Systematic Review Article: Optimal CCHP Combined with Thermal Energy Storage System Design Using Genetic Algorithm

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ABSTRACT

In recent years, cogeneration systems have been considered to increase the efficiency and optimal use of energy sources for the production of electrical energy and heat energy. Electricity and heat energy cogeneration systems can achieve up to 70% efficiency, and at the realistic and subsidized rates of energy carriers, the beneficiaries of these systems supply the demand and supply sectors. In this study, the optimal working point of a system consisting of several independent units, capable of trading electricity, based on the consumption of various fuels, and utilization of storage tank was determined using genetic algorithm, and modeling accuracy were compared. Other references have also been made. The simulation results show that in the temperate seasons and summer, the cogeneration system meets all electrical and thermal requirements during the 22-23 hours due to the high electricity grid rate and at the end of 24 hours, the total cogeneration cost for almost all seasons 50% less than the conventional production system. It has also been shown that the use of absorption chillers has improved the ratio of electrical and heat loads, and the efficiency of the cogeneration system has increased compared to the previous state, and the heat energy loss has also decreased.

Introduction

The efficiency of cogeneration systems and their relative superiority over individual generation systems depends on the operating point of the system and the amount of electrical and heat energy utilized in an optimal combination. Technical specifications of the cogeneration system, electric and heat load curves, access to the electricity distribution network, access to other heat sources (auxiliary boilers, city heating systems), and the costs of supplying electricity from each of these sources are effective on the designated point. Work affects. As can be seen in Figure (5), in general, the cogeneration system is capable of being connected to the electricity distribution network and exchanged with it. In this case, the electricity shortage will be purchased from the grid, or the surplus will be sold to the grid. In this case, the operating point of the system can fluctuate

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between the minimum point to the maximum power. The required heat energy is provided by both the auxiliary boiler and the cogeneration system [1].

In this case, the electrical power generated by the system is determined by minimizing the cost of providing electricity and heat, as well as the amount of environmental pollution of the system. One of the critical points in the operation of cogeneration systems is to determine the optimal operating point of the system according to the operating conditions of the system, which has been studied in numerous articles. In Reference [2], the optimal working point of a steam turbine primary propulsion system is determined using auxiliary programming. Since the steam turbine start-up and exit time is long, it does not take into account the costs of operating the system in optimization, and it is assumed that the system is always connected to the grid. In Reference [3], the optimal working point of the cogeneration system is also determined using parallel programming. In this study, in addition to the cost of production, the environmental contamination of the co-generation system has been considered, and an algorithm has been proposed to determine the optimal operating point of the system. In [2], the mathematical modeling of the cogeneration system has been studied to determine the optimal working point of the system, but no method has been provided to determine the optimal working point. Reference [5] using complex linear programming has provided a method to optimize the performance of the cogeneration system by assuming constant mechanical drive efficiency over the long term. In Reference [2], a co-generation system with thermal energy storage capability is examined, and the amount of electrical energy generated by the system is determined by the grid operator. In this study, the distribution of electricity demand between different generators in order to reduce the final cost of production is investigated. In references [6] and [7], the effect of thermal energy storage capability on the performance and environmental contamination rate of the cogeneration system has been investigated.

Activities undertaken in the discussion of determining the optimal operating point are mainly focused on systems without a heat storage tank, and the costs of operating and leaving the system are not taken into account. In this study, for a system with the capability of buying and selling electric energy, using different fuels, the heat storage tank, and considering the system efficiency as a function dependent on the operating point and the costs associated with setting up and leaving the system. The optimal working point of the system is determined.

In the case of cogeneration systems with the heat storage tank, it is important to note how the boiler operates [8]. In this study, it is assumed that the auxiliary boiler works at constant power.

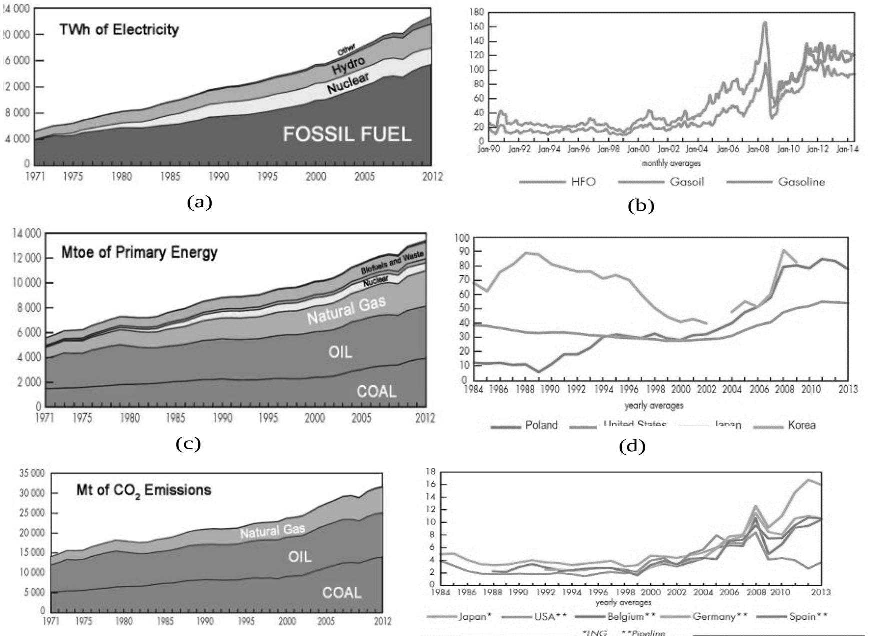
Lowering the fluid temperature of the tank will light up the auxiliary boiler.

Turning on and off the auxiliary boiler, the thermal energy storage system, as well as turning on and off each cogeneration unit, converts the energy supply cost function into a discrete, nonlinear, and derivative function. Given these conditions, the genetic algorithm was used to determine the optimal working point of the cogeneration system [1].

Combined Cooling, Heating and Power (CCHP)

Distributed Energy Demand

The rapid rise in global energy demand, coupled with the expected decline in fossil fuel energy sources and their impact on global climate change, has called for urgent and creative ways to resolve the energy crisis [1]. Figure 1 provides an idea of the world's energy production numbers, fuel consumption, emissions, and fuel prices. Along with the shift to clean renewable energy technologies, distributed and locally sustainable energy systems are the way forward because they are more effective in the long run. They can help the central grid, especially in times of emergency such as sudden demand, natural disasters, terrorism, etc. A proven approach to distributed energy generation is the use of Refrigeration, Heating, and Energy Systems (CCHP), which combines the use of traditional techniques with newly developed technologies to meet modern needs in energy, economic and environmental policies. Compared to a centralized approach to save electricity, CCHP systems use thermal energy from fossil fuel-based electric power generation for heating, ventilation, and cooling (HVAC) [2]. Since HVAC represents a large part of energy consumption in residential and industrial sectors (Figure 2), this method can save much energy.



(a) (b)

(c) (d)

(e) (f)

Figure 1. (a) World electric generation by fuel (TWh). (b) Rotterdam oil product spot price (USD/barrel) (c) World primary energy supply by fuel (Mtoe) (d) Steam coal or electricity generation (USD/tonne) (e) World CO2 emissions by fuel (Mt of CO2) (f) natural gas import price USD/Million BTU [8].

The global power of CHP systems is presented in Table 1. These systems are used in a wide range of institutions such as universities (Pennsylvania State University), airports (Shanghai Pudong International Airport, China), seawater desalination plants (Iran), for district heating (Finland, Denmark, Germany), Internal hospitals, supermarkets have been installed. Supermarket, textile mills, etc. The economical, efficient, and low-cost design of this system requires full attention to the energy needs of a particular region. Table 2 shows an idea of the scale of the system in terms of energy capacity and typical usage [3].

