Designing a Model to Reduce Energy Consumption Costs in a Local Energy Network

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Abstract:
Reduction of fossil fuel consumption and utilization of renewable energy resources in order to achieve several objectives in relation to the environment, preservation of fossil fuel resources and optimal exploitation of existing energy sources constitute pivotal programs of governments and organizations in all of the developed and most of the developing countries. In this article, energy flow in a local energy grid including the production, producers and consumers of energy is modeled as a mathematical programming pattern to minimize costs and maximize users' satisfaction and with respect to the network limitations for a mathematical programming pattern for modeling. Finally, the optimization model is implemented for the energy grid of a chemical production factory. The results indicate that using this model for the studied factory reduces the level of energy costs by 10 percent.

Keywords:
Energy Network, Mathematical Programming, Optimization

1. Introduction

A local energy network is a set of producers, consumers and storage devices of energy which operates to fulfill the energy requirements of a complex. Management of the production, storage and consumption of energy in a local energy network can minimize the network costs considering limitations of the energy network components and needs during different time periods as well as taking into account the energy users' contentment. Limitation of resources, relatively high costs and environmental concerns in connection with energy consumption are of the important issues of the recent centuries so that majority of governments and organizations allocate a significant budget to this item. Energy consumption optimization is one of the areas much examined particularly in the last century. Lots of studies have been conducted in this regard. The studies have mostly intended to improve the consumption among the final consumers through improved mechanisms and operational systems; however, some research have addressed the way and type of consumption as the variables affecting the consumption rate and investigated reduction of costs through finding the optimum composition of the fuel in the network.

The present paper presents a mathematical modeling for a local energy network and then optimizes the energy consumption rate using the mathematical programming. The energy grid of this analysis consists of 3 general parts, each of which in turn can be divided into various components. The three branches comprise consumers, suppliers and storage sources in a network of energy.
Most of large Iranian industries like iron and steel manufacturing industries (such as Esfahan Mobarakeh Steel, Khuzestan Steel, Esfahan Steel), petrochemical and refinery industries (like all petrochemical plants and refineries located all around the country), power industry (such as combined cycle power plants) have a continuous production; therefore, they need a program to meet diverse requirements of the energy. Since the country's electrical energy grid neither basically is not capable to meet fully the energy consumption needs of these industries in all hours of the day, due to the limitation of household consumption (the peak hours of electricity consumption), or the energy grid can't provide other forms of energy needed for these plants, so these industries have separate and self-sufficient local units energy production. To tackle the optimization of energy consumption in a grid may help reduction of energy supply costs and ultimately optimum production in these industries. Simultaneous concentration on the consumer behavior optimization and energy production in a local network requires a comprehensive model. The model provided in this research studies all components of energy network simultaneously and by the use of a mathematical modeling production and consumption costs of energy are reduced due to the network dynamic demand and the optimum pattern of the consumption is presented according to the needs, requirements and limitations of the network.

2. Review of literature

To investigate further some works done in the field of modeling energy systems are provided in the following.

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3. Mathematical modeling of energy systems

In recent decades, several models have been proposed in the field of energy management systems. These models have been used widely for optimal allocation of energy resources, technologies and services in accordance with the executive goals. For example, Sharma et al (1979) offered a design method for optimizing compressed air storage and power generation systems. Kavrakoglu (1980) has developed a dynamic linear programming model for planning energy systems on a national scale. Smith (1980) has presented a linear model for production planning and energy distribution in New Zealand. From the perspective of the close relationship between economic development and energy consumption in Pakistan, Riaz (1981) has offered an optimal conclusion approach from a common review of a series of generation models for five prominent industries in this country. Badira (1982) expressed application of the linear programming method in energy management with a particular case of deciding between alternative energy sources. In order to facilitate the management of energy-related activities in a free-market economy in a specific area, a model of linear optimization was developed by Schulz and Stehfest (1984). Samouilidis et el have explained an overall assessment of the modeling approaches to electricity and energy systems planning on the basis of two linear optimization models: the model of global energy system and the model of electricity generation as a sub-system. Kahen (1991) has generally reviewed optimization models for managing diverse systems. Tiris et al (1994) developed a linear optimization model and a multi-objective model to coordinate the interaction between energy, economy and environment in Turkey on a long-term base. Craft (2004) has mathematically modeled a grid of energy in a University. Hudson (2005) developed a broad model based on research in operations for co-generation power. Krueger (2006) has presented a comprehensive assessment of energy resources from different perspectives, including fossil fuels, energy sustainability, consumption patterns, heavy demand for energy, environmental impacts, reducing energy resources, renewable energies, nuclear energy, economic aspects, industrial aspects, energy consumption and transport systems. Ostadi et al (2007) have developed a nonlinear programming approach for identifying patterns of efficient energy consumption in a model production factory. Given that energy consumption is a vital quality index in most of Chinese production industries, Xiao et al (2009) have presented an energy optimization model to decline the consumption based on energy forecasting model and genetic algorithm. In another study, Beck et al (2008) developed a modeling-based approach to support optimal design of energy networks by combining the overall optimization and agent-based optimization tools. Their approach was tested and implemented in the form of a case study of regional production management of electricity in South Africa. Bujak (2009) has offered a mathematical model to determine the optimal amount of energy consumption in a series of boilers. The model then was evaluated in a series of steam systems on different scales of boilers made up of tube shell structure with a gas burner.

