100 kW.

A sensitivity analysis is implemented according to difference of fuel and energy price in Iran and United States (Table 1) [13-16].

Table 1- Energy and fuel prices in Iran and United States.

| Fuel or Energy | Price in Iran | Price in US |
|---|---|---|
| Diesel | 0.106 \$/L | 0.6525 \$/L |
| Natural Gas | 0.03 \$/m3 | 0.35 \$/m3 |
| Electricity | 0.03 \$/kWh | 0.109 \$/kWh |

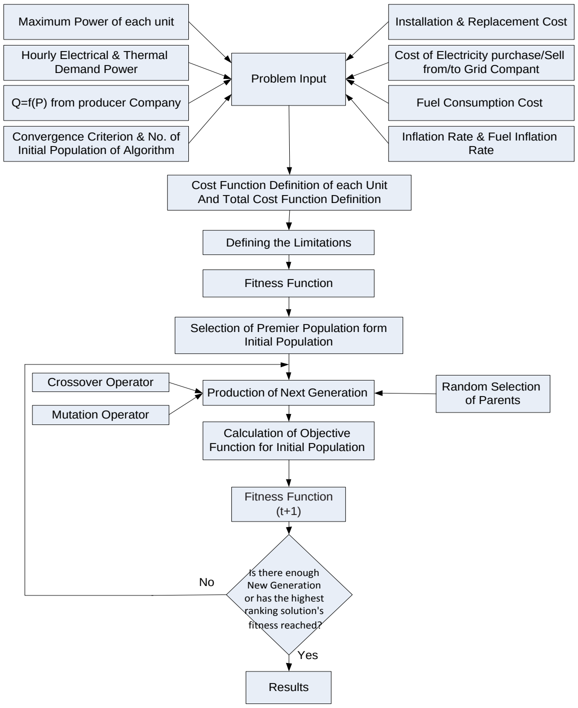

Fig.3 proposed optimization Genetic algorithm

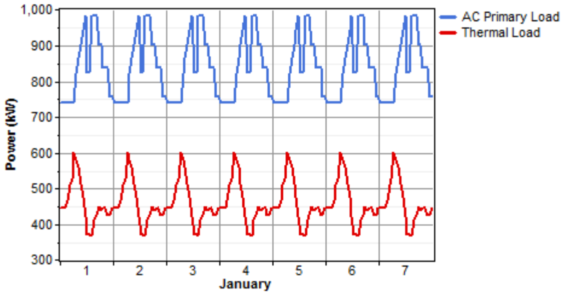

Fig.4 Electrical and Thermal demand power

**Cogeneration system in Iran**

When the proposed algorithm is finished running the simulations, a list of all feasible system configurations is viewable. The feasible Results are listed in order of most cost-effective to least cost effective (from top to bottom). Table 2 shows the 20 categorized optimization results based on net present cost (Total NPC). They are the most cost effective configuration of each system design. The amount of fuels consumption, working hours of each generators and net grid purchases are shown in Table 3.

The total net present cost of a system is the present value of all the costs that it incurs over its lifetime, minus the present cost.