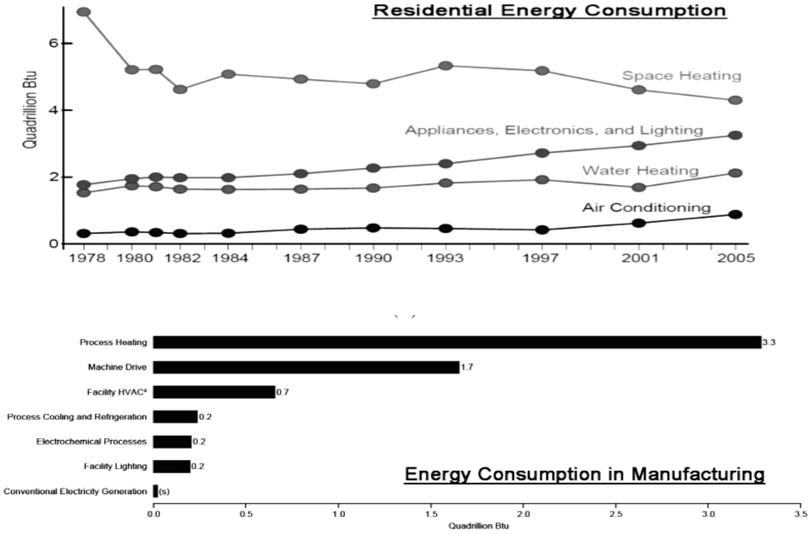
Table 1. Installed CHP capacity by country in MW [8]

Country	Capacity	Country	Capacity	Country	Capacity
Australia	1864	Greece	240	Portugal	1080
Austria	3250	Hungary	2050	Romania	5250

Belgium	1890	India	10012	Russia	65100
Brazil	1316	Indonesia	1203	Singapore	1602
Bulgaria	1190	Ireland	110	Slovakia	5410
Canada	6765	Italy	5890	Spain	6045
China	28153	Japan	8723	Sweden	3490
Czech	5200	Korea	4522	Taiwan	7378
Denmark	5690	Latvia	590	Turkey	790
Estonia	1600	Lithuania	1040	UK	5440
Finland	5830	Mexico	2838	US	84707
France	6600	Netherlands	7160	Germany	20840
Poland	8310				

Table 2. Power system scale concerning power capacity and application area [8]

Configuration	Capacity	Application Area
Micro-scale	<20 kW	Distributed Energy System
Small-scale	20 kW - 1 MW	Supermarkets, retail stores, hospitals, office buildings, universities
Medium-scale	1 MW - 10 MW	Large factories, hospitals, schools
Large-scale	>10 MW	Large industries. Waste heat used in universities, district heating



(a)

(b)

Figure 2. (a) Breakdown of energy consumption for a household over the years. (b) Breakdown of energy consumption in manufacturing for a single year [8].

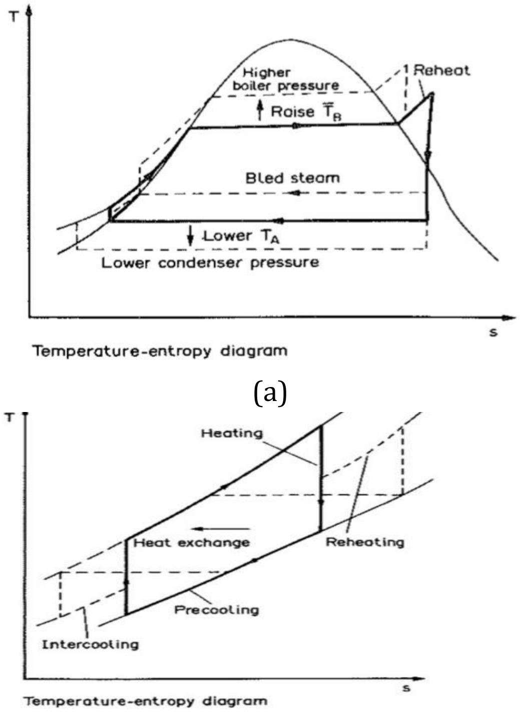
Improvement Design Strategies

The primary purpose of any power plant design is to achieve more work efficiency to provide specific heat (or fuel energy). This plant should be designed to simulate the nearest possible period, the Carnot cycle [4]:

$$\eta_{carnot} = \frac{W}{Q_0} = 1 - \frac{T_{\min}}{T_{\max}} \quad (1)$$

In a conventional thermal power plant, approximately one-third of the input fuel energy usually appears as electrical energy; two-thirds of the energy as lukewarm water is transferred to the rivers or the sea in cooling towers.

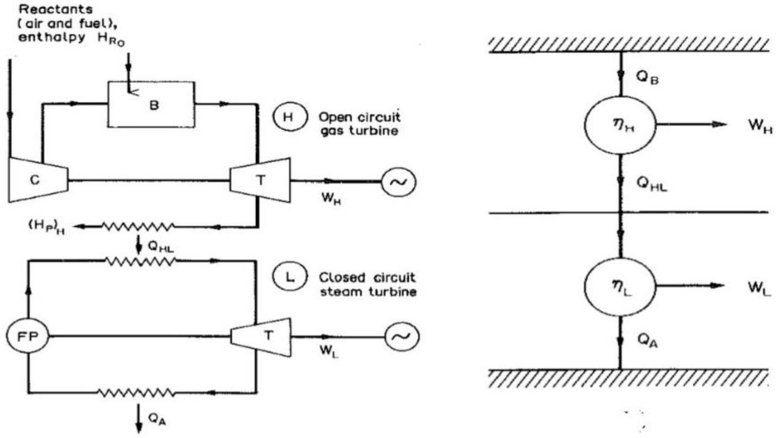
Therefore, in order to increase thermal efficiency, other design adjustments are required. Heat exited from the turbine can be reused by one or a combination of the following methods: (1) regeneration, (2) the combined gas and steam cycle, or (3) co-generation (i.e., CHP) and its development systems, Production (i.e., CCHP). Individual adjustments were made to increase the plant's thermal efficiency locally in the initial investigation of the Rankin and Jules Burton cycle power plants (Figure 3). The regeneration procedure, which involves reusing the heat lost in the cycle, may be performed by boiler bleeding or heat exchangers. However, the scope of this amendment is limited [5].



(a)

(b)

Figure 3. Temperature-entropy diagram showing modifications to basic (a) Rankine cycle and (b) Joule-Brayton cycle to increase thermal efficiency [9].



(a) (b)

Figure 4. Gas turbine/Steam turbine combined power plant (a) schematic and (b) block diagram [10].

