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An Optimization Model for A Proposed Trigeneration System

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ABSTRACT
The combined cooling, heating, and power (CCHP) systems play an important role in the reduction of carbon emissions and the increase of energy efficiency for businesses and social organizations. Because of its potentials, tri-generation system has become a preference during the last decade. In this paper a hybrid tri-generation system is proposed for a university campus. The system is also important because it uses renewable energy sources as well as non-renewable energy sources. The objective of this paper is to propose an optimization model for this new Tri-generation system.
Keywords: Tri-generation, Optimization Model, Linear Programming.

I.

I. INTRODUCTION

The population growth, urban development and industrialization cause rapid energy demand increases in the Globe. Electricity demand growth rate shows an average 7-8% in the past year and 4-5% of the overall energy demand is expected to continue in the same way in the next 15-20 years. Therefore, targets in the energy sector are supply the energy by considering the economic growth and to support social development efforts, timely, adequate, reliable, considering the environmental impact.

It is necessary to prefer using domestic and renewable sources, while new priorities are given to the development and efficiency in consumption is focused. National energy policies are expected to include increase in fuel flexibility and consideration of environmental impact of the energy generation processes. Cogeneration and trigeneration systems are among the systems that can be used to satisfy all of these objectives.

Cogeneration is the simultaneous generation of usable heat and power (usually electricity) in a single process. Cogeneration uses a variety of fuels and technologies across a wide range of sites, and scheme sizes. The basic elements of a cogeneration plant comprise one or more prime movers (a reciprocating engine, gas turbine, or steam turbine) electrical generators, or other machinery, where the steam or hot water generated in the process is utilized via suitable heat recovery equipment for use either in industrial processes, or in community heating and space heating.

Combined heating and power (CHP) systems and combined cooling, heating and power (CCHP) systems have become the main solutions to improve the energy efficiency and to reduce greenhouse gas (GHG) emissions, as a result of the rapid development of distributed energy supply systems.

Trigeneration is a single production process that combines the production of electrical, thermal and cooling energy starting from a single source of primary energy, namely that supplied by the fuel. Trigeneration (CCHP) can definable the evolution of cogeneration. Trigeneration systems are more efficient in power generation compared to the classical systems. Because trigeneration systems can simultaneously meet the power, heating and cooling needs from the same sources. In the recent years, systems for combined power, heat and cold production, so-called trigeneration systems, have been applied in increasing numbers. Such as universities, hospitals, airports, cold storage facilities, industrial plants especially food industry such as dairy, pasta industry, sugar factories, etc. require a supply of electricity, heat and cold.

The framework is constructed in three steps. In the first step, Linear programming model is developed and this model is used for university campus energy demand satisfaction. All the components of tri-generation system are defined by expert decision and for a year we analyzed which source is used.

II. PROBLEM FORMULATION

Trigeneration (CCHP) can be defined the evolution of cogeneration [1].Trigeneration is a single production process that combines the production of electrical, thermal and cooling energy starting from a single source of primary energy [2]. In the recent years, trigeneration systems, have been applied in increasing numbers [3]. Such as universities, hospitals, airports, cold storage facilities, industrial plants especially food industry such as dairy, pasta industry, sugar factories, etc.

require a supply of electricity, heat and cold [4-5]. Figure 1 shows the schematic presentation of trigeneration systems.

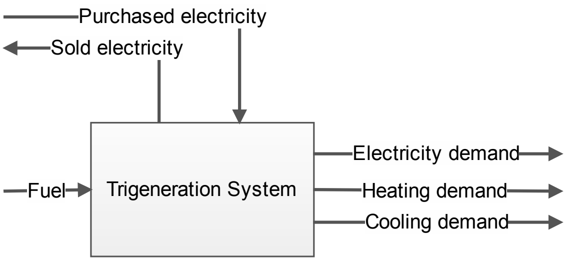

Figure1. Trigeneration System

A typical CCHP system has several different components for meeting the energy demand. Such as gas turbine (or reciprocating engine) for the prime mover, a heat recovery steam generator (HRSG) and an auxiliary boiler to produce heating, absorption or electrical chiller. There are many options for a trigeneration system and because of these options energy management is a very complex issue. In this paper an optimization model is constructed for a university trigeneration system. This model is solved for one year period.

2.1 Proposed Trigeneration System

The proposed tri-generation system consist of a power generation unit(PGU),a waste recovery system, absorption and electrical chiller, thermal collector and photovoltaic systems. In figure 2 this model can be seen.

