CHP Sizing in Residential Building Using MINLP Optimization Method

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Abstract— **Combined heat and power (CHP), or cogeneration, is one of the power and heat generation systems that applied in a wide range of residential applications. The CHP unit most applications are in the residential building that the both electricity generation and the heating consumption supplying is applied. In CHP, the heat losses of the gas turbine are used for the building heating purposes. In this paper, the optimal size of the CHP unit based on the electrical power grid purchasing cost, CHP unit and boiler operation cost, CHP unit and auxiliary boiler annual investment cost, emission cost and the power load consumer benefit cost due to power marketing to the power grid are defined as the most important parameters of the objective function that are minimized using Mixed Integer Nonlinear Programming (MINLP) optimization method. The approaches of the paper are organized into two different scenarios of CHP unit presence in the residential building. In the case of the CHP unit connection to the residential building, the electrical and thermal loads are supplied. But, in the case of the CHP unit disconnection from the residential building, the thermal and electrical loads are supplied by the auxiliary boiler and power grid, respectively.**

Keywords- Auxiliary boiler; CHP unit; MINLP optimization method; Natural gas; Residential building

I. INTRODUCTION

Cogeneration or Combined heat and power (CHP) is the use of a heat engine or a power station to generate electricity and useful heat at the same time. Trigeneration or Combined cooling, heat and power (CCHP) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector [1]. The increasing trend of fossil fuel price all around the world and environmental concern caused by pollutant gas emission in power industry have led to extreme pressure on power system operators to seek the application of distributed generations to the demand side of power system, integration of Distributed Energy Resources (DERs), e.g. wind power, solar energy, etc. as well as the optimal utilization of CHP systems [2]. The thermodynamic efficient use of a fuel to generate power and heat is the main approach of CHP. The CHP system based on using the waste heat in contrast to conventional power plants, reuse this thermal energy in the electricity generation process [3]. The difference between trigeneration and cogeneration is in that the trigeneration is used for both heating and cooling systems; typically in an absorption refrigerator. The CHP system has many applications in the power and energy supplying process, especially in the residential buildings and industrial domains. Due to this, the residential need for heating and electricity in detached single- family households in Denmark is investigated in [4]. The improvement of the energy efficiency of the waste heat with mid- low temperature is the other utilization of the CHP system [5]. In addition, the CHP and CCHP systems play an important role in the power market to supply the residential and industrial loads. The CHP economic dispatch using opposition-based group search optimization is discussed in [6] that the opposition-based group search optimization has been presented to solve four non-smooth/non-convex CHP economic dispatch problems. Similar to [6], the economic power sharing in a CHP- based Micro-Grid is presented in [7]. The same study of the CCHP system is done in [8] that the optimization analyses of this system with energy level is the main approach of it.

The optimizations used of the DERs power generation need to investigate these distributed power generation sources at different aspects. As a case study, the CHP model based district heating system with renewable energy production and energy storage is presented in [9]. In [9], a planning model consisting of energy balances and constraints for system control and operation is built and an efficient algorithm is developed. To optimization the maximum energy harvesting from the CHP system a thermal energy storage option combined with CHP system is suggested in [10]. In [10], a CHP system is investigated with and without a thermal energy storage option for eight different commercial building types located in Chicago, IL. As cogeneration important role in energy utilization, the optimization algorithm for solving CHP economic dispatch is discussed in [11]. For this purpose, select the optimal size of the CHP system required present an improved model based on maximum return on investment as well as reducing primary energy resource consumption and environmental impact [12].

Determine the CHP unit optimal size is the purpose of this paper. Due to this, by using Mixed Integer Nonlinear Programming (MINLP) the optimization problem of the CHP unit at different aspects is determined. For this purpose, two basic scenarios are considered: First, the CHP unit is supplied both thermal and electrical energy requirements. In this condition, the minimum cost of the CHP and the auxiliary boiler are determined. Second, the thermal and electrical loads are supplied by the auxiliary boiler and the power grid, respectively. In this condition, the optimal size of the CHP and the auxiliary boiler are determined. In the case of the CHP unit connection to the residential building, addition to supplying the electrical and thermal loads, the extra power generation is marked to the power market. But, in the case of the disconnection of CHP unit from the residential building, the electrical and thermal loads are supplied by the power grid and the auxiliary boiler, respectively. Similar to the paper approach, the optimal scheduling of the residential energy system is presented in [13]. The paper presentation is classified as follows: The CHP unit operation is discussed in section II. In section III, the CHP unit objective function and constraints are presented. The case study simulation, results and discussions are stated in section IV. In section V, the conclusion is presented.

