Long Run Analysis of Natural Gas and Electricity Export via System Dynamics

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Analyzing different scenarios for exporting natural gas and electricity is the main subject in this paper. The place of Iran as the owner of second largest reserves of natural gas in the world and exporting it to different countries increase the notability of this study. On the other hand, in the restructured power system, the role of natural gas is growing in the electricity generation. This paper analyzes exporting natural gas and electricity via three scenarios, including 1) direct transfer of natural gas at real time and forward prices, 2) exporting the electricity, considering fuel payment and without fuel cost and 3) conversion of natural gas into electricity and transferring via the power market. Markove Chain Monte Carlo (MCMC) is applied for modelling the natural gas price during the studied time horizon. In this regard, the scenarios are analyzed via system dynamics. Published data by energy information administration (EIA) about natural gas price, the costs of generation by different technologies and plans for exporting the natural gas and electricity are used in this study. The results show that exporting the natural gas or the electricity in suitable forward price are the most profitable scenarios. Transferring the natural gas at real time price is profitable, while exporting the electricity at the real time price of power market can not meet the economic goals, even by expanding the renewable resources.

keywords: *Natural Gas; Electricity; Power Market; System Dynamics.*

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NOMENCLATURE

j firm number

i load section characteristic

t time

y year

rr rate of return

Γ_{NG} natural gas price

Π total profit

Φ energy amount

Ω energy price

Υ energy transfer investment

HR heat rate

OM operation and maintenance cost

CO pollution cost

I investment cost

MC marginal cost

F fuel price

D market demand

δ demand section duration

L demand section amount

g demand growth rate

E_d exported demand

GC total generation cost

CP generation capacity

PI profitability index

m investment multiplier

α slope of m

β location of m

IR investment rate

$\dot{L}$ demand variation rate

$\dot{RE}$ firm retirement rate

$Res.Rat$ reserve ratio

TCP total generation capacity

UC under construction capacity

CT construction time

CN constructed capacity

LT life time

V_w wind speed

γ weibull shape parameter

η weibull scale parameter

V_r rated wind speed

V_{ci} cut in wind speed

V_{co} cut out wind speed

1. INTRODUCTION

As a clean energy resource, natural gas is increasingly consumed in different fields such as electricity generation despite its price uncertainty. Iran is the second owner of the natural gas resources in the world after Russia ; it can be revealed as an energy hub in the MIDDLE East by exchanging the natural gas and electricity with other countries.

Exporting the natural gas directly or its conversion into the electricity is one of the unclear points in a long run decision making for export. By restructuring of the power system in Iran, the role of investors in capacity expansion was increased; they consider their own profit rather than cultural and political causes as the only motivation for expanding the capacity. To this end, long run analysis of exporting the electricity from this market to the other countries instead of the natural gas is the other challenge for the investors.

System dynamics is a conceptual tool for long run analysis of social and economic systems; it applies control theories for studying the long run effect of different decisions and policies by recognizing a system, its effective parameters and their mutual relation. The technique is helpful in long run analysis of different decisions, some of which either are not applicable in real world or cause heavy damage to the society.

Scholars have sought long run behavior of different systems via the system dynamics, in which the expansion of generation capacity is one of them. In [1], Shaojie *et.al* have modeled effective factors in launching the capacity via the system dynamics. They have considered effective factors such as advertising, market, transport system, storing and *etc.*, some of which are not applicable in the power market. Based on adjusting the launch scale, they have classified strategies into two categories, namely static strategy for the short term and dynamic strategy for the long term.

Some theorists have employed the system dynamics for analyzing different subjects in the restructured power markets. Olsina *et.al* in [2] have modeled a free power market by the system dynamics for gaining significant insight into the long run behavior. They have focused on replicating the structure of power markets and the logic of relationships among system components in order to derive its dynamical response, instead of the optimization models. Capacity payment is another topic that is studied by the system dynamics by the researchers. In [3] the capacity payment is analyzed in system dynamics. Moreover, the probability density function of the demand to the market is suggested. The authors in [4] have analyzed different policies for capacity payment in Iran electricity market. Reference [5] analyzes different incentives for capacity expansion in Korean electricity market using system dynamics. In [6] the important events in Swiss electricity market such as the retirement of nuclear power plants and integrating with the European union is analyzed by the system dynamics.

The mutual relation between tradable green certificate (TGC) and the power market is analyzed in [7], [8]. They reconnoitered different factors in each market, their relationship and the reciprocal relations among the markets. Different strategies for the players in the TGC market is considered and the best one for achieving the objective of the players is extracted.

Different patterns of the power plant construction was analyzed through the system dynamics by Ford in [9] - [11]. As a common pattern in industries, he has concluded that timely construction can lead to the economic goals of the investors, while the lag of construction behind the demand growth leads to a boom in the price during the peak load and a dramatic drop after completing the power plant. Authors in Ref. [11] have introduced construction time as the cause of fluctuation in the power market during the over and under supply periods; variations are dampened by a constant capacity payment besides the energy premium.