The model presented in this paper determines optimum level of production and consumption in every segment of the network according to the network restrictions and based on stochastic dynamic demand. The model calculates the optimal level of energy consumption commensurate with the costs of energy consumption in a petrochemical complex. Considering the energy grid as integrated and full coordination of all consumers and producers and storage devices is the main difference between this study and others.

4. Model:

In this section, the mathematical model used to optimize the energy consumption of an energy network is explained and described. The energy network examined in this study is a chemical plant. The main product of the factory is the base of polyester fiber that is produced during a multistep process. After producing, the product is sent to the polyester manufacturing plant. Raw materials of the factory are made from two major substances: methanol and p-xylene.

To better understand the relationship between each of these sections, the general scheme of the plant's departments and relationships between its components are shown in Figure 1.

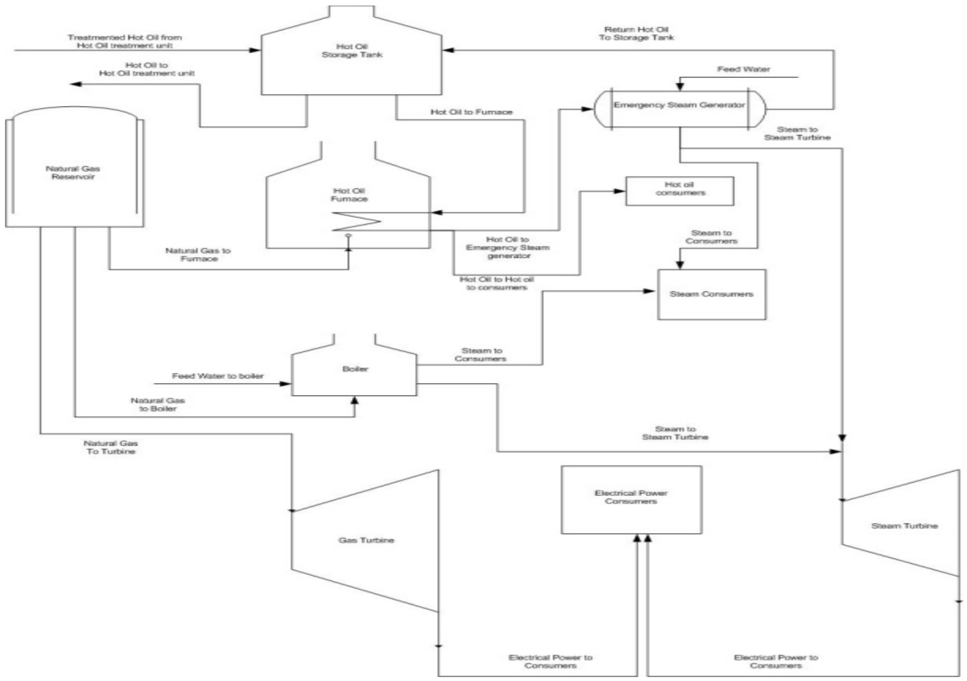

Figure1. General scheme of the factory as a process map

4.1 Mathematical Model

Each component in the studied energy grid is shown by a node in the network model. The network components include energy producers composed of electrical and non-electrical energy producers and energy consumers that in turn divide into two categories of electrical and non-electrical energy consumers and finally the energy storage devices. The current rate is of the main variables in the model. The rate of the current transition from the node m to the node n for any period of $T \in [t, t+1)$ is shown by the nonnegative variablex_{mnt}. Due to the nature of the energy grid, more than one path can't exist between any two nodes. As for any equipment in the network components balance equations are written on the basis of input and output current material, to define the variable introduced based on the quantity type passing each arrow is not necessary. Corresponding to each node, there is an equation in the network model that links the node input to its output. The energy grid of this plant is displayed in Figure 2 as a set of nodes and arrows.