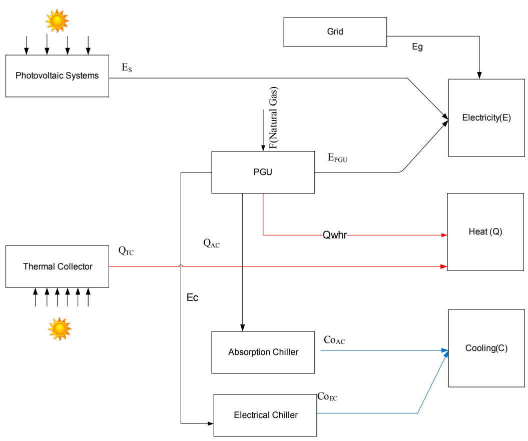

Figure 2. Proposed Tri-generation System

The university's electric demand is planned to met by power generation unit and photovoltaic systems out of high energy demand periods. In this high demand times university can buy the electricity from the grid.

Waste heat recovery system and thermal collector meet the heat demand of the university and the cooling demand met by absorption chiller and electrical chiller.

The capacities of the all components are in Table 1. These capacities have been determined by specialists considering electricity, heat and cooling demands of the university for a year.

Table 1. Capacity of the components

Capacity(kWh)	
K_{PGU}	4000
K_{WHR}	4000
K_{AC}	2800
K_{EC}	3500
$K_{Photovoltaic}$	100
K_{TC}	500

The proposed system is not only uses nonrenewable energy resources but also renewable sources.

III. LITERATURE SURVEY

Trigeneration systems consist of components such as power generator, heat recovery unit, electrical equipment, and absorption or electrical chillers for cooling.All components make the system very complex. Mathematical modeling is often used to make decisions in these types of problems [6].Mathematical modeling techniques have been extensively used for optimal sizing problems of cogeneration and trigeneration systems [7].

When the studies in the literature are examined, the aims can be classified as energy / exergy activity, environmental or economical optimization. In some studies, linear programming, nonlinear programming, mixed integer programming, mixed linear nonlinear integer programming methods have been chosen as the optimization methods. Energy sources can be classified diesel, natural gas, solar energy, wind, geothermal, biomass, and others.

Tuula [8] developed a mixed integer linear programming model aimed at increasing power generation in a small-scale cogeneration plant. The developed model was run for the four different plants and electrical efficiency and power / heat ratio increased when system components were changed. Lozano et al. [9] demonstrated the characteristics of a simple trigeneration system in different modes of operation. The developed linear programming model ensures that the optimum operating mode corresponding to the least variable cost is determined. Rubio et al. [10] have developed a systematic optimization model for the natural gas, solar energy and biomass based trigeneration system. Economic compatibility and greenhouse gas emissions are optimized by nonlinear programming. Buoro et al. [11] used a mixed integer linear programming model to determine the optimal design and operation style of the trigeneration system. The purpose of minimizing total annual cost, they determine the type and size of the power generator, the hourly loads of the system components, the hourly energy balance, and the amount of energy to be purchased or sell the grid. Carvalho et al. [12] has provided a tri-generation system at the hospital to determine optimal system design and strategy throughout the year with economic and environmental criteria. Zhou et al[13-14] have set up two mathematical models to determine the optimal design of the system aimed at minimizing total annual cost. Freschi et al [15] have established a multi-objective model that assesses management costs and environmental impacts. Hu et al.[16] have developed a system that combines biomass and solar energy in their work. They have made an optimization by considering biomass suitability and weather with a mixed integer programming model that uses cost effectively. Buoro et al. [17] have tended to determine the optimum production strategy that meets the energy needs of an industrial location. They have developed an optimization model for a cogeneration plant that uses solar energy to meet energy demands by minimizing costs with a mixed integer liner programming model. Brandoni and Renzi [18] developed a linear programming model to determine the optimum configuration for the micro-cogeneration system using solar energy. Malekshah et al. [19] determined the optimal size of the CHP unit by Mixed Integer Nonlinear Programming (MINLP) optimization method. Omu et al. [20] developed a new formulation of MILP for designing of a solar thermal system.

IV. MATHEMATICAL MODEL

In this section the optimization model for the proposed trigeneration model is explained. This model consists of three different criteria concept.