In a combined cycle plant (Figure 4), the two rotating stations are combined so that the QHL heat from the "top" (top cycle) plant (Joule-Bryton gas turbine cycle) of the efficiency ηH source and "The bottom plant "(bottom) is used with an efficiency of ηL (steam turbine cycle). These two plants are cyclic and use two different working fluids. A brief analysis of this plant to determine thermal efficiency is provided as follows [5]:

$$W_H = \eta_H Q_B \qquad (2)$$

$$W_L = \eta_L Q_{HL} \qquad (3)$$

$$Q_{HL} = Q_B(1-\eta_H) \qquad (4)$$

$$\eta_{th} = \frac{W_H + W_L}{Q_B} = \eta_H + \eta_L - \eta_H \eta_L \qquad (5)$$

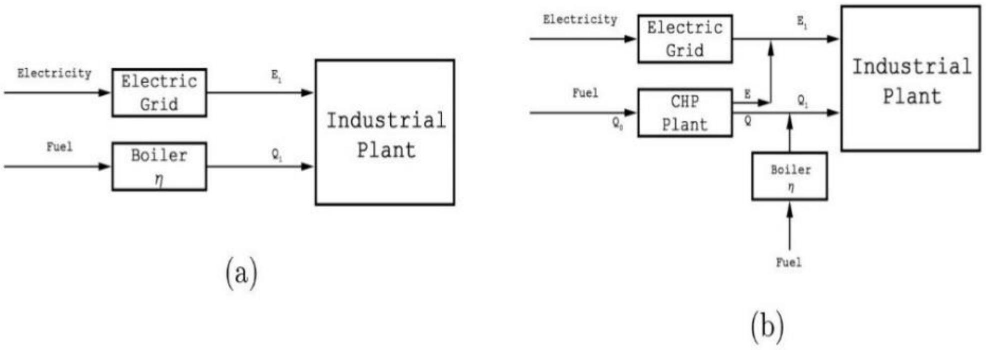


Figure 5. (a) Separate generation of heat and electricity for industrial plants. (b) Co-generation of heat and electricity for industrial plant [12].

As a result, higher cycle efficiency is increased by ηL (1 - ηH) using the waste heat to generate energy in the lower cycle [10].

CHP enables the use of wasted steam in the combined cycle power plant. Figure 5. Simplified configuration of CHP facilities against separate heat and power generation is shown. The plant requires E1 and Q1 values of electricity and heat, respectively. CHP Energy provides E and Q values of energy and heat. Extra fuel and fuel can be purchased to meet factory requirements. The CHP station's overall efficiency can be as follows [7]:

$$\eta_{CHP} = \frac{Q+E}{Q_0} \qquad (6)$$

The ηCHP is also referred to as the Energy utilization Factor (EUF). Since all the heat used in power generation is not used to provide heat, the overall efficiency of the CHP system can reach 90% compared to 35-40% for the individual power plant [12].

Technical Review

Combined Cool, Heat, and Power is a combination of axial power and useful heat produced by a system using two different forms of useful energy using a primary energy source [8].

The technology was first used in steam cycle power plants, using steam extracted from the cycle for heating purposes in the plant and surrounding units. Although this would reduce the efficiency of such power plants, it would save a great deal on fuel consumption. In recent years, the application of these systems, which results in high energy consumption, has not been limited to steam power plants and has been extended to other power generators, whether mechanical or electric, so that any power generating system can be used to any size today. It was designed and implemented as a single unit, making it possible to utilize the heat generated by the generator or motor in addition to generating electrical or mechanical power by the device. Combined plants can be divided into five general categories:

Recovery from Extraction Condensing;
Recovery from Back-Pressure Turbines;
Recovery from gas turbine heat recovery;
Recycling from the Combined Cycle;
Recycling from Reciprocating Engines.

The most unaffected cogeneration plants are those using Back-pressure turbines. These power plants generate electricity and heat in a steam turbine. Another significant component of Back-pressure power plants is a boiler designed to burn solid, liquid, or gaseous fuels [9].

Extraction Condensing

Heat generation by dispersed production can be done in plants equipped with Extraction Condensing. By removing some of the steam before reaching the final stage of the turbine. Central heating can be used for industrial use by steam extracted from the turbine. The steam pressure reduction station is used when the steam turbine is not in use. In this case, reliable steam will be provided to heat the processes. Note that this steam generating system does not apply if the steam turbine is not used. In a conventional power plant, only electricity is produced, but in an Extraction Condensing plant, some of the steam is generated from the turbine to generate heat [10].

Backpressure Power Plants

In conventional steam power plants, high-pressure steam is produced in the boiler, so-called live steam. This vapor passes through the turbine, and, after full expansion, low pressure enters a condenser. In this section, the residual heat in this steam is transferred by air or water. In a back-pressure turbine, steam is driven out of the middle parts of the turbine by higher pressure, and this steam is used for heating purposes. This steam can be used directly as process steam (for example, in paper machines) or as a hot fluid in a heat exchanger to heat water in district heating systems [11].

Industrial Backpressurere Power Plants

At industrial back-pressure power plants, the backpressure of the turbine is usually maintained at full and partial loads with constant process conditions. Some of the higher quality steam can also be extracted from the middle parts of the turbine. This steam can be used in industrial processes or can be consumed indoors. CHP will not apply if the steam reaches the internal consumption of the plant. The higher the steam extracted from the turbine, the less electricity produced [12].

Backpressure Power Plants for Use in District Heating

In conventional district heating systems, hot water, which carries energy, is passed through heat exchangers. The temperature of this water will vary with the ambient temperature changes. Depending on the design of the grid, the outlet temperature of the power plant is assumed to be between 120 and 150°C. For example, if the average outlet water temperature is between 80 and 85 degrees, the return water temperature will be about 50 to 55 degrees Celsius. In some cases, boilers in series with heat exchangers are considered to increase the temperature of the outlet water. It should be noted that the increase in heat due to the passage of these boilers should not be included in the calculation of the total efficiency of the CHP system. The higher the water temperature of the outlet than the district heating system, the lower the power output [12].

Gas Turbine and Heat Recycling Boiler

A simple, low-cost system for generating scattered heat and power can generate heat recovery by combining a gas turbine and a boiler. Hot exhaust gases pass through a gas recycling boiler and provide the steam required for the process or heating required. In these types of power plants, hot air from the gas turbine outlet passes the heat recovery boiler and transfers its heat to the carrier fluid (water). In many cases, natural gas is used as fuel, but diesel or a combination of gas and diesel is also used as fuel. The amount of heat recovered depends on the type of fuel consumed and the temperature of the heat recovered. If natural gas is used as a gas turbine fuel, the temperature of the exhaust gas from the recycling boiler can be reduced to about 60 to 100°C. Be controlled [11]. In some cases, the power plant is equipped with an auxiliary burner that uses exhaust gas from the gas turbine instead of the combustion air. Naturally, the heat generated from auxiliary burners should not be taken into account in calculating the heat generated from CHP. In some cases, the exhaust from the gas turbines will be equipped with a by-pass, which can only be used when the boiler is recycled and unnecessarily removed from the system.

Combined Cycle Power Plants

Recently, combined cycle power plants, including one or more gas turbines, including heat recovery boilers and steam turbines, have become commonplace. A combined cycle power plant consists of one or more gas turbines and steam turbines. Depending on the type of steam turbine, the power plant can be either conventional or dispersed. These units can be used as CHP units if the auxiliary coolers are not used to cool the steam turbine outlet. The characteristic of all combined cycle power plants is the heat recovery from the exhaust gas of the gas turbines [13]. This heat is used by recycling boilers to produce the steam needed for steam turbines. Auxiliary boilers are commonly used to heat auxiliary boilers to increase the steam quality of auxiliary burners that use gas turbine exhaust gas as inlet air. Combined cycle systems in which the condenser output fluid is used to heat form the basis of the combined cycle dispersed generation systems [9].