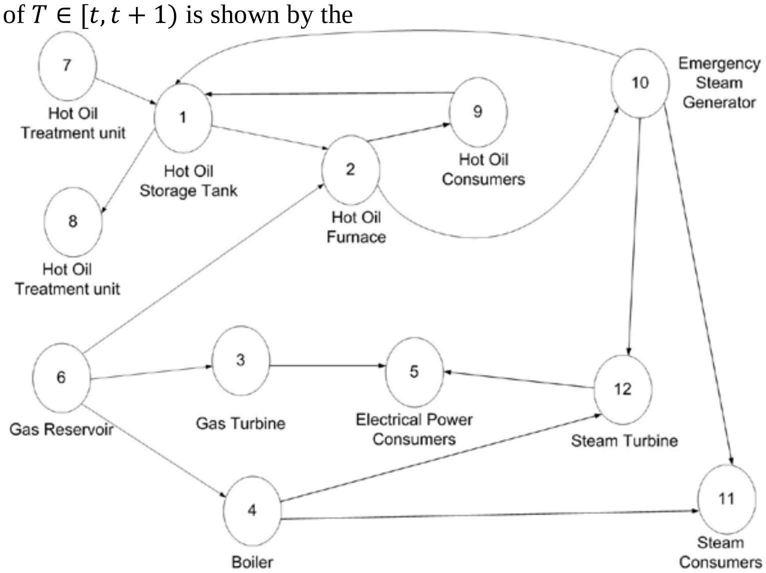

Figure2. The plant map as a set of nodes and arrows

4.2 Model assumptions

Planning horizon is limited.
The demand rate in each period is random and dynamic.
Values of other parameters are absolute and known.
Equipment is available in all periods. (Not considered the possibility of equipment failure.)
The demand rate does not change during the period (changes in demand during the period is considered negligible).

Sets and indices

Sets and indices used in the model are introduced as the below:
CN The set of consumer nodes
ECN The set of electrical energy consumer nodes
$NECN$ *The set of non-electric energy consumer nodes*
EPR *The set of electric power-generation nodes*
$NEPR$ *The set of non-electric power-generation nodes*
TR *The set of transmission nodes*
IS *The set of energy storage nodes inside the network*
OS *The set of energy storage nodes outside the network*
t *The index representing the number of periods in the studied horizon* $t = 1,2,\ldots T$
j *The index of consumption nodes*
i *The index of production nodes*
k *The index of the energy storage devices*
s *The index of scenarios number*

Parameters

Parameters used in the model are as the following:
Mnf *The low limit of the current from the node m to the node n*
Mxf *The upper limit of the current from the node m to the node n*
C_i *The cost of per unit of the fuel consumed in the producer node i*
C_{kt}
c'_{kt}
B *The cost of per unit of the oil refined in toman*
D_{jst} *The amount of energy required to the consumption node j in the scenario s in period t*
A_{jt} *The amount of energy required to the producer j in the production level of zero in period t*
PM_{st} *Production volume in the period t*
p_s *Incidence probability of the scenario s*
α_j *The amount of energy needed to the consumer unit j for producing a unit of the product*
AI_{mn} *Fixed cost of equipment inspection in the event of a sudden increase or decrease in the current rate between two nodes of* m *and* n *from the period* $(t-1)$ *to* t
γ *A number greater than zero*
M *A very large number*

Variables

Model variables that ultimately determine the optimal level of production and consumption in both production and consumption nodes are as follows:
X_{mnst} *The rate of convection currents from the node* m *to the node* n *in period* t
Y_{st} *The oil stored in the tank at time* t *in kilograms*
u_{mst} *0 and 1 variable representing the current established from the node* m *in period* t
W_{mnst} *Non-negative variable representing the rate of current increase from the period* $(t-1)$ *to* t *between two nodes of* m *and* n
W'_{mnst} *Non-negative variable representing the rate of current decrease from the period* $(t-1)$ *to* t *between two nodes of* m *and* n
F_{mnst} *0 and 1 variable representing a current increase more than* γ *between two nodes of* m *and* n *from the period* $(t-1)$ *to* t
Z *Variable representing the objective function value*

Restrictions

- Energy consumer nodes restrictions

$$\sum_{i \in PR} x_{ijt} \geq D_{jt} \quad \forall j \in CN \ , \ t = 1,2,\ldots,T \quad (1)$$

The need for energy in each energy consumer is a linear function of the production rate at the concerned factory. This function is determined as follows:

$$D_{jt} = A_{jt} + PM_t \,.\, \alpha_j \quad \forall j \in CN \ , \ t = 1,2,\ldots,T \quad (2)$$

- Restrictions related to electrical power-generation nodes

$$f\left(\sum_{k \in IS} x_{kit} + \sum_{k \in OS} x_{kit}\right) = \sum_{j \in ECN} x_{ijt} \quad \forall i \in EPR\ , \ t = 1,2,\ldots,T \quad (3)$$

In the above equation f is the function to convert inputs to outputs.