4.1. Constraints

This model has three different constraint concepts. First one is demand equations. To meet the energy, heating and cooling needs of the university; the amount of energy produced by the system must be equal to the requested amount. Energy and balance constraints establish this balance. In criteria (1) and (2) respectively show the electricity and heat demand balance. The electricity that produced by the grid and photovoltaic systems or purchased from the grid have to equal the electricity demand (1). The same equation must be provided for heat demand (2).

$$E_t^{grid} + E_t^{Photovoltaic} + E_t^{PGU} - E_t^{EC} - E_t^{D} = 0 \quad (1)$$

$$Q_t^{WHR} + Q_t^{TC} - Q_t^{AC} - Q_t^{D} = 0 \quad (2)$$

The cooling required by the university is provided by the absorption and electrical chiller. Therefore, the amount of cooling produced by the trigeneration system must be equal to the demand for an hour. (3) shows this limitation.

$$Co_t^{AC} + Co_t^{EC} - Co_t^{D} = 0 \quad (3)$$

The second constraints consepts is balance and efficiency equations. In constraint (4), the natural gas amount used by the power generation unit multiplied by the electrical efficiency value of this unit is equal to the electricity generated by the power generation unit for one hour.

$$F_t^{ng} * \eta_{PGU} - E_t^{PGU} = 0 \quad (4)$$

Balance and efficiency constraint can be seen for waste heat recovery system in (5)

$$F_t^{ng} * \eta_{WHR} - Q_t^{WHR} - Q_t^{AC} = 0 \quad (5)$$

For any hour in a year, the heat or the electric that absorbed from the PGU, multiplied by the performance coefficient of this component is equal to the cooling produced by this unit .Respectively this balance is established (6) and (7) for absorption and electrical chiller.

$$Q_t^{AC} * Cop_{AC} - Co_t^{AC} = 0 \quad (6)$$

$$E_t^{EC} * Cop_{EC} - Co_t^{EC} = 0 \quad (7)$$

Table 2. Efficiency Factors

Efficiency Factors	
η_{PGU}	0,437
η_{WHR}	0,47
COP_{AC}	0,7
COP_{EC}	5

The efficiency factors and coefficient of performance are in Table2.

The next concept of constraint is capacity constraints. All components in the system cannot perform or produce energy type bigger than their capacities. These constraints (8) to (13) provide capacity constraints respectively for power generation unit, waste heat recovery system, absorption chiller, electrical chiller, photovoltaic systems and thermal collector. All the capacities are taken from Table 1.

$$E_t^{PGU} \le K_{PGU} \quad (8)$$

$$Q_t^{WHR} \le K_{WHR} \quad (9)$$

$$Co_t^{AC} \le K_{AC} \quad (10)$$

$$Co_t^{EC} \le K_{EC} \quad (11)$$

$$E_t^{Photovoltaic} \le K_S \quad (12)$$

$$Q_t^{TC} \le K_{TC} \quad (13)$$

Finally, all variables must be greater than zero.

$$E_t^{Photovoltaic}; E_t^{PGU}; E_t^{Grid}; E_t^{EC}; Q_t^{WHR} \ge 0 \quad (14)$$

$$Q_t^{TC}; Q_t^{AC}; Co_t^{AC}; Co_t^{EC}; F_t^{ng} \ge 0 \quad (15)$$

4.2. Objective Function

The objective function aims minimizing the total cost of the energy production system. On average, the university is admitted to work 23 days every month for a year. Therefore, the model is solved for six thousand six hundred and twenty-four hours according to the following formula.

t= 12 * 23 * 24 = 6624 hours

The total system cost is consisting of present value of the investment cost, yearly maintenance costs and operating costs.

$$\min r*(C_{INV}) + C_{OP} + C_M \quad (16)$$

$$r = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (17)$$

This is the capital recovery factor (17) and it expresses the current value of the investment cost. In this equation *i* is the interest rate % 7, *n* is the 15 years and r is 0, 11329 from this formulation.

$$C_{INV} = C_{INV}^{Photovoltaic} + C_{INV}^{PGU} + C_{INV}^{AC} + C_{INV}^{EC} + C_{INV}^{TC} \quad (18)$$

The total investment cost is the sum of the all system components investment costs. It can be seen (18) and the investment costs of the system components in Table 3.

Table 3. Investment Costs

Investment Costs (Euro/kWh)	
Photovoltaic Systems	1200
Thermal Collector (TC)	200
PGU	450
Absorption Chiller(AC)	125
Electrical Chiller(EC)	100

$$C_{OP} = \sum_{t=1}^{t=6624} F_t^{ng}(p_{ng}) + \sum_{t=1}^{t=6624} E_t^{grid} * (p_{grid}) \quad (19)$$

Yearly operation cost is consist of the natural gas cost and purchased electricity cost that we need in pick demand times of the year (19).Operation costs for the system are in Table 4.