Power Plants Equipped with Reciprocating Motors

This method is similar to the gas-dispersed generation method, with the use of reciprocating internal combustion engines instead of gas turbines. In power plants using reciprocating motors, heat can be recovered from engine oil or engine coolant water from the heat of the exhaust gases. The electrical efficiency of reciprocating motors is between 35% and 42%, and if the environmental regulations require a significant reduction in nitrogen oxides, this efficiency is reduced by 1%. Given that advanced engines have cooler exhaust gases (about 400), heat recovery can only be steam; for example, a 4.2 MW diesel engine can produce 1.5 MW steam and 1.3 MW hot and cold. Given that the total fuel consumption for this engine will be about 10 MW, the total efficiency of the complex is about 88% [10].

Methods

Genetic Algorithm

Genetic Algorithm (Genetic Algorithm - GA) is a computer science search technique for finding an approximate solution to search optimization and problems. A genetic algorithm is a particular type of evolutionary algorithm that uses biological techniques such as inheritance and mutation [1].

The genetic algorithm, known as one of the random optimization methods, was invented by John Holland in 1967. Later, with the efforts of Goldberg 1989, this method found its place, and today, due to its capabilities, it is well-positioned, among other methods.

Genetic algorithms are usually implemented as a computer simulator in which the population of an abstract sample (chromosomes) of the solution candidates of an optimization problem leads to a better solution. Traditionally solutions have been in the form of strings of 0 and 1 but have been implemented in other ways today. The hypothesis begins with a completely random population and continues for generations. In each generation, the capacity of the entire population is evaluated, several individuals are randomly selected from the current generation (based on competencies) and modified (deducted or reconfigured) to form the new generation, and the algorithm is transformed into the current generation in the next iteration [13].

For example, if we want to model oil price fluctuations using external factors and simple linear regression, we will produce the following formula: Oil price at time t = Factor 1 Interest rate at time t + Factor 2 Unemployment rate at time t + Constant 1. We will then use a criterion to find the best set of coefficients and constants to model oil prices. There are two essential points to this method. The first is that the method is linear, and the second is that we specify the parameters used instead of searching through the “parameter space[12].”

Using the Genetic Algorithm, we set up a formula or scheme, which expresses something like “Oil prices at time t are a function of maximum four variables.” The genetic algorithm will then be executed, which will search for the best function and variables. The genetic algorithm’s work is deceptively simple, very understandable, and remarkably the way we believe animals have evolved. Following the above, one follows the population of possible formulas.

The variables that specify each given formula are shown as a set of numbers that make up the individual’s DNA [11].

The genetic algorithm engine generates an initial population of formulas. Each person is tested against a set of data and remains the most relevant (perhaps 10% of the most appropriate); the rest are excluded. And change (random change of DNA elements). It is observed that over many generations, the genetic algorithm tends to formulate more precise formulas. While neural networks are both nonlinear and nonparametric, the great attraction of genetic algorithms is that the final results are more noticeable than the other methods. The final formula will be visible to the human user, and standard formulas can be applied to these formulas to provide a level of confidence. The technology of genetic algorithms is continually improving, for example, by equating viruses that are produced alongside formulas to break weak formulas and thus make the population stronger overall.

In short, the genetic algorithm (or GA) is a programming technique that uses genetic evolution as a problem-solving paradigm. Evaluates the candidate solution, most of which are selected at random [9].

Genetic Algorithm (GA) is a computer science search technique for finding optimal solutions and search problems. Genetic algorithms are one of a variety of evolutionary algorithms inspired by the science of biologics such as inheritance, mutation, natural selection, natural selection, and composition.

Solutions are generally represented as 2s of 0s and 1s, but there are other display methods. Evolution starts from a completely random set of entities and is repeated over the next generations. In each generation, the best are chosen, not the best.

A solution to the problem is shown by a list of parameters called chromosomes or genomes. Chromosomes are generally represented as a simple sequence of data, although other data structure types can also be used. Initially, several features are randomly generated to create the first generation. During each generation, each attribute is evaluated, and fitness is measured by the function of fitness [12].

The next step is the creation of the second generation of the population, based on selection processes, based on characteristics selected by genetic operators: linking chromosomes to each other and changing. For each individual, a pair of parents is selected. The choices are such that the most appropriate elements are selected so that even the weakest elements have the chance of being selected to avoid approaching the local answer. There are several patterns to choose from Roulette, Tournament, etc. [13].

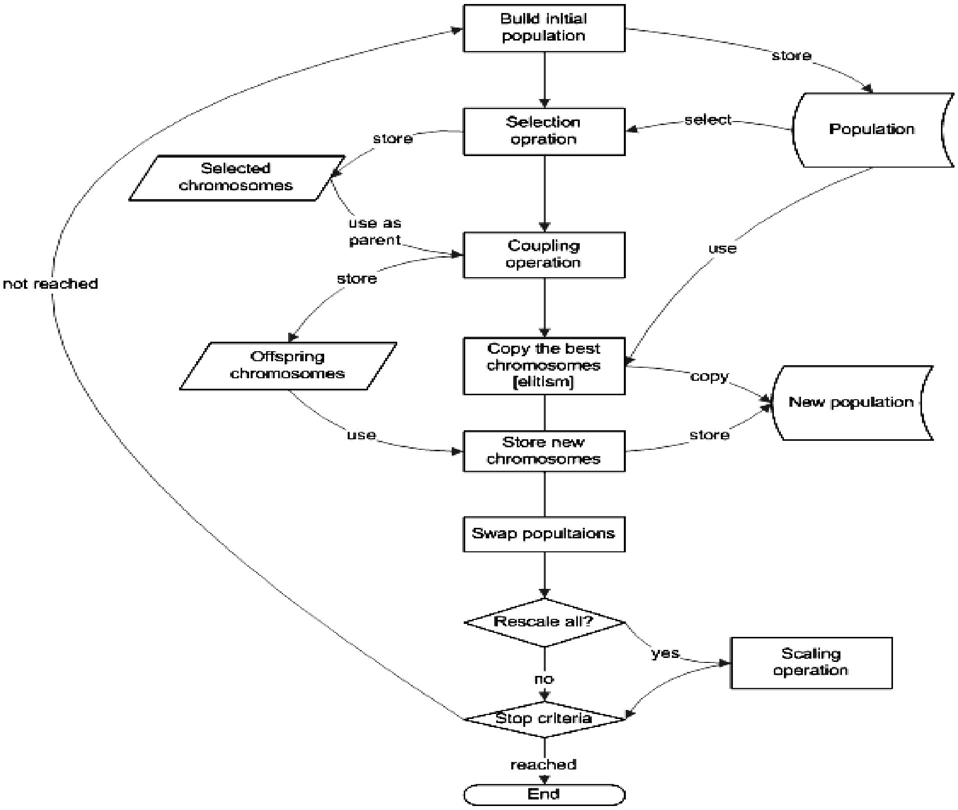


Figure 6. The flowchart of the GA [14].

Genetic algorithms usually have a probability of being between 0.6 and 1, indicating the probability of a child being born. The organisms are reunited with this probability. Binding creates two child chromosomes, which are added to the next generation. These are done until the right candidates are found for the next generation. The next step is to change the new offspring. Genetic algorithms have a small, constant change probability, usually of a degree of about 0.01 or less. Based on this probability, the child's chromosomes change randomly or mutate, especially with the bits mutated in the chromosome of our data structure [12].

This process creates a new generation of chromosomes, which is different from the previous generation. The whole process is repeated for the next generation, and the pairs are selected for the mix; the third generation populations are created, and so on. This process is repeated until we reach the final stage [11].