II. CHP UNIT OPERATION MODEL

Combined heat and power (CHP), also known as cogeneration, is the simultaneous production of electricity and heat from a single fuel source, such as: natural gas, biomass, biogas, coal, waste heat, or oil. CHP is not a single technology, but an integrated energy system that can be modified depending upon the needs of the energy end user. CHP unit play an important role to supply the energy needs as well as to reducing the environment impact of power generation. Some benefits of the CHP are classified as follows: CHP unit requires less fuel to generate the required energy output and cause reduced the transmission and distribution losses. CHP can be designed to provide high-quality electricity and thermal energy to a site regardless of what might occur on the power grid, decreasing the impact of outages and improving power quality for sensitive equipment. CHP reduces air pollution and greenhouse gas emissions because of less fuel are burned to generate each unit of energy output. The CHP unit has economic benefits that can save facilities considerable money on their energy bills due to its high efficiency and can provide a hedge against unstable energy costs. In addition, CHP provides:

- Onsite generation of electrical and/or mechanical power.
- Waste-heat recovery for heating, cooling, dehumidification, or process applications.
- Seamless system integration for a variety of technologies, thermal applications, and fuel types into existing building infrastructure.

The two most common CHP system configurations are as follows: Gas turbine or engine with heat recovery unit; Steam boiler with steam turbine. The gas turbine or engine with heat recovery unit schematic model is presented in Fig. 1. Gas turbine or reciprocating engine CHP systems generate electricity by burning fuel (natural gas or biogas) to generate electricity and then use a heat recovery unit to capture heat from the combustion system's exhaust stream. This heat is converted into useful thermal energy, usually in the form of steam or hot water. Gas turbines/engines are ideally suited for large industrial or commercial CHP applications requiring ample amounts of electricity and heat. The steam boiler with steam turbine schematic model is shown in Fig. 2. Steam turbines normally generate electricity as a byproduct of heat (steam) generation, unlike gas turbine and reciprocating engine CHP systems, where heat is a byproduct of power generation. Steam turbine-based CHP systems are typically used in industrial processes, where solid fuels (biomass or coal) or waste products are readily available to fuel the boiler unit [14], [15].