(4.10)

Table 4. Operation Costs

Operation Costs (YTL/kWh) (4.11)	
P_{grid}	0,345
P_{NG} (4.12)	0,0832

(4.13)

$$C_M = \sum_{t=1}^{t=6624} E_t^{Photovoltaic} * \omega_{fotovoltaik} + \sum_{t=1}^{t=6624} E_t^{PGU} * \omega_{PGU} + \sum_{t=1}^{t=6624} CO_t^{AC} * \omega_{AC} + \sum_{t=1}^{t=6624} CO_t^{EC} * \omega_{EC} + \sum_{t=1}^{t=6624} Q_t^{TC} * \omega_{TC} \quad (20)$$

Maintenance cost C_M is the sum of the all system components maintenance costs for one year.

4.3. Optimization Results

In order to illustrate the developed methodology, university trigeneration system is examined. The optimization model for the proposed trigeneration system is solved for a year.

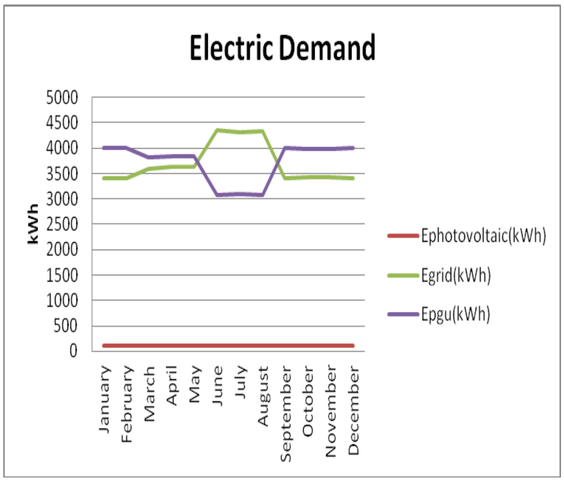

Figure 3.Electric Demand

It has been investigated from which sources the electricity, heat and cooling demand is met for a year. In figure 3 the photovoltaic systems is work for the maximum capacity in all months. In peak demand time June, July and August the system production is not enough for the demand. These months university purchases the electric from the grid in maximum level.

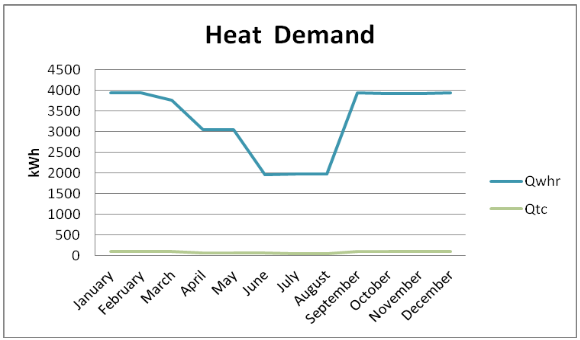

Figure 4. Heat Demand

In figure 4. heat demand that meet from the waste heat recovery is decrease in June,July,August.Thermal collector produce the heat its maximum capacity level.

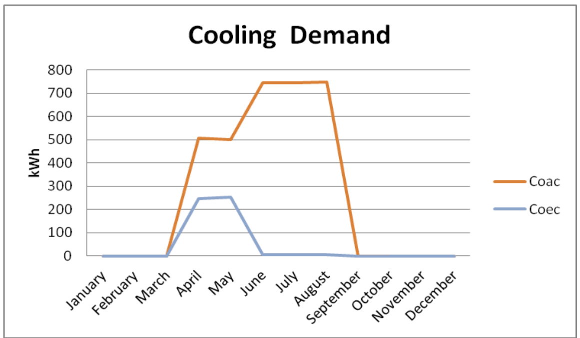

Figure 5. Cooling Demand

In figure 5 cooling demand that meet from the absorption chiller is increase in June,July,August.Electrical chiller is used less compared to absorption chiller.

V. CONCLUSION

The generated tri-generation model can be applied in different public institutions and production systems. In this paper has been applied for university campus. It is aimed to include renewable energy sources in the system while the components of the system are determined. For this reason, photovoltaic systems and thermal collectors have been included in the system in order to utilize solar energy for electricity, heat energy production and indirectly for cooling energy production. While creating a mathematical model of the system, the real life problems as well as the studies in the literature have been guiding.

By resolving the model for 6624 hours, it has been investigated from which source the electricity, heat and cooling demands are met for each time zone.

It is aimed that this work will be a guide for the university campus or public institutions planning to use the tri-generation system. Renewable energy sources are also thought to be beneficial in terms of reducing operating costs.

In future studies the different capacity values of the elements constituting the tri-generation system and the cost comparison for different components can be realized. Thus, the performance of different designs and the effects of the financial can be investigated.

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