Operators of a Genetic Algorithm

Each problem requires two elements before a genetic algorithm can be used to find an answer: First, a method is needed to provide an answer that the genetic algorithm can work on that. Traditionally, an answer is represented as a string of bits, numbers, or characters. The second is a way to calculate the quality of each proposed answer using proportional functions. For example, if the problem considers any possible weight for a backpack without breaking the backpack (see the backpack problem), a method of answering can be considered as a sequence of bits 1 and 2, which; or Whether or not the weight is added to the backpack is measured. The proportion of response is measured by determining the total weight for the proposed answer [10]. The optimization procedure in the genetic algorithm is based on a random-directed procedure. This method is based on the theory of gradual evolution and Darwin's fundamental ideas. In this method, a set of random parameters is randomly generated for several constants called populations, after executing a numerical simulator that represents the standard deviation and Or we fit that set of information to that member of that population. Repeat this process for each of the created members, then formulate the genetic algorithm operators, including fertilization, mutation, and next-generation selection, and continue this process until the convergence criterion is met. Commonly, three criteria are considered as a stop criterion [9]:

Algorithm execution time.

The number of generations created.
Error Criterion Convergence

Genetic Algorithm Applications

Hydrological Routing of Runoff in Dry River Network
Help solve multi-criteria decision-making problems
Multi-objective optimization in water resources management
Optimization and re-design of power distribution networks

Termination Conditions for Genetic Algorithms Are

To a fixed number of generations.

Finish allotted budget (calculation time/money).
Find an individual (child produced) that meets the minimum (minimum) criterion.
Obtain the highest degree of fitness for children or no other better results.
Manual inspection.
Top combinations.

CCHP Modeling

The modeling approach for analyzing and improving Discrete Production (SP) and CCHP plants is described in this chapter. The design of CCHP systems should consider the best strategies for load demand, trade-offs between cost savings, energy savings, and net pollutant emissions. Several performance standards and operational strategies have been discussed for this purpose [8].

Operational Strategies

The CCHP operational strategy dictates system loading and fuel consumption. You can use the following strategies to control CCHP systems:

After Electric Charge (FEL): Here, the PGU generates all the electricity needed to meet the electrical need and uses the lost heat to provide the maximum amount of convection possible. If the recovery heat is not sufficient, an auxiliary boiler is used to supply the heat required by the facility. This strategy is also called electricity demand management (EDM) [6].

After Transmission (FTL): The system provides all the thermal and electricity demand generated to meet the highest possible electrical demand. Extra electricity from the grid may be needed if needed. Also referred to as thermal demand management (TDM).

Essential Load Operation: The system only covers a certain amount of electrical and thermal load of the facility. Any additional needs should be purchased from the power grid or boiler.

EDM and TDM strategies may not guarantee the best performance of the system. This is due to factors such as differences in demand and fuel prices. Some optimization techniques must be considered to maximize system performance [5].

System Model

The typical SP system providing cooling, heating, and power is shown in Figure 7(a). Except for some heat energy provided by burning fuel (FSPb), all the energy demand is satisfied by the electric grid. Total energy from the grid is given as,

$$E_{grid}^{SP} = E + E_c + E_p^{SP} \qquad (7)$$

where energy consumed by the chiller can be replaced by,

$$Ec = \frac{Q_c}{COP_e} \qquad (8)$$

The fuel energy used to provide ESP grid is,

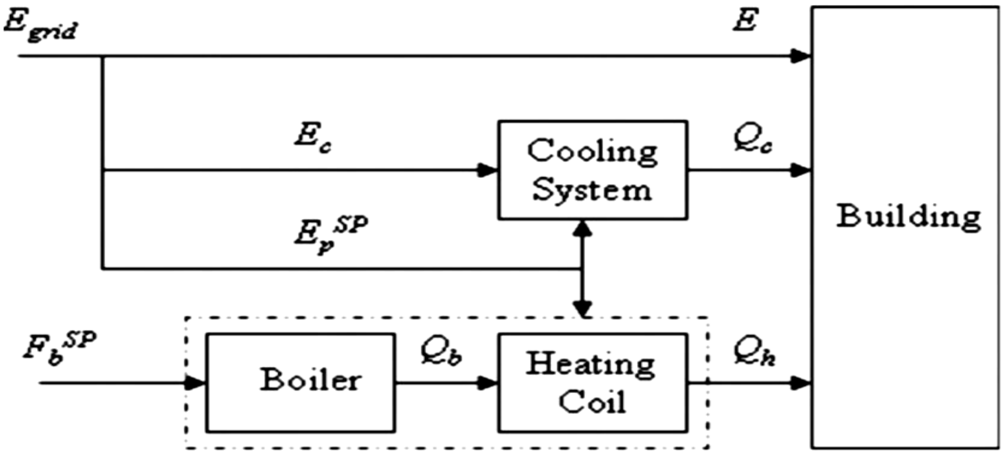
$$F_e^{SP} = \frac{E_{grid}^{SP}}{\eta_e^{SP} \eta_{grid}} \qquad (9)$$

Similarly, the fuel energy used to provide Qh is,

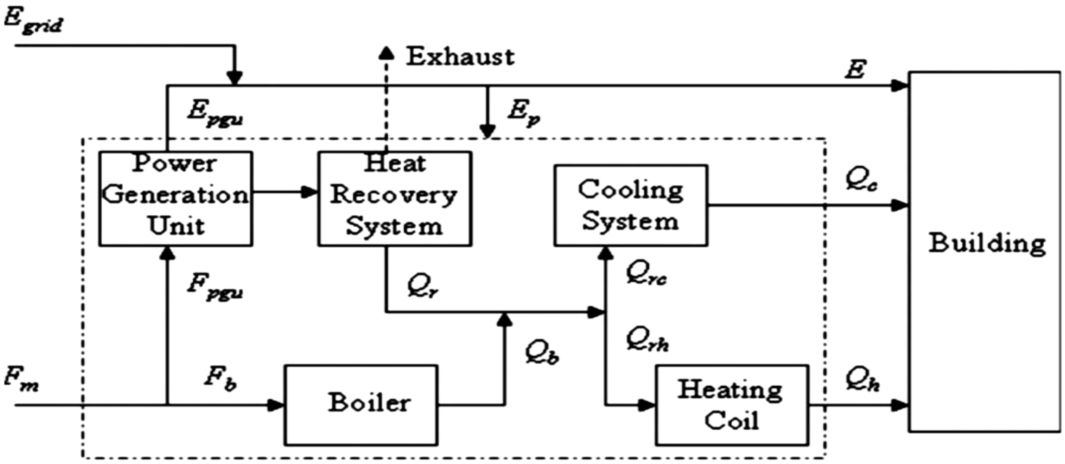
$$F_b^{SP} = \frac{Q_h}{\eta_b^{SP} \eta_h} \qquad (10)$$

Finally, the total fuel energy consumed is,

$$F^{SP} = \frac{E}{\eta_e^{SP} \eta_{grid}} + \frac{E_p^{SP}}{\eta_e^{SP} \eta_{grid}} + \frac{Q_c}{COP_e . \eta_e^{SP} . \eta_{grid}} + \frac{Q_h}{\eta_b^{SP} . \eta_h^{SP}} \qquad (11)$$



(a)



(b)

Figure 7. (a) SP system flow diagram. (b) CCHP system flow diagram [6].