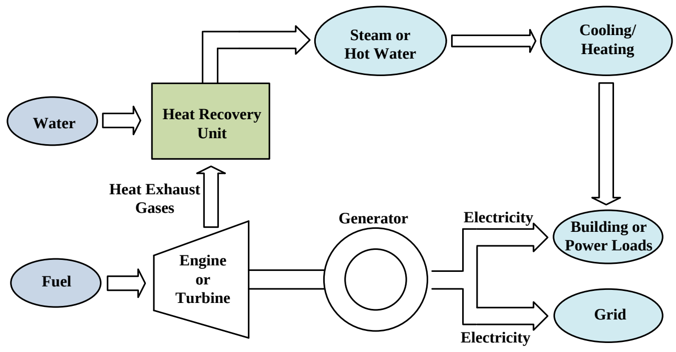

Figure 1. Gas turbine or engine with heat recovery unit model

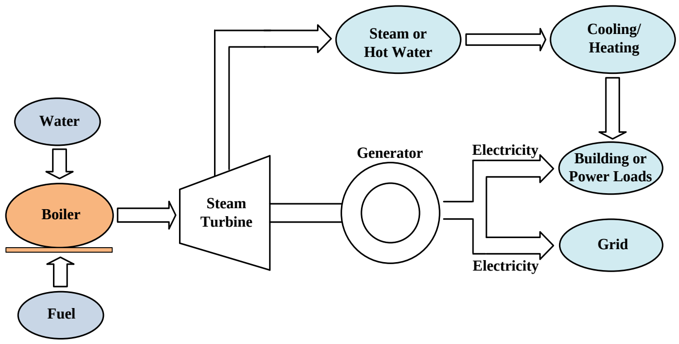

Figure 2. Steam boiler with steam turbine model

III. THE OBJECTIVE FUNCTION AND CONSTRAINTS

In this paper, to determine the CHP unit optimal size two different scenarios are considered. In the first scenario, the electrical and thermal loads are supplied by the CHP unit. In this condition, the optimal capacity of the CHP unit and the boiler is determined. In the second scenario, the electrical and the thermal loads are supplied by the power grid and the auxiliary boiler, respectively. In this condition, the optimal capacity of the auxiliary boiler to minimize the cost is determined. In both scenarios, the optimization process is done by MINLP method. MINLP is a powerful modeling paradigm that has been employed by engineers, economists, and operations researchers to model a wealth of decision-making applications that involve discrete decisions and nonlinearities. Over the past two decades, algorithm developers have been increasingly drawn to MINLP and the challenges encountered at the intersection of combinatorial optimization and nonlinear optimization. This paper performance flowchart is presented in Fig. 3. The presented flowchart is related to the paper operation steps and is not focused on the optimization process. The

MINLP optimization process is considered in each scenario as the constraint values.

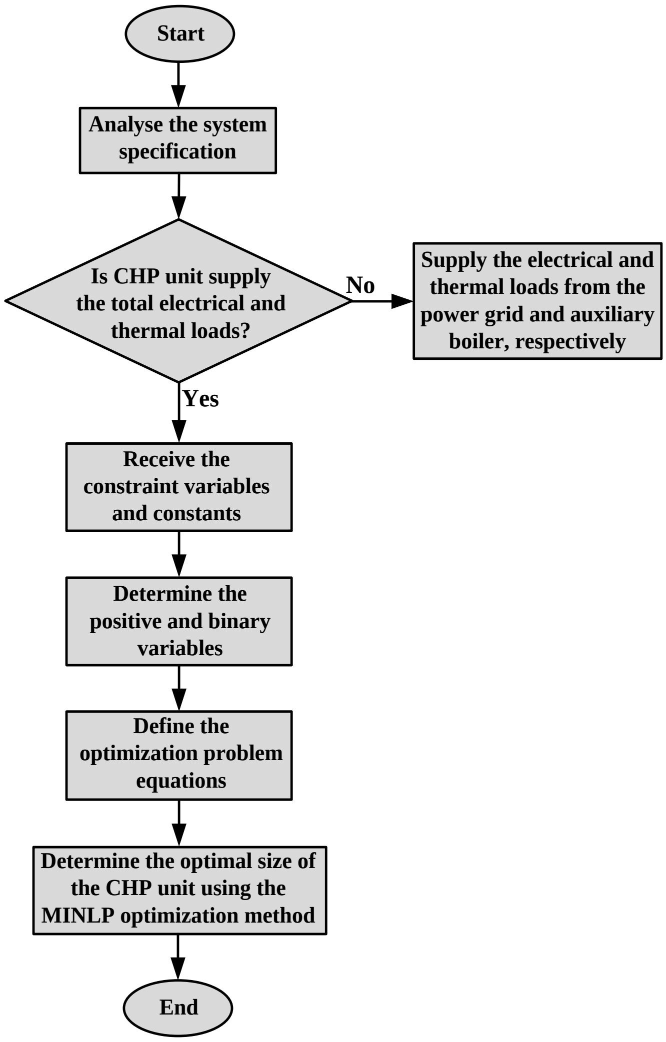

Figure 3. The CHP unit optimization flowchart

A. *Scenario I*

The CHP unit optimal economic cost is determined based on the MINLP optimization method. In this scenario, the annual total electrical and thermal loads supplying amount are minimized based on the expression (1). In the stated equation, the revenue from the CHP generation electrical amount sales is considered as a negative term of the optimization problem [16].