- Restrictions related to producer nodes of non-electric energy output

$$g\left(\sum_{k \in IS} x_{kit} + \sum_{k \in OS} x_{kit}\right) = \sum_{j \in NECN} x_{ijt} \quad \forall i \in NEPR\ , \ t = 1,2,\ldots,T \quad (4)$$

In the above equation g is the function to convert inputs to outputs.

- Restrictions on storage nodes within the network

$$\sum_{j \in NECN} x_{jkt} - \sum_{i \in NEPR} x_{kit} - \sum_{j \in NECN} x_{kjt} = Y_{k(t)} - Y_{k(t-1)} \quad \forall k \in IS\ , \ t = 1,2,\ldots,T \quad (5)$$

Y represents the amount of energy stored in the storage node at a certain time period.

Objective function

Average costs for energy are as follows:

$$Min\ Z = \sum_s p_s \sum_t \left(\sum_{i \in NEPR \cup EPR} \sum_{k \in OS} c_{kt} x_{kist} + \sum_{i \in NEPR} \sum_{k \in IS} \alpha_k\ c'_{kt} x_{kist} \right). \quad (6)$$

Relations (1-6) express the model in a state that sudden changes in network energy flow need not be inspected. With regard to the fact that in the case of applying a major change in the production or consumption rate some equipment such as gas turbine and boiler requires inspection and control, the objective function of the model changes as the below and some restrictions are added to the model.

Since the variation in outgoing power or the energy produced by the manufacturer is the main agent of the inspection cost imposition, INS set is defined as follows:

$$INS = \{(i, j) : i \in (NEPR \cup EPR),\ j \in (NECN \cup ECN)\}$$

$$x_{mnt} - x_{mn(t-1)} = W_{mnt} - W'_{mnt} \qquad \forall (m, n) \in INS,\ t = 1, 2, \ldots, T \qquad (7)$$

$$W_{mnt} - W'_{mnt} = \gamma + (M.F_{mnt}) \qquad \forall (m, n) \in INS,\ t = 1, 2, \ldots, T \qquad (8)$$

The objective function expressing average costs of energy changes as the below:

$$Min\ Z = \sum_s p_s \sum_t \left(\sum_{i \in NEPR \cup EPR} \sum_{k \in OS} c_{kt} x_{kist} + \sum_{i \in NEPR} \sum_{k \in IS} \alpha_k c'_{kt} x_{kist} + \sum \sum_{(m.n) \in INS} F_{mnt}\ AI_{mn} \right) \quad (9)$$

Optimizing the energy network for the chemical plant

The amount of energy consumption in intake nodes of the studied chemical factory grid is a function of two factors of production and the air temperature of the environment. Since there is no limitation of demand for the products of this factory, the production rate is only a function of the amount of raw materials and the amount of available raw materials is a function of time and order delivery deduction. According to the point that random variations in the amount of energy required for each period is considered little (zero) and also the effect of environmental temperature on the level of demand is little compared to the effect of the production rate, the random variable of the energy demand level can be regarded as a discrete random variable. In this study, first, with discretization of the environment temperature variable the distribution function of the demand rate random variable is obtained and then, using this distribution the presented model is implemented.

To estimate the distribution function of the energy demand

- Effect of Temperature

With the increase of air temperature, the electrical power is needed for cooling the equipment and providing the required process conditions. On the other hand, decrease of the air temperature can cause more consumption of steam and thus natural gas to supply the required temperature of the process. Here, in order to simplify estimation of the energy demand and due to the climatic conditions that the studied factory is facing, the condition of ambient temperature is divided into 4 parts. Each part includes a temperature range of 10 degrees. With the increasing number of ranges and reducing the length of each range, the effect of the discretization can be lessened to the desired level. Ranges considered in this study are as follow:

1. (-20) to (-10) °C
2. (-10) to (0) °C
3. (0) to (10) ° C
4. (10) to (20) C

In order to simplify, the possibility of going from one state to another is considered independent of time and only dependent on the previous state.

- The effect of raw materials delivery

Raw materials for the intended chemical plant are of low level petroleum derivatives or in other words, petrochemical products. Petrochemical products are purchased from the stock channel. Deduction of the amount delivered and the delivery time is uncertain. But one of the three following states happens:

- First state: on-time delivery of raw materials. The production continues normally.
- Second state: delayed delivery of row materials. In this case, it is necessary to reduce the factory's production capacity in order that until the arrival of the purchased materials the available raw materials satisfy the factory's need in order not to stop the production. Given that the production capacity is reduced, the need to energy will decrease.
- Third state: the non-delivery of raw materials may occur due to numerous factors such as the drop in the production of petrochemical plants because of their feed reduction or sudden failures causing the sudden stop of the production unit. Since a complete stopping and restarting of the production line costs high and causes serious damages to the equipment, it should be tried not to stop the production line as far as possible. Therefore, in this state, the capacity of the plant is reduced as much as possible.