The schematic for a CCHP system is shown in Figure 7(b) The electrical energy balance yields the expression [7].

$$E_{grid} + E_{pgu} = E + E_p \quad (12)$$

The fuel energy consumed to provide E_{pgu} *is*

$$F_{pgu} = \frac{E_{pgu}}{\eta_e} \quad (13)$$

The recovered waste heat is given as

$$Q_r = F_{pgu}\eta_{rec}(1-\eta_e) \quad (14)$$

The heat balance equation between the cooling system and heating coil yields

$$Q_r + Q_b = Q_{rc} + Q_{rh} \quad (15)$$

The heat consumed by the cooling system and the heating coil is estimated as

$$Q_{rc} = \frac{Q_c}{COP_{ch}} \quad (16)$$

$$Q_{rh} = \frac{Q_h}{\eta_h} \quad (17)$$

The additional fuel energy that the auxiliary boiler uses is given as

$$F_b = \frac{Q_{rc} + Q_{rh} - Q_r}{\eta_b} \quad (18)$$

Finally, the total fuel energy consumed is

$$F = F_{pgu} + F_b \quad (19)$$

For the EDM operation strategy, Egrid = 0 is substituted in the above equations as all the electric requirement is fulfilled by the CCHP system. Similarly, for the TDM operation strategy, Qb = 0 as no heat is required from the boiler [9].

Performance Factors

In order to quantify the benefits achieved by the CCHP system over the separated production (SP) system, the energy efficiency criteria described in this Chapter are not enough. Therefore, additional performance criteria have been formulated as follows [16]:

Energy Savings: Primary Energy Savings (PES) is the ratio of energy saved by the CCHP system in comparison with an SP system to the energy consumed by the SP system.

$$PES = \frac{F^{SP} - F}{F^{SP}} = 1 - \frac{F}{F^{SP}} \quad (20)$$

where F is the fuel energy required by the CCHP system, PES is measured relative to a reference system. The primary energy ratio (PER) is a criterion with an absolute value. It is defined as the ratio of the energy demand to the fuel energy required to satisfy the demand [17].

$$PER = \frac{E+Q_c+Q_h}{F} \quad (21)$$

where E is the electricity demand, Qh is the heat energy demand, and Qc is the demand for cooling energy [18].

Exergy Efficiency: Exergy analysis is used to identify sources of irreversibility losses, both internal and external, to the system. The exergy of electricity, cooling and heating is defined respectively as,

$$EX_e = E \quad (22)$$

$$EX_c = \left(\frac{T_0}{T_c} - 1\right) Q_c \quad (23)$$

$$EX_h = \left(1 - \frac{T_0}{T_h}\right) Q_h \quad (24)$$

where T0 is the ambient temperature, Tc and Th are the cold water and hot water temperatures, respectively. The exergy of fuel is given as [5],

$$EX_f = \gamma_f V_f HHV_f = \gamma_f V_f R_f LHV_f = 1.03F \quad (25)$$

Where γf denotes the exergy grade function for the fuel, defined as the ratio of fuel chemical exergy to fuel higher heating value HHVf and Vf is the gas consumption. LHVf is the low heating value of gas, and Rf is the ratio of HHVf to LHVf. For natural gas, the product of γf and Rf is 1.03 and VfLHVf is the same as F. [19] Based on the above definitions of component exergies, the exergy efficiency of the CCHP system is defined as [9],

$$\eta_{ex} = \frac{EX_e + EX_c + EX_h}{EX_f} \quad (26)$$

CO2 Emission Reduction (CO2ER): The amount of CO2 emission (CO2E) from the system can be determined using the emission conversion factor of fuel as,

$$CO_{2E} = \mu_{CO2,g} F + \mu_{CO2,e} E_{grid} \quad (27)$$

where µCO2,g, and µCO2,e are the CO2 emission conversion factors for gas and electricity from the grid (Egrid). In comparison to the SP system, CO2 emission reduction CO2 ER by using CCHP is defined as,

$$CO_2ER = \frac{CO_2E^{SP} - CO_2E}{CO_2E^{SP}} = 1 - \frac{CO_2E}{CO_2E^{SP}} \quad (28)$$

CO2ER shows the environmental benefits achieved by the use of a CCHP system over an SP system [21].

Annual Total Cost Saving (ATCS): Here to the performance of the CCHP system is compared to a reference SP system. The annual total cost is a sum of the capital cost of the equipment (Ce) and the energy charge (Cm). The equations are defined as [6],

$$ATC = C_e + C_m \quad (29)$$

$$ATCS = \frac{ATC^{SP} - ATC}{ATC^{SP}} \quad (30)$$

Performance and Optimal Point Modeling

In this study, the objective function is defined based on maximizing revenue or minimizing the cost of a cogeneration system concerning the ability of electricity exchange with the grid and the possibility of storing and retrieving heat energy in the tank. The objective function consists of two parts: income and cost. Proceeds from the sale of electricity to the grid:

$$J_1 = \sum_{t \epsilon T} P_{El,sell}(t) Price(t) \quad (31)$$

In this study, it is assumed that the cogeneration system has several independent (U) units, and each unit is capable of consuming various fuels such as natural gas, furnace oil, diesel, etc. Costs include fuel costs for cogeneration units and the cost of electricity purchased from the grid. Cost of fuel for cogeneration units:

$$J_2 = \sum_{t\epsilon T} \sum_{u\epsilon U} \sum_{r\epsilon R} Cost_r P_{r,u}(t) \quad (32)$$

Cost of purchased electricity:

$$J_3 = \sum_{t\epsilon T} P_{El,Buy}(t) Cost_e(t) \quad (33)$$

Cost of alternative-burner Fuel:

$$J_4 = \sum_{r\epsilon R} \sum_{t\epsilon T} \left\{ [P_{th} - \sum_{u\epsilon U} Q_u(t)] * \left(\frac{sign(P_{th} - \sum_{u\epsilon U} Q_u(t)) + 1}{2} \right) \right\} * Cost_r) \quad (34)$$

The cost of turning off each unit of cogeneration system:

$$J_5 = \sum_{t\epsilon T} \sum_{u\epsilon U} Cost_{s,u} * I_u \qquad (35)$$

Finally, the objective function, which consists of all revenues and expenses, is given below.

$$J = Max\{J_1 + J_2 - J_3 - J_4 - J_5\} \quad (36)$$

System Constraints

Provision for the complete supply of electric and heat loads

Because all the electrical and heat energy needed must be supplied. The relevant constraint is as follows.

$$P_{e,demand} = P_{e,co} - P_{El,sell} + P_{El,buy} \qquad (37)$$

$$P_{Q,demand} = P_{Q,co} - P_{Q,B} + P_{Q,T} \quad (38)$$

Capacity Generation Limit

The electrical and thermal power produced by the cogeneration system has limitations that are considered inequalities in optimization.

$$P_{ei,min} < P_{ei,co} < P_{ei,max} \quad (39)$$

$$P_{Qi,min} < P_{Qi,co} < P_{Qi,max} \quad (40)$$

The efficiency of the cogeneration system, in addition to the above inequality, also includes zero, which represents the system's exit from the consumption grid. As the system enters and exits, the startup cost and system exit will also be considered in the objective function.

Fluid Tank Limitations

The hot fluid reservoir has a temperature and pressure limit. If the fluid is liquid, the fluid temperature must always be within a certain range. If the fluid is a vapor in addition to temperature, the vapor pressure will be a limiting factor.

$$P_{T,min} < P_T < P_{T,max} \qquad (41)$$

$$T_{T,min} < T_T < T_{T,max} \qquad (42)$$

If the tank temperature drops below the minimum TT, min, the auxiliary boiler is switched on and increases the tank temperature to a certain TT, b, and then switches off. If the reservoir temperature exceeds the maximum value, the heat recovery from the converter is stopped, and the exhaust gases enter the environment directly [20].