$$min\left\{\begin{array}{l} C_{total} = C_{pur}^{utility} + C_{op}^{CHP} + C_{op}^{boiler} + C_{inv}^{CHP} \\ + C_{inv}^{boiler} + C_{tax} - C_{sell}^{utility} \end{array}\right\} \quad (1)$$

Where: $C_{pur}^{utility}$ is the electrical power grid purchasing cost, C_{op}^{CHP} is the CHP unit operation cost, C_{op}^{boiler} is the boiler operation cost, C_{inv}^{CHP} is the CHP unit annual investment cost, C_{inv}^{boiler} is the auxiliary boiler investment cost, C_{tax} is the emission cost and $C_{sell}^{utility}$ is the benefit cost of power selling to the power grid. The CHP unit and the auxiliary boiler annual cost are determined as (2) and (3):

$$C_{inv}^{CHP} = C^{CHP} \times CAP^{CHP} \times \frac{I}{1 - \frac{I}{(1+I)^{T^{CHP}}}} \quad (2)$$

$$C_{inv}^{boiler} = C^{boiler} \times CAP^{boiler} \times \frac{I}{1 - \frac{I}{(1+I)^{T^{boiler}}}} \quad (3)$$

Where: CAP^{CHP} is the CHP unit capacity, C^{CHP} is the CHP unit purchasing cost for 1 kW, T^{CHP} is the lifetime of CHP unit, I is the discount rate, CAP^{boiler} is the auxiliary boiler capacity, C^{boiler} is the auxiliary boiler purchasing cost for 1kW, T^{boiler} is the auxiliary boiler lifetime. The CHP unit and auxiliary boiler annual cost is calculated by (4) and (5). The annual investment cost is composed as two parts: The fuel cost of the utilities which is depended on the utility gas consumption values and the repair and maintenance cost which is depended on the utilities thermal and electrical power generation amount.

$$C_{op}^{CHP} = \sum_{d=1}^{365}\sum_{h=1}^{24} E_{CHP}(d,h)\left(\begin{array}{l} \frac{P_{gas}}{\alpha \times HR} + C_m^{CHP} + E_{CHP}(d,h) \\ + water\_c \times cost\_water \end{array}\right) \quad (4)$$

$$C_{op}^{boiler} = \sum_{d=1}^{365}\sum_{h=1}^{24} H_{boiler}(d,h)\left(\frac{P_{gas}}{\eta \times HR} + C_m^{boiler}\right) \quad (5)$$

Where: $E_{CHP}(d,h)$ is the CHP unit power generation at the hour h of day d, $H_{boiler}(d,h)$ is the boiler thermal generation at the hour h of day d, $water\_c$ is the CHP unit water consumption for 1 kilowatt hour power generation (liter/ kilowatt hour), c_water is the consumption water cost (Rial/ liter), P_{gas} is the natural gas purchasing cost (Rial/ m^3), α is the CHP unit efficiency, η is the boiler efficiency, HR is the thermal rate, C_m^{CHP} is the CHP unit repair and maintenance cost, C_m^{boiler} is the boiler repair and maintenance cost. One of the disadvantages of the renewable energy sources is uncertainty in power generation. The CHP unit like the other distributed energy resources is not available at 24 hours a day. Due to this, the loads are supplied by the power grid and auxiliary units [17]. The annual purchasing cost of the power grid is calculated by (6) where the (7) and (8) expressions are the defining statements of the (6).

$$C_{pur}^{utility} = \sum_{d=1}^{365}\sum_{h=1}^{24} E_{pur}^{utility}(d,h) \times P_{elec}^{pur}(d,h) \quad (6)$$

$$E_{pur}^{utility}(d,h) = E^{utility}(d,h) \times \frac{\left(sign\left(E^{utility}(d,h)\right) + 1\right)}{2} \quad (7)$$

$$E^{utility}(d,h)=load_{elec}(d,h)+\frac{load_{cooling}(d,h)}{CSOC} - E_{CHP}(d,h) \quad (8)$$