Table 2- Categorized Optimization Results of cogeneration system in Iran

| | DG (kW) | MT (kW) | GG (kW) | FC (kW) | Battery | Conv. (kW) | Grid (kW) | Initial capital ($) | Operating cost ($/yr) | Total NPC ($) | COE ($/kWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | | 1100 | | | | 0 | 656,250 | 127,121 | 1,162,814 | 0.038 |
| **2** | 100 | | 1000 | | | | 0 | 643,750 | 130,813 | 1,165,024 | 0.038 |
| **3** | | | | | | | 1100 | 404,335 | 236,970 | 1,348,634 | 0.03 |
| **4** | 100 | | 800 | | | | 200 | 857,398 | 131,841 | 1,382,770 | 0.045 |
| **5** | 100 | | | | | | 1000 | 423,566 | 243,052 | 1,392,099 | 0.046 |
| **6** | | | 1000 | 100 | | 100 | 0 | 918,500 | 122,755 | 1,407,664 | 0.046 |
| **7** | | | 1000 | | | | 100 | 920,824 | 122,461 | 1,408,818 | 0.046 |
| **8** | | | 100 | | | | 1000 | 469,816 | 237,030 | 1,414,353 | 0.046 |
| **9** | | 100 | | | | | 1000 | 509,316 | 229,679 | 1,424,563 | 0.047 |
| **10** | 100 | 400 | 600 | | | | 0 | 860,250 | 142,162 | 1,426,749 | 0.047 |
| **11** | | 100 | 800 | | | | 200 | 943,148 | 122,503 | 1,431,311 | 0.047 |
| **12** | 100 | 600 | 400 | | | | 0 | 935,250 | 143,274 | 1,506,180 | 0.05 |
| **13** | 100 | 1000 | | | | | 0 | 1,006,250 | 127,818 | 1,515,591 | 0.05 |
| **14** | | 1100 | | | | | 0 | 1,052,500 | 122,649 | 1,541,243 | 0.051 |
| **15** | 1100 | | | | | | 0 | 267,500 | 322,705 | 1,553,444 | 0.051 |
| **16** | | | | 100 | | 100 | 1000 | 698,316 | 232,980 | 1,626,715 | 0.054 |
| **17** | 200 | 200 | 600 | | | | 100 | 986,824 | 162,272 | 1,633,458 | 0.054 |
| **18** | 100 | 600 | 200 | | | | 200 | 1,113,898 | 143,509 | 1,685,767 | 0.056 |
| **19** | | | | 1100 | 0 | 1100 | 0 | 3,366,000 | 372,395 | 3,756,186 | 0.698 |
| **20** | | 100 | 800 | | 1360 | 300 | 0 | 3,775,500 | 396,681 | 5,356,226 | 0.609 |

Table 3- fuel consumptions, working hours of each generators and net grid purchases according to Table 2.

| | Net grid purchases | Natural gas | Diesel (L) | DG (hours) | MT (hours) | GG (hours) | FC (hours) |
|---|---|---|---|---|---|---|---|
| **1** | 0 | 1,898,577 | | | | 8,760 | |
| **2** | 0 | 1,875,664 | 24,459 | 1,825 | | 8,760 | |
| **3** | 7,341,809 | 478,984 | | | | | |
| **4** | 335,177 | 1,780,973 | 52,734 | 1,825 | | 8,760 | |
| **5** | 7,159,313 | 466,968 | 52,734 | 1,825 | | | |
| **6** | 0 | 1,893,729 | | | | 8,760 | 1,825 |
| **7** | 0 | 1,896,342 | | | | 8,760 | |
| **8** | 7,159,313 | 514,074 | | | | 1,825 | |
| **9** | 6,465,825 | 598,314 | | | 8,760 | | |
| **10** | 0 | 1,715,811 | 24,459 | 1,825 | 8,760 | 8,760 | |
| **11** | 225,677 | 1,833,415 | | | 2,920 | 8,760 | |
| **12** | 0 | 1,658,996 | 24,459 | 1,825 | 8,760 | 8,760 | |
| **13** | 0 | 1,601,139 | 24,459 | 1,825 | 8,760 | | |
| **14** | 0 | 1,619,200 | | | 8,760 | | |
| **15** | 0 | 32,671 | 2,138,152 | 8,760 | | | |
| **16** | 7,177,563 | 499,243 | | | | | 1,825 |
| **17** | 0 | 1,641,194 | 194,077 | 5,475 | 8,760 | 8,760 | |
| **18** | 335,177 | 1,550,998 | 52,734 | 1,825 | 8,760 | 8,760 | |
| **19** | 0 | 1,794,665 | | | | | 8,760 |
| **20** | 0 | 1,879,113 | | | 5,475 | 8,760 | |

Table 4- electrical and thermal production and consumption

| Electrical Detail | MWh/yr | % | Thermal Detail | MWh/yr | % |
|---|---|---|---|---|---|
| Electrical load Consumption | 7,341.9 | 100 | Thermal load Consumption | 4,020.5 | 100 |
| Gas Generator Production | 7,341.9 | 100 | Gas Generator Production | 3,086.7 | 76 |
| Grid purchases | 0 | 0 | Boiler | 950.2 | 24 |
| Excess electricity | 0 | 0 | Excess thermal | 16.4 | 0.4 |
| Unmet load | 0 | 0 | Unmet load | 0 | 0 |
| Capacity shortage | 0 | 0 | Capacity shortage | 0 | 0 |