Implementation Method

In the next step, different steps of the genetic algorithm are implemented to determine the optimal working point of the cogeneration system. As mentioned in the introduction, the cost function is discrete, nonlinear, and indivisible, and according to the specific features of the genetic algorithm mentioned below, the genetic algorithm is used. Generally, programming and implementation of optimization are relatively more straightforward, and by applying different methods of chromosome coding, the problem can be reduced. The algorithm has relatively good convergence speed, lower side computation, the ability to find the absolute optimum, and local optimum points can also be found by limiting the initial generation [10].

GA Modelling

The first step in the genetic algorithm is the search space coding. The interfaces of each of the units of the cogeneration systems constitute the search space. Thus, each chromosome contains information about the output power of each unit of the co-production system. The coding of the search space is done according to the following relation [16-18].

$$Step = \frac{P_{ei,max} - P_{ei,min}}{2^N - 2} \qquad (43)$$

where N is the number of genes per chromosome. The interval is divided between the minimum and maximum amount of power output per unit. Based on the above relation, the power output is coded and decoded as relationships [19-21].

$$P_{ei} = P_{ei,min} + n_i * Step \qquad (44)$$

where ni is rounded to the nearest integer, then the power output changes of each unit in steps of one-step length is the binary value of ni, which is considered as the values of the chromosomes. The advantage of this method is that new generations always remain within the permitted range of each generator, and there is no need to modify the new generation. The only exception to the coding is the power of zero (shutdown of a system), which is modeled as a chromosome with zero values [11-13].

Calculate the Fit Function

Since the genetic algorithm of the selected chromosomes must have high fitness, therefore, the fitness rate is considered to be the objective function inverse. Since the values of the objective function can be positive or negative, they are subtracted from the number M always to be positive [14-16].

$$Function_{Fitness} = \frac{1}{M - obj.f} \qquad (45)$$

In some cases, especially in systems that have similar units, working in the absolute optimum may require significant variations in the power output of each unit. For example, the power changes of each unit in a system that has two generating units can be modified as follows.

Table 3. The Example initial points

PL	P1	P2	example
5	3	2	1
5.2	1.5	3.7	2

For such a system to operate at absolute optimum, it is necessary to reduce the power of the first unit from 1.5 MW to 3 MW and increase the power of the second unit from 2 MW to 37 MW. One can find a local optimum for the new load by limiting the search space to the neighborhood of the first task. If the cost difference between the two points is negligible, the local optimal point can be selected as the new work point. Changes in the power output of each unit can also be considered as a penalty factor in the fitness calculations [22-24].

$$Penaltyfactor = k\left(\frac{\sum_{i \epsilon U}\left(P_i - P_i'\right)^2}{\left(P_L - P_L'\right)^2}\right) \qquad (46)$$

k is the constant P'i and P'L, respectively, the output of unit i and the electrical power required. In this case, the fitness function changes as follows [23-25].

$$Function_{Fitness} = \frac{1}{A-obj.f+Penaltyfactor} \qquad (47)$$

In this case, the optimum operating point will be close to the current operating point to be selected for priority. In each generation, after decoding the chromosomes, the value of the target function is determined, and consequently, the amount of fitness for each chromosome is calculated. Following the application of genetic operators to the current generation, a new generation will be produced. Here, two active and passive methods are employed to stop the algorithm [24-26].

Case Study

Appendix 1 provides information on a cogeneration system. With the above method, the optimal working point of this system is determined at different times. The amount of electricity and heat required and the amount of electricity and heat produced by the cogeneration system for load consumption in temperate and warm seasons are shown in Figures (19) - (11).

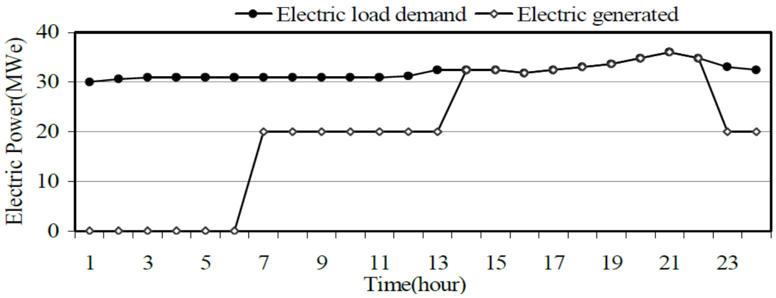


Figure 11. Electricity demand vs. system's production in the mild seasons.

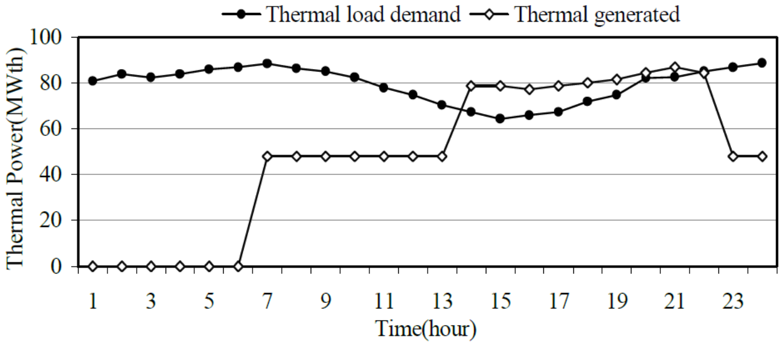


Figure 12. Heat demand vs. system's production in the mild seasons.

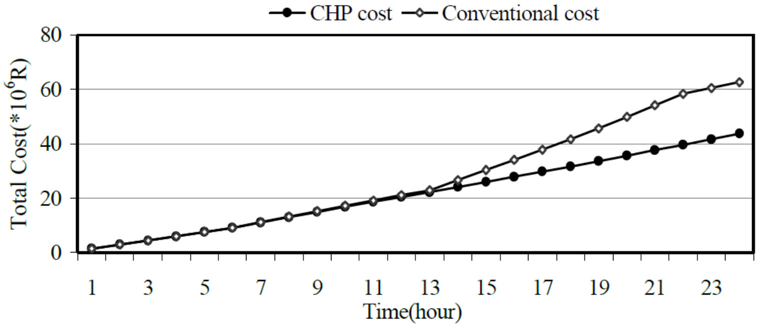


Figure 13. CCHP fuel cost vs. conventional system fuel cost in the mild seasons

In temperate seasons, due to the equilibrium amount of electrical and heat energy, the heat generated by the cogeneration system is not produced except in peak load times. As shown in Figures (11) and (12), in the temperate seasons, the system is switched off during the early hours (1-6) and the electrical and thermal energy production is equal to zero [27-29]. From 7 am to 13 pm, the cogeneration system supplies more than half of the electrical and heat loads, and from then until 22 pm, it supplies all electrical loads and simultaneously all heat loads due to high electricity rates. It can be seen in Figure 6 that at the end of the 24 hours, the total cost of the cogeneration system is approximately 50% lower than that of the conventional production system [30-32].

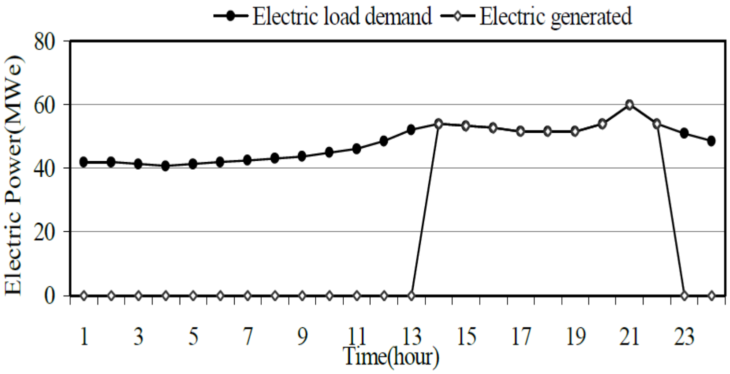


Figure 14. Electricity demand vs. system's production in the summer season.