Where: $E_{pur}^{utility}(d,h)$ is the electrical purchasing cost at the hour h of day d, $P_{elec}^{pur}(d,h)$ is the power purchasing cost at the hour h of day d, $E^{utility}(d,h)$ is the CHP unit power generation and the loads power consumption difference value at the hour h of day d. If this sign of the value is positive, it means that the power is received from the power grid and if the sign of the value is negative, it means that the power is injected to the power grid. For this purpose, $sign$ in the (7) is indicates the $E^{utility}(d,h)$ sign. In addition, $load_{elec}(d,h)$ is the load amounts at the hour h of day d, $load_{cooling}(d,h)$ is the cooling system power at the hour h of day d and $CSOC$ is the cooling system operation coefficient. The greenhouse gasses production costs is another term of the objective function that is considered as (9).

$$C_{tax}=\sum_{d=1}^{365}\sum_{h=1}^{24}\left[\begin{array}{l} E_{pur}^{utility}(d,h)\times CI_{ele} + \\ \left(\frac{E_{CHP}(d,h)}{\alpha}+\frac{H_{boiler}(d,h)}{\eta}\times CI_{gas}\right)\end{array}\right]\times CT \quad (9)$$

Where: CI_{ele} is the carbon density of the power grid that is determined based on the fuel type and the efficiency of power plants, CI_{gas} is the carbon density of the natural gas and CT is one kilogram carbon production cost. The revenue of the electricity is calculated as (10) and (11).

$$C_{sell}^{utility}=\sum_{d=1}^{365}\sum_{h=1}^{24}E_{sell}^{utility}(d,h)\times P_{elec}^{sell}(d,h) \quad (10)$$

$$E_{sell}^{utility}(d,h)=E^{utility}(d,h)\times\frac{\left(sign\left(E^{utility}(d,h)\right)-1\right)}{2} \quad (11)$$

Where: $E_{sell}^{utility}(d,h)$ is the power selling to the power grid at the hour h of day d, $P_{elec}^{sell}(d,h)$ is the electricity selling cost to the power grid at the hour h of day d.

B. Constraints of scenario I

The power system generation and power load consumption equivalence: The electrical loads are supplied by the CHP unit and the power grid. When the CHP unit power generation could not supply the loads, the loads are supplied by the power grid. To create a balance between the power generation and the load consumption, the exchange power should be equal. The exchange power between a CHP unit and the power grid is considered as (12).

$$E^{utility}(d,h)+E_{CHP}(d,h)=load_{elec}(d,h) + \frac{load_{cooling}(d,h)}{CSOC} \quad (12)$$

The system thermal generation and consumption equivalence: Similar to the electrical power system generation and power load consumption equivalence, between the thermal generation and consumption should be creating a balance. In this condition, the input and output thermal value to the storage tank should be considered as (13).

$$\frac{E_{CHP}(d,h)}{\alpha}\beta+H_{boiler}(d,h)+f_{out}(d,h)\times H_{out}(d,h) - f_{in}(d,h)\times H_{in}(d,h)=L_{space}(d,h)+L_{water}(d,h) \quad (13)$$

Where: $H_{in}(d,h)$ is the input thermal value to the storage tank, $H_{out}(d,h)$ is the output thermal value to the storage tank, $f_{out}(d,h), f_{in}(d,h)$ are the binary variables, $L_{space}(d,h)$ is the required thermal value for heating the environment and $L_{water}(d,h)$ is the required thermal value for supplying the hot water.

The input and output constraints of the storage tank: The thermal input of the storage tank should be determined in the allowable limit that is determined as (14).

$$f_{out}(d,h)+f_{in}(d,h)\le 1 \quad (14)$$

The CHP unit and boiler power generation capacity: The CHP unit and auxiliary boiler power generation capacity in every moment should be less than the CHP unit capacity. These constraints are presented in (15) and (16).

$$E_{CHP}(d,h)\le CAP^{CHP} \quad (15)$$

$$H_{boiler}(d,h)\le CAP^{boiler} \quad (16)$$

The thermal amount of the storage tank: The thermal of the storage tank is depending on the input and output amounts. The thermal amount of the storage tank at the time h+1 and day d is equal to the thermal amount of the storage tank before the time h in addition to the thermal amount of the storage tank at the time h minus the output thermal amount in the time h. These constraints are presented as (17) and (18).