The technical and economic details about each system configuration can be extracted. For example for the most cost value of all the revenue that it earns over its lifetime. The cost of energy (COE) is defined as the average cost per kWh of useful electrical energy produced by the system. The NPC is a more trustworthy number than the COE, so the systems are ranked by net present cost.effective design (the first result of Table 2, Table 4 defines the detailed electrical and thermal production and consumption, Table 5 and 6 show the detailed information of Gas Generator and Boiler respectively. The electricity and heat production diagram of generator serving the electrical and thermal loads are shown in Fig 5 for the same week of Fig 4.

### Cogeneration system in United States.

In this section, the same factory, loads and condition are considered by the new energy and fuel price. The new dada is analyzed and simulated through the proposed algorithm and a list of all feasible system configurations is achieved. The feasible Results are listed in order of the most cost effective based on its net present cost. Table 7 shows the 20 categorized optimization results which are the most cost effective configuration of each system design. The amount of fuel consumptions, working hours of each generators and net grid purchases in Categorized Optimization Results (Table 7) are shown in Table 8.

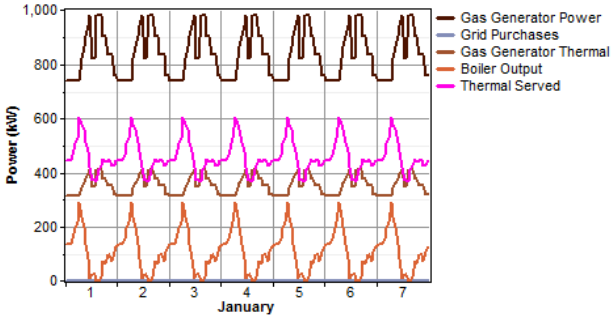

Fig 5. Electricity and heat production diagram

Table 5- Detailed information of Gas Generator

| Quantity | Value | Units |
|---|---|---|
| Hours of operation | 8,760 | hr/yr |
| Number of starts | 1 | starts/yr |
| Operational life | 14.8 | yr |
| Capacity factor | 76.2 | % |
| Fixed generation cost | 11 | $/hr |
| Marginal generation cost | 0.00722 | $/kWh |
| Electrical production | 7,341,872 | kWh/yr |
| Mean electrical output | 838 | kW |
| Min.-Max. electrical output | 740-982 | kW |
| Thermal production | 3,086,704 | kWh/yr |
| Mean thermal output | 352 | kW |
| Min.-Max. thermal output | 313-411 | kW |
| Fuel consumption | 1,785,378 | m3/yr |
| Specific fuel consumption | 0.243 | m3/kWh |
| Fuel energy input | 17,630,612 | kWh/yr |
| Mean electrical efficiency | 41.6 | % |
| Mean total efficiency | 59.2 | % |

Table 6- Detailed information of Boiler

| Quantity | Value | Units |
|---|---|---|
| Hours of operation | 8,395 | hr/yr |
| Total production | 950,158 | kWh/yr |
| Mean output | 113 | kW |
| Min. output | 0 | kW |
| Max. output | 289 | kW |
| Fuel consumption | 113,198 | m3/yr |
| Specific fuel consumption | 0.119 | m3/kWh |
| Fuel energy input | 1,117,833 | kWh/yr |
| Mean efficiency | 85 | % |

## 6 Conclusion

Cogeneration is playing an increasingly important role since it provides an economic solution to satisfy the demands on electric power and district heat simultaneously. The importance of CHP in existing power systems has become more evident regarding lower fuel consumption, lower cost and more environmental friendly energy generation in recent years. Furthermore, cogeneration can provide high quality and reliable electricity supply. Therefore, modeling of CHP systems plays a crucial role in assessing different CHP configurations, operational strategies, and novel technologies. In this paper the technical and economical sizing of CHP systems is carried out considering capital, investment, installation, operation, maintenance and replacement costs based on optimal heat and power dispatch. A new cost function is introduced and a genetic algorithm (GA) is developed to solve the problem of heat and power allocation. Furthermore, a sensitivity analysis was implemented to show how the optimal solutions would vary due to changes of some key parameters. The modeling and simulations demonstrate the proposed algorithm is capable of defining the CHP system size accurately