Different scenarios can be considered as a Markov chain because the transition probability depends only on the current state. In addition, the air temperature and materials delivery are regarded as two independent factors. Composing different scenarios of the effect of the air temperature and the mentioned delivery, 12 different states are made that as a result of each one the amount of the need to energy (energy demand) will be different. All 12 states are expressed and numbered for ease of use.

1. The air temperature from (-20) to (-10) and timely delivery of raw materials

2. The temperature from (-20) to (-10) and the delayed delivery of raw materials
3. The temperature from (-20) to (-10) and non-delivery of raw materials
4. The temperature from (-10 to 0) and timely delivery of raw materials
5. The temperature from (-10 to 0) and delayed delivery of raw materials
6. The temperature from (-10 to 0) and non-delivery of raw materials
7. The temperature from (0) to (10) and timely delivery of raw materials
8. The temperature from (0) to (10) and delayed delivery of raw materials
9. The temperature from (0 to 10) and non-delivery of raw materials
10. The temperature from (10) to (20) and timely delivery of raw materials
11. The temperature from (10) to (20) and delayed delivery of raw materials
12. The temperature from (10) to (20) and non-delivery of raw materials

These states form a Markov chain independent of time. The transition probabilities were calculated as follows:

In this production unit, the consumption energy can be classified in three general groups of electricity power, steam and hot oil. To explain the model we used the following notations:

s The index representing each state of the need for energy

p_s Incidence probability of the state s

DE_s The required electrical energy proportional to the state s

DV_s The required steam proportional to the state s

DHO_s The required hot oil proportional to the state s

x_{ij} The current rate from the node i to the node j

M A large number

For example, the amount of the need for electrical power in the first case is expressed by DE_1 . Each of the above 12 state, if happens, has a certain amount of energy consumption.

Oil storage tank:

The amount of oil in the reservoir is equal to the amount of the oil existing already plus the oil incoming to the reservoir minus the oil outgoing from the tank. The relation (1) expresses the amount of the oil incoming to and outgoing from the reservoir and their relationship with the amount of the oil stored in the tank. Oil flow rate is measured in kilograms per hour and the amount of the oil stored inside the oil tank in kilograms.

X71t + X91t + X101t – X18t – X12t = Y(t+1) – Y(t) (1)

The oil returned from the refinement unit is represented by X71t and the sent oil is represented by X18t .Due to continuous prevention of the increase or decrease of the oil stored in the tank, the amount of the oil sent to the refining unit is equal to the amount of the oil received from there. The relations 2, 3, 4 express the relationship between input and out flows from the oil storage reservoir and the relation 5 indicates the limitation of the oil stored in the reservoir at any moment in time.

18t = 0.25(X12t) 2)
71t = X18t 3)
91t + X10-1t = X12t 4)
0000 $\leq$ Yt $\leq$ 90000 5)

Hot oil furnace:

As indicated in Figure 1, after leaving the tank, the oil comes to the furnace to increase the temperature. Oil furnace has two input flows: the input flow from the oil storage tank and the natural gas flow to the furnace. The amount of the oil incoming to the furnace is equal to the amount of the oil outgoing from it. With increasing the oil entering the furnace, the gas injected into the furnace increases, too; as a result, the output hot oil temperature remains constant. There is a linear relationship between the amount of the oil outgoing from the furnace and the amount of the natural gas incoming to it. Inlet gas flow rate is expressed in cubic meters per hour and the oil flow rate in kilograms per hour. The equation 6 shows the relationship between the flow incoming to the hot oil furnace in terms of gas and the outgoing flow in terms of hot oil. The equation 7 expresses the relationship between input and output oil hot flows from the furnace and relations 8 and 9 show the limitation of the amount of the gas and oil incoming to the furnace.

X29t + X2-10t) = 1.7 (X62t) + 600(u2t) 6)
29t + X2-10t = X12t 7)
In $_{62}$ $\leq$ X62t $\leq$ **Mx** $_{62}$ 8)
In $_{12}$ $\leq$ X12t $\leq$ **Mx** $_{12}$ 9)

Gas turbine:

The input natural gas after combustion and electricity generation is used for preheating the water incoming to the boiler. Like the furnace oil, a linear relationship is established between the amount of gas entering the gas turbine (in cubic meters per hour) and the amount of electricity produced (in MW). Equation 10 represents the relationship between the gas incoming the gas turbine and the amount of the electricity produced by the turbine. Like the previous node, the relations 11 and 12 express the limitation of the amount of gas entering the gas turbine and the amount of the electricity generated by it.