$$H_{sto}(d,h+1)=H_{sto}(d,h)-f_{out}(d,h)\times H_{out}(d,h) + f_{in}(d,h)\times H_{in}(d,h) \quad if \quad h\ne 24 \quad (17)$$

$$H_{sto}(d+1,h)=H_{sto}(d,h)-f_{out}(d,h)\times H_{out}(d,h) + f_{in}(d,h)\times H_{in}(d,h) \quad if \quad h=24 \;\; and \;\; d\ne 365 \quad (18)$$

Where: $H_{sto}(d,h+1)$ is the thermal amount of the storage tank at the time of h+1 and day d, $H_{in}(d,h)$ is the input thermal amount of the storage tank at time h and day d, $H_{out}(d,h)$ is the output thermal amount of the storage tank at the time h and day d. In addition, the thermal amount of the storage tank in every moment should be less than the storage tank capacity as (19).

$$H_{sto}(d,h+1)\le CAP^{tan} \quad (19)$$

The CHP unit, boiler and storage tank capacity: To determine the optimal capacity of the boiler and storage tank, the total capacity of the boiler and storage tank should be less than a specific maximum value. The mentioned constraints are presented as (20).

$$
\begin{aligned}
&CAP^{tan} \le CAP^{tan}_{max} \\
&CAP^{CHP}_{min} \le CAP^{CHP} \le CAP^{CHP}_{max} \\
&CAP^{boiler} \le CAP^{boiler}_{max}
\end{aligned}
\tag{20}
$$

C. Scenario II

In this scenario, the required thermal and the loads required power amounts are supplied by the boiler and the power grid, respectively. In this condition, the only variable term is the boiler capacity. According to the boiler constraints, the equality of the generated thermal and the consummated loads, the boiler capacity should be equal to the maximum thermal consumption value. For this purpose, some constraints of this scenario are defined as follows where the annual total cost is defined as (21), (22) and (23):

$$C_{total} = C^{utility}_{pur} + C^{boiler}_{run} + C^{boiler}_{inv} + C_{tax} \tag{21}$$

$$C^{utility}_{pur} = \sum_{d=1}^{365}\sum_{h=1}^{24} E^{utility}_{pur}(d,h) \times P^{pur}_{elec}(d,h) \tag{22}$$

$$E^{utility}_{pur}(d,h) = load_{elec}(d,h) + \frac{load_{cooling}(d,h)}{CSOC} \tag{23}$$

In (21), (22) and (23), the terms expression are similar to the scenario I constraint values and variables.

D. Constraints of scenario II

The power system generation and power load consumption equivalence: In this scenario, the power generation and the power load consumption is equal and defined as (24).

$$E^{utility}(d,h) = load_{elec}(d,h) + \frac{load_{cooling}(d,h)}{CSOC} \tag{24}$$

The system thermal generation and consumption equivalence: Similar to the electrical power system generation and power load consumption equivalence, between the thermal generation and consumption should be creating a balance. In this condition, the input and output thermal value to the storage tank should be considered as (25).

$$H_{boiler}(d,h) = L_{space}(d,h) + L_{water}(d,h) \tag{25}$$

The thermal amount of the boiler: The thermal amount of the boiler in every moment should be less than the boiler capacity and is defined as (26) [15].

$$H_{boiler}(d,h) \le CAP^{boiler} \tag{26}$$

In (24), (25) and (26), the terms expression are similar to the scenario I constraint values and variables.

IV. SIMULATION, RESULTS AND DISCUSSIONS

According to the presented constrains of the two scenarios, the case study is a residential building with a CHP unit. One of the goals of installation of the CHP unit in the residential building is using both electrical and heating advantages. Based on this strategy, the maximum benefit is included to the power consumer. For this purpose, in this paper the optimal CHP unit capacity with considering two different scenarios is considered. The CHP unit optimization values are calculated by GAMS software. The residential building electrical, cooling, and heating and the required hot water load profile for the spring season is presented in Fig. 4. The consumption load variations in the other seasons are stated in Table I.