Table 7- Categorized Optimization Results of cogeneration system in United States.

| | DG (kW) | MT (kW) | GG (kW) | FC (kW) | Battery | Conv. (kW) | Grid (kW) | Initial capital ($) | Operating cost ($/yr) | Total NPC ($) | COE ($/kWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | | | 1100 | | | | 0 | 656,250 | 734,096 | 3,581,542 | 0.1 |
| **2** | | 1100 | | | | | 0 | 1,052,500 | 640,307 | 3,604,054 | 0.1 |
| **3** | 100 | | 1000 | | | | 0 | 643,750 | 743,830 | 3,607,828 | 0.1 |
| **4** | 100 | 1000 | | | | | 0 | 1,006,250 | 653,069 | 3,608,658 | 0.101 |
| **5** | | 1000 | 100 | | | | 0 | 1,052,500 | 641,945 | 3,610,578 | 0.101 |
| **6** | | 100 | 1000 | | | | 0 | 729,500 | 729,371 | 3,635,963 | 0.101 |
| **7** | 100 | 200 | 800 | | | | 0 | 764,750 | 726,537 | 3,659,919 | 0.102 |
| **8** | 100 | 400 | 600 | | | | 0 | 860,250 | 704,073 | 3,665,904 | 0.102 |
| **9** | 100 | 800 | 200 | | | | 0 | 982,250 | 674,649 | 3,670,652 | 0.103 |
| **10** | | 800 | 100 | | | | 200 | 1,197,148 | 642,552 | 3,757,647 | 0.106 |
| **11** | 100 | 800 | | | | | 200 | 1,150,898 | 655,855 | 3,764,406 | 0.106 |
| **12** | | | 1000 | 100 | | 100 | 0 | 918,500 | 728,180 | 3,820,215 | 0.108 |
| **13** | | 100 | 800 | | | | 200 | 943,148 | 722,381 | 3,821,755 | 0.108 |
| **14** | | 1000 | | | | | 100 | 1,283,324 | 637,046 | 3,821,880 | 0.108 |
| **15** | | | 1000 | | | | 100 | 920,824 | 728,722 | 3,824,699 | 0.108 |
| **16** | | 1000 | | 100 | | 100 | 0 | 1,281,000 | 638,831 | 3,826,671 | 0.108 |
| **17** | | 200 | 800 | 100 | | 100 | 0 | 1,039,500 | 711,499 | 3,874,743 | 0.11 |
| **18** | | | | | | | 1100 | 404,335 | 967,902 | 4,261,316 | 0.109 |
| **19** | | | | 1100 | | 1100 | 0 | 3,366,000 | 946,149 | 6,042,532 | 0.156 |
| **20** | | 800 | | 100 | 1360 | 300 | 0 | 3,146,806 | 914,726 | 6,837,125 | 0.175 |

Table 8- fuel consumptions, working hours of each generators and net grid purchases according to Table 7.

| | Net grid purchases | Natural | Diesel (L) | DG (hours) | MT (hours) | GG (hours) | FC (hours) |
|---|---|---|---|---|---|---|---|
| **1** | 0 | 1,898,577 | | | | 8,760 | |
| **2** | 0 | 1,619,200 | | | 8,760 | | |
| **3** | 0 | 1,875,664 | 24,459 | 1,825 | | 8,760 | |
| **4** | 0 | 1,601,139 | 24,459 | 1,825 | 8,760 | | |
| **5** | 0 | 1,620,265 | | | 8,760 | 1,825 | |
| **6** | 0 | 1,890,486 | | | 1,825 | 8,760 | |
| **7** | 0 | 1,789,724 | 24,459 | 1,825 | 8,760 | 8,760 | |
| **8** | 0 | 1,715,811 | 24,459 | 1,825 | 8,760 | 8,760 | |
| **9** | 0 | 1,617,449 | 24,459 | 1,825 | 8,760 | 8,760 | |
| **10** | 335,177 | 1,550,113 | | | 8,760 | 1,825 | |
| **11** | 435,552 | 1,505,949 | 24,459 | 1,825 | 8,760 | | |
| **12** | 0 | 1,893,729 | | | | 8,760 | 1,825 |
| **13** | 138,761 | 1,836,377 | | | 5,475 | 8,760 | |
| **14** | 0 | 1,619,200 | | | 8,760 | | |
| **15** | 0 | 1,896,342 | | | | 8,760 | |
| **16** | 0 | 1,623,237 | | | 8,760 | | 1,825 |
| **17** | 0 | 1,809,536 | | | 8,760 | 8,760 | 1,825 |
| **18** | 7,341,809 | 478,984 | | | | | |
| **19** | 0 | 1,794,665 | | | | | 8,760 |
| **20** | 0 | 1,643,293 | | | 8,760 | | 5,475 |