X35t = 0.005(X63t) – 7(u3t) (10)
$Mn_{63} \leq$ X63t $\leq Mx_{63}$ (12)
$Mn_{35} \leq$ X35t $\leq Mx_{35}$ (13)

Boiler:

The water incoming to the boiler turns to a superhot steam. The amount of the water entering the boiler is equal to the amount of the steam outgoing from the boiler in tonnes per hour. Therefore, the equilibrium equation is based on the steam outgoing from the boiler. Equation 13 represents the relationship between this relation and equations 14 and 15 express the limitation degree of the gas incoming the boiler and the steam outgoing from it.
(X4-12t + X4-11t)= 0.007(X64t) – 1(u4t) (13)
$Mn_{64} \leq$ X64t $\leq Mx_{64}$ (14)
$Mn_{4(11+12)} \leq$ (X4-11t + X4-12t) $\leq Mx_{4(11+12)}$ (15)

Consumers of electrical power:

The amount of the need for electric power in the factory is expressed by Equation 16. This relationship suggests that the total capacity of electricity generation by electrical manufacturers should be more than the amount required to electricity consumers. The need for electrical power is expressed in megawatts.

$$X_{35t} + X_{12\text{-}5t} \geq D_5 \quad (16)$$

Hot oil consumers:

this unit includes heat exchangers requiring high levels of temperature. The equation 17 represents the amount of the need for the hot oil in the factory. The minimum circulating hot oil should be more than the amount of the need for the hot oil. Since the oil utilized in the factory is a valuable chemical material and its waste results in environmental pollution, the oil circulation cycle is a closed cycle and its value is always constant. This closed cycle is expressed by the relation 18.
X29t $\geq D_9$ (17)
X29t = X91t (18)

Steam users:

Equation 19 expresses the amount of the need for the steam in the plant. The steam produced in the factory should not exceed the amount needed to the steam among its consumers. The amount of the steam required at the plant is expressed in tonnes per hour.
X4-11t + X10-11t $\geq D_{11}$ (19)

Emergency steam generation unit:

In order to provide the required steam in particular and emergency circumstances as well as to help supplying the steam required in the plant, special heat exchangers are involved. The hot oil in kilograms per hour and the superhot steam in tonnes per hour are the input and output of these transducers, respectively. There is a linear relationship between the hot oil incoming to transducers and the outgoing steam (Equation 20). Equations 21 and 22 express the limitation of the stem flow outgoing from the emergency steam generation unit. The relation 23 show the minimum hot oil entering this unit and the relation 24 represents equality of the input and output oil of the unit.
(X10-11t + X10-12t) = 0.02(X2-10t) – 15(u10t) (20)
$Mn_{10-12} \leq$ X10-12t $\leq Mx_{10-12}$ (21)
$Mn_{10-11} \leq$ X10-11t $\leq Mx_{10-11}$ (22)
$Mn_{2-10} \leq$ X2-10t (23)
X2-10t = X10-1t (24)

Steam turbines:

As the gas turbine, steam turbine is used to produce electrical power. Steam turbine input is the steam in tons per hour and its output is the electric power in megawatts. Equation 25 expresses the relationship between the steam incoming to the steam turbine and electric power outgoing from it. The relation 26 indicates the required steam for the turbine and Equation 27 represents the limitation of the electricity amount generated by the steam turbine.
X12-5t = 0.5(X4-12t + X10-12t) - 0.5(u12t) (25)
X10-12t + X4-12t $\geq D_{12}$ (26)
$Mn_{12-5} \leq$ X12-5t $\leq Mx_{12-5}$ (27)
This study was conducted to minimize energy consumption costs in the factory. Costs are divided into two categories:
1. The cost of fuel
2. The cost of oil treatment and refinement
As mentioned earlier, C represents the cost per unit of gas consumption in cubic meter and B represents the cost for per unit of refined oil in kg, both are calculated in toman. Currently, gas consumption costs 70 toman per cubic meter and the oil for refinement costs140 toman per kg.
Costs are considered fixed and linear in this model.

$$Min\ Z = \sum_{s=1}^{12} \sum_{t=1}^{T} p_s .[B .X18ts + C .(X62ts + X63ts + X64ts)] \quad (28)$$

Findings

The required parameters for this problem are displayed in Tables 1, 2 and 3. The model offered for the energy network of the studied chemical factory is a mixed linear programming model. The model is solved via the software Lingo8 and the final results are shown in Table 2.