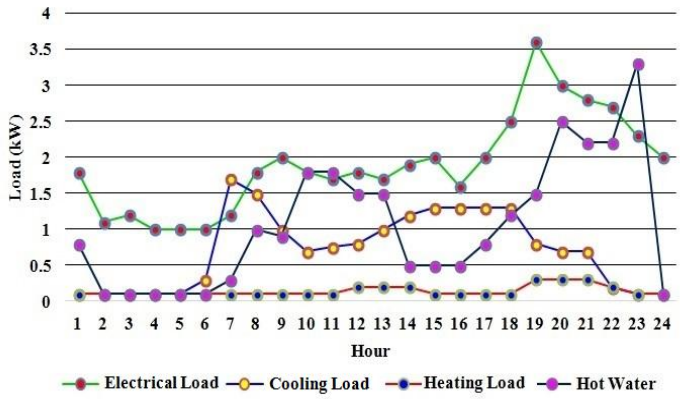

Figure 4. The residential building load consumption amounts in a spring day

TABLE I. THE RESIDENTIAL BUILDING LOAD VARIATIONS IN COMPARISON WITH SPRING SEASON

Season	Electrical load variations	Cooling load variations	Heating load variations	Hot water consumption variations
Summer	+20%	+20%	-20%	-20%
Autumn	0	0	0	0
Winter	-20%	-20%	+20%	+20%

TABLE II. CASE STUDY SPECIFICATION

Case	Quantity	Value
Power Grid	Efficiency (%)	36
	Carbon density (kg/kWh)	0.377
	Energy sales price to customers (Rial/kW)	500
	Energy purchase price of customers (Rial/kW)	1000
Natural Gas	Carbon density (kg/kWh)	0.235
	Price (Rial/m^3)	600
Cooling System	Cooling System Operation Coefficient (CSOC)	4
Boiler	Efficiency (%)	80
	Primary ivestment cost (Rial/kW)	0.17 million
	Life time (year)	20
CHP unit	Electrical efficiency (%)	25
	Thermal efficiency (%)	62
	Primary investment cost (Rial/kW)	20 million
	Life time (year)	20
	Thermal rate (kWh/m^3)	12.8

The case study specification is presented in Table II. The power system, natural gas, cooling system, boiler and the CHP unit are the main data of the case study. In Table II, the cost values are pricing based on Rials that is the official currency of Iran. According to Table II, the system total costs depend on different parameters such as the electrical purchase and sell cost, the natural gas purchase cost, the primary investment cost of CHP unit and ect. To investigate the mentioned parameters effect on the case study system two basic states are presented as follows:

- The electricity purchase price from the power grid effect on total cost: In this case, the introduced total equations and parameters are considered constant and only the purchase price of electricity from the power grid is increased. Due to this, the total cost of the scenario I (presence of CHP unit) than the scenario II (without CHP unit) is decreased. This means that the electricity purchase price from the power grid is increased. For this purpose, presence of CHP unit in the residential building is cost effective. In scenario II, the electricity price variation cause to increase the electricity purchase cost from the power grid. But in scenario I, because of the constant natural gas price, the power generation of the CHP unit is constant, too. In this case, the only electricity purchase cost is related to the CHP unit uncertain generation that should be supplied by the power grid. So, the electricity price of the scenario I is more than scenario II that is indicated in Fig. 5 with the green line. According to Fig. 5, using of the CHP unit is more cost effective whatever the green line value is lower than the other lines.