## REFERENCES

[1] R Beith, Small and Micro Combined Heat and Power (CHP) Systems, Advanced Design, Performance, Materials and Applications, Woodhead Publishing, April 2011, ISBN: 978-1-84569-795-2

[2] M. Basu, "Combined heat and power economic emission dispatch using nondominated sorting genetic algorithm-II" International Journal of Electrical Power & Energy Systems, Elsevier, Volume 53, December 2013, Pages 135–141.

[3] A. Sashirekhaa, J. Pasupuletib, N.H. Moina, C.S. Tanc, "Combined heat and power (CHP) economic dispatch solved using Lagrangian relaxation with surrogate subgradient multiplier updates" International Journal of Electrical Power & Energy Systems, Elsevier, Volume 44, Issue 1, January 2013, Pages 421–430.

[4] M. Basu, "Artificial immune system for combined heat and power economic dispatch", International Journal of Electrical Power & Energy Systems, Elsevier, Volume 43, Issue 1, December 2012, Pages 1–5.

[5] Chun-Lung Chena, Tsung-Ying Leeb, Rong-Mow Janb, Chia-Liang Luc, "A novel direct search approach for combined heat and power dispatch", International Journal of Electrical Power & Energy Systems, Elsevier, Volume 43, Issue 1, December 2012, Pages 766–773

[6] B. Mohammadi-Ivatloo, M. Moradi-Dalvand, A. Rabiee, "Combined heat and power economic dispatch problem solution using particle swarm optimization with time varying acceleration coefficients", Electric Power Systems Research, Elsevier, Volume 95, February 2013, Pages 9–1.

[7] K. A. Pruitta, R. J. Braunb, A. M. Newmanc, "Establishing conditions for the economic viability of fuel cell-based, combined heat and power distributed generation systems" Applied Energy, Elsevier, Volume 111, November 2013, Pages 904–920

[8] M. R. Haghifama, M. Manbachib, "Reliability and availability modelling of combined heat and power (CHP) systems" International Journal of Electrical Power & Energy Systems, Volume 33, Issue 3, March 2011, Pages 385–393.

[9] A. Khaliqa, B. K. Agrawala, R. Kumarb, "First and second law investigation of waste heat based combined power and ejector-absorption refrigeration cycle", International Journal of Refrigeration, Elsevier, Volume 35, Issue 1, January 2012, Pages 88–97.

[10] E. Khorram, M. Jaberipour, "Harmony search algorithm for solving combined heat and power economic dispatch problems", Energy Conversion and Management, Elsevier, Volume 52, Issue 2, February 2011, Pages 1550–1554.

[11] S. Mitraa, L. Sunb, I. E. Grossmanna, "Optimal scheduling of industrial combined heat and power plants under time-sensitive electricity prices" Energy, Elsevier, Volume 54, 1 June 2013, Pages 194–211.

[12] J. J. Wang, Z. Q. Zhai, Y. Y. Jing, and C. F. Zhang, "Particle swarm optimization for redundant building cooling heating and power system," Appl. Energy, vol. 87, pp. 3668–3679, Dec. 2010.

[13] U.S. Energy Information Administration (EIA) http://www.eia.gov/electricity/monthly

[14] Energy Prices and Taxes - SINGLE ISSUE- Quarterly publication, 2014, ISBN 0256-2332

[15] National Iran Gas Company (NIGC) http://mgd.nigc.ir/MGD2/Default.aspx?PID=278

[16] Iran Ministry of Energy (MOE) http://tariff.moe.gov.ir.