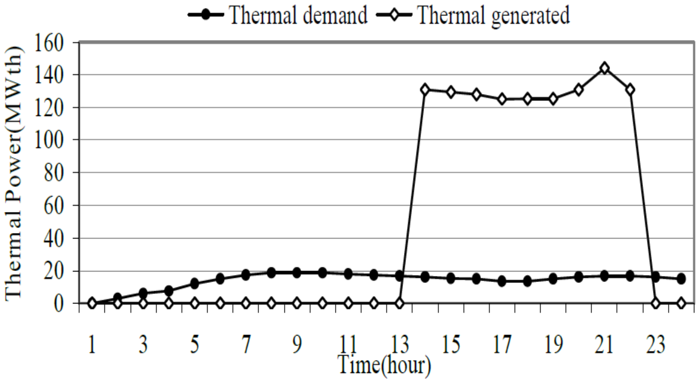


Figure 15. Heat demand vs. system's production in the summer season.

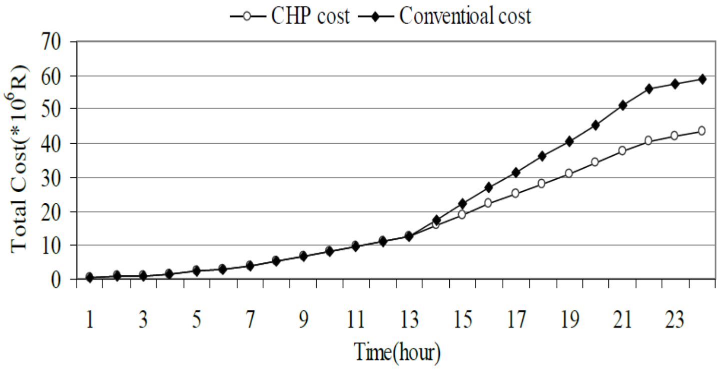


Figure 16. CCHP fuel cost vs. conventional system fuel cost in the summer season.

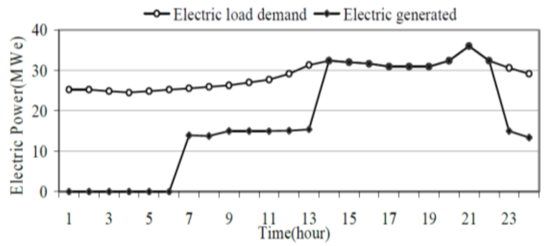


Figure 17. Electricity demand vs. system's production (Absorption chiller) in the summer season.

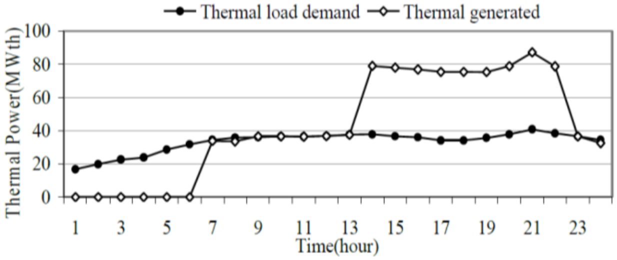


Figure 18. Heat demand vs. system's production (Absorption chiller) in the summer season.

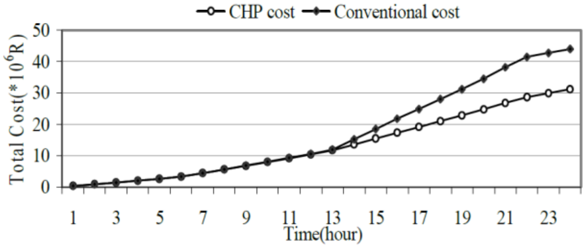


Figure 19. CCHP (absorption chiller) fuel cost vs. conventional system fuel cost in the summer season.

A comparison of the performance of the systems during the summer is shown in Figures (14) - (16). As can be seen, the optimum operating time for the cogeneration system is from 13 to 22 hours, which fulfills all the electrical energy needs, saves a great deal of heat generated, and operates the conventional system during the rest of the time [33-35]. It is done. Finally, during the summer, it can be seen from Figure 16 that the total cost of the cogeneration system, such as the temperate seasons, is approximately 50% lower than that of the conventional production system. In the summer, as the temperature rises, and as a result of the increase in cold requirements, the amount of electricity needed increases. Increasing the electric charge and decreasing the heat charge increase the PHR ratio. More significant PHR Consumption than PHR generation generates additional heat energy, which is quite evident in Figure 19. In this case, due to the mismatch of production and the need for heat energy, the cogeneration system is more regarded as a local production system than the cogeneration system [36-38].

Absorption chillers can also be used to meet the cold needs. Absorbing chillers use heat energy as input energy and do not require electricity. For the case study of the previous section, it is assumed that the cooling needs are met by an absorption chiller. In this case, the amount of electrical and heat energy required and the amount of electrical and heat energy produced by the co-generation system are shown in Figures (18) and (19). In this case, the ratio of electricity and heat load is more balanced, and the efficiency of the cogeneration system is increased compared to the previous state, and the heat energy loss is reduced compared to the previous state [39-41].

Conclusion

In this study, it was shown that the efficiency and efficiency of cogeneration systems depended on the operating point of the system and the PHR of production and consumption. For optimal operation of co-production systems, it is necessary to be as close as possible to PHR production and PHR consumption. The availability of an auxiliary boiler, especially in cases where the PHR of production is higher than the PHR of consumption and the system of co-generation with the electricity needed to produce the required heat energy, will significantly increase the efficiency of the co-generation system. Heat storage tank To avoid heat loss, in cases where surplus heat is generated on demand, it will increase the efficiency of the co-generation system. It has also been shown that absorption chillers are useful in balancing the electrical and heat loads and increasing the efficiency of the cogeneration system and reducing heat loss. The results of this study show that in Iran, cogeneration systems can be economically beneficial. If the tariffs for electricity and natural gas are increased and their subsidies reduced by the government, it can be expected that this type of operation can be exploited. Systems lead to the protection of national reserves. In general, the optimum working point of co-generation systems with electrical efficiency above 25% and heat efficiency above 50% can be determined as follows.

Complete supply of electricity through the city's electricity grid during off-hours.

Complete supply of electricity through the cogeneration system at peak hours.

Supply a fraction of the electrical load through the cogeneration system to provide all the required heat load.

Appendix 1

The mechanical efficiency of the turbine and the amount of heat recovered from the exhaust gases are considered as a quadratic function of the mechanical power produced by the turbine [4].

$$h_t = aP^2 + bP + c$$
$$Q = AP^2 + BP + C$$

Table (5) gives the coefficients related to the efficiency function and the heat output of the turbine.

Electricity tariffs at different times are based on the 2012 Tehran Regional Electricity Tariffs shown in Table (6).

The price of natural gas is 0.04 $/m3 based on the National Iranian Gas Company tariff.

Table 5. Turbine power coefficient [3]

a	b	c
0.0051	3.2293	16.5098
A	B	C
-0.0246	3.1610	-5.3224

Table 6. Energy Tariff [3]

Hour day	1-7	7-14	14-20	20-24
Price ($/kwh)	0.01	0.03	0.09	0.03

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