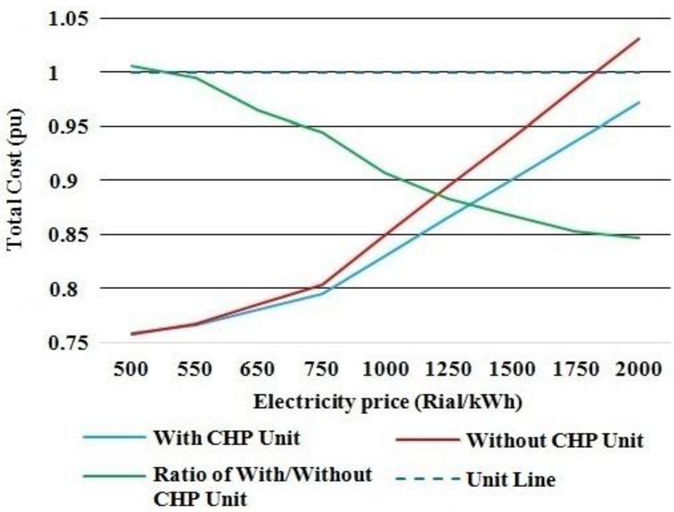

Figure 5. The total cost of thermal and electricity supplying based on the electricity purchase price from the power grid

- The natural gas purchase price effect on total cost: In this case, the natural gas price effect on the CHP unit is investigated. According to Table II, the natural gas price is considered 600 (Rial/m^3). The total parameters of the system are constant and the only variable factor is the natural gas price. The simulation results of this condition are presented in Fig. 6. According to Fig. 5, the total cost of two scenarios is increased due to the natural gas price increase. But, the interesting point is the natural gas price ratio in two scenarios. According to Fig. 5, due to the natural gas price, the green curve with two points of 800 and 8000 (Rial/m^3) is maximized. Using the CHP unit at the price of 600 (Rial/m^3) is cost effective. By increasing the natural gas price from 600 to 800 (Rial/m^3), the ratio of with/without CHP unit is increased. This means that in this condition using the CHP unit is not cost effective. Also, by increasing the natural gas price from 1000 to 8000 (Rial/m^3), the ratio of with/without CHP unit is increased. So, the natural gas price in 8000 (Rial/m^3) is the worst economic state. In contrast, the natural gas price in 600 (Rial/m^3) is the best economic state.

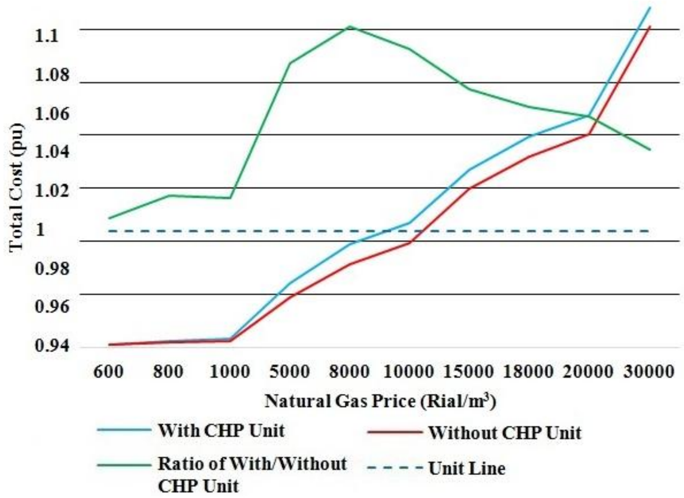

Figure 6. The total cost of thermal and electricity supplying based on the natural gas price

V. CONCLUSION

Installation of the CHP unit in a residential building provides many financial and technical benefits for the power load consumer. The CHP unit electricity generation price is less than the electricity purchase price of the power grid. The CHP technologies have the additional benefit of producing thermal energy that can be used as heat, converted to electricity, or converted to cooling when coupled with an absorption chiller. In addition, in the case of the marketed extra power generation to the power grid, the economic benefit to the consumer is not negligible. The CHP unit presence in the residential building is investigated into the two scenarios. According to the simulation results, the electricity purchase price from the power grid in the state of the CHP unit presence in the residential building is cost effective. In this condition, by increasing the thermal and electrical demand, the difference in CHP unit presence is becoming more visible. In addition, by increasing it, the natural gas demand is increasing, too. In this condition, the presence of the CHP unit at the high natural gas prices is not cost effective. Due to this, the electrical and thermal loads are supplied by the power grid and the auxiliary boiler, respectively. According to the simulation results, the minimum capacity of CHP unit and the maximum capacity of auxiliary boiler for a residential building with considering the storage tank are determined 1 kW and 100 kW, respectively.

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