Table1. The amount of the required energy based on the 12 states

DE1 = 11	DV1 = 19	DHO1 = 2800
DE2= 11	DV2 = 19	DHO2 = 2800
DE3= 11	DV3 = 19	DHO3 = 2600
DE4= 12	DV4 = 19	DHO4 = 2600
DE5= 12	DV5 = 18	DHO5 = 2500
DE6= 12	DV6 = 17	DHO6 = 2500

DE7= 13	DV7 = 17	DHO7 = 2400
DE8= 13	DV8 = 16	DHO8 = 2400
DE9= 13	DV9 = 15	DHO9 = 2400
DE10= 14	DV10 = 14	DHO10 = 2300
DE11= 14	DV11 = 14	DHO11 = 2300
DE12= 14	DV12 = 14	DHO12 = 2300

Table2. Values of the parameters required for solving the model

Energy flow	Minimum limit (Mn)	Maximum limit (Mx)
X62	1000	2000
X12	2300	4000
X63	3000	4000
X35	8	13
X64	2000	3000
X4(11+12)	13	20
X10-11	3	5
X10-12	2	4
X12-5	3	6

Using transition probability matrix, likelihood of the each of the 12 state will be obtained.

Table3. Probabilities related to each of the 12 state of the production scenarios

I	1	2	3	4	5	6	7	8	9	10	11	12
p_i	0.094529	0.188169	0.101864	0.125640	0.062348	0.124109	0.067186	0.082868	0.028399	0.056532	0.030603	0.037746

Gas consumption costs 70 toman per cubic meter and the oil for refinement costs140 toman per kg.

$x_{12}(s) = \left\{\begin{matrix} 4000, 4000, 3800, 3800, 3700, 3700, 3600, 3600, \\ 3600, 3500, 3500, 3500 \end{matrix}\right\}$

$x_{18}(s) = \{1000,\ 1000,\ 950,\ 950,\ 925,\ 925,\ 900,\ 900,\ 900,\ 875,\ 875,\ 875\}$

$x_{71}(s) = \{1000,\ 1000,\ 950,\ 950,\ 925,\ 925,\ 900,\ 900,\ 900,\ 875,\ 875,\ 875\}$

$x_{91}(s) = \left\{\begin{matrix} 2800, 2800, 2600, 2600, 2500, 2500, 2400, 2400, \\ 2400, 2300, 2300, 2300 \end{matrix}\right\}$

$x_{10-1}(s) = \{1200\}$

$x_{2-10}(s) = \{1200\}$

$x_{29}(s) = \left\{\begin{matrix} 2800, 2800, 2600, 2600, 2500, 2500, 2400, 2400, \\ 2400, 2300, 2300, 2300 \end{matrix}\right\}$

$x_{35}(s) = \{8,\ 8,\ 8,\ 8,\ 8,\ 8,\ 8.5,\ 8.5,\ 8.5,\ 9.5,\ 9.5,\ 9.5\}$

$x_{4-12}(s) = \{6\}$

$x_{4-11}(s) = \{14,\ 14,\ 14,\ 14,\ 13,\ 12,\ 12,\ 11,\ 10,\ 9,\ 9,\ 9\}$

$x_{62}(s) = \left\{\begin{matrix} 2000, 2000, 1882, 1882, 1823, 1823, 1764, 1764, \\ 1764, 1705, 1705, 1705 \end{matrix}\right\}$

$x_{63}(s) = \left\{\begin{matrix} 3000, 3000, 3000, 3000, 3000, 3000, 3100, 3100, \\ 3100, 3300, 3300,\ 3300 \end{matrix}\right\}$

$x_{64}(s) = \left\{\begin{matrix} 3000, 3000, 3000, 3000, 2857, 2714, 2714, 2571, \\ 2428, 2285, 2285, 2285 \end{matrix}\right\}$

$x_{10-11}(s) = \{5\}$

$x_{10-12}(s) = \{4\}$

$x_{12-5}(s) = \{4.5\}$

$Y(t) = \{38800,\ 37600,\ 36400,\ 35200\}$

Regarding the amount of the oil stored in the tank, it is necessary to note that the amount for every 12 state has been constant in a specific period, but it is different for each period compared to the previous one. For this reason, Y(t) is used to display the amount of the oil inside the tank at each period. The value of the objective function that is in fact the energy consumption price is equal to 2689462 toman, taking into account that gas consumption costs 70 tomans per cubic meter and the oil for refinement costs140 tomans per kg.

Sensitivity analysis of the model answers

In order to analyze the answers, like the previous section, we change the amount of the required energy and observe the model reaction in the calculation of the variables values.

Changing the amount of the need for the electric energy:

If the need for electrical energy increases, the rate of its production by turbine will also increase spontaneously and consequently a higher amount of gas should be sent to the turbine. Thus, the value of the objective function will be 2687950 toman. This value is normal according to the increase in the amount of the required gas consumption.

Regarding changes of the other parameters of the problem, the obtained solutions confirm validity of the model.

Indeed, the results reveal that the model reflexes a rational reaction proportional to every variation. In order to avoid prolongation of the word, we simply express the results obtained.

Due to the increase of the required electrical energy, the hot oil sent to the emergency vaporizer unit is declined and instead the oil sent to the hot oil consumers is supplied to the new amount. To supply the electric power needed for the factory, since the steam generated by the emergency vaporizer and consequently the steam sent to the steam turbine by the emergency vaporizer is reduced, the steam sent to the steam turbine by the boiler increases. As the steam supplied by the emergency vaporizer for the steam consumers is declined, this lack is compensated through the increase of sending the steam from the boiler to the steam users. The gas price change doesn't impact on the consumption rate of the each type of energy, including steam, electricity and hot oil. This is because the natural gas is the only source of fuel energy in the factory and can't be replaced. With the rising cost of oil refining, the oil sent for treatment drops and thus the oil sent to the furnace is also reduced. Due to the reduction of the oil sent to the furnace, the gas consumed in the furnace will be reduced, too.

5. Conclusion

In this study, using mathematical programming, energy consumption costs are minimized in an energy network. The presented mathematical model is a programming model with linear functions. Stochastic demand and scenarios were considered as discrete. Accidental damages are not considered in this model. Taking into account this research data, energy costs decreased by 10% .

References

[1] Badiru, A. B. and P. S. Pulat,(1995). “Comprehensive Project Management: Integrating Optimization Models, Management Principles, and Computers”. Cliffs, NJ: Prentice-Hall.

[2] Beck, J.; Kempener, R.; Cohen, B.; Petrie, J.(2008) “A complex systems approach to planning, Optimization and decision making for energy networks”. Energy Policy,Vol 36:2795-2805.

[3] Bujak, J. (2009).“Optimal control of energy losses in multi-boiler steam systems”. Energy ,Vol 34:1260-1270.

[4] Craft, D.(2004),"Local energy management through mathematical modeling and optimization",Phd thesis, Massachusetts, Massachusetts Institute of Technology, Department of Operations Research.

[5] Himmelblau,D.M.(1989),"Basic principles and calculations in chemical engineering",NJ: Prentice Hall.

[6] Hudson, C.R, (2005). “Adaptive Nonlinear Optimization Methodology for Installed Capacity Decisions in Distributed Energy/Cooling Heat and Power Applications”. Master thesis, Knoxville, University of Tennessee .

[7] Kavrakoğlu, I.(1980). “Decision analysis in the energy sector”, Appl. Math. Model. Vol 4:456-462.

[8] Kahane, A.(1991). “New perspectives for energy efficiency and system optimization”. Energy Policy ,Vol 19:199-201.

[9] Kruger, P.(2006).” Alternative Energy Resources: The Quest for Sustainable Energy”. New York ,John Wiley & Sons Inc.

[10] Ostadi, B.Moazzami, D. Rezaie, K.(2007). “A non-linear programming model for optimization of the electrical energy consumption in typical factory”. Appl. Math. Comput., Vol 187:944-950.

[11] Riaz, T.(1981) “Energy policy formulation for Pakistan An optimization approach”. Energy Econ. Vol 3:191-197.

[12] Samouilidis, J.E.; Psarras, J.; Papaconstantinou, D.V.(1984)” Electricity planning vs. energy planning: A modeling approach”. Omega ,Vol 12:341-346.

[13] Schulz, V.; Stehfest, H.(1984)” Regional energy supply optimization with multiple objectives”. Eur. J. Oper. Res. Vol 17:302–312.

[14] Sharma, A.; Chiu, H.H.; Ahrens, F.W.; Ahluwalia, R.K.; Ragsdell, K.M.(1979) “Design of optimum compressed air energy-storage systems”. Energy,Vol 4:201–216.

[15] Smith, B.R.(1980).“Modeling New Zealand’s energy system”. Eur. J. Oper. Res,Vol 4: 173–184.

[16] Tiris, M.; Atagunduz,G.; Dincer, I.(1994) “Energy, economy and environment modeling: Applications for Turkey”. Energy,Vol 19:1005–1009.

[17] Xiao, D.; Pan, X.L.; Yuan, Y.; Mao, Z.Z.; Wang, F.L.(2009) “Modeling and optimization for piercing energy consumption”. Int. J. Iron Steel Res. Vol 16: 40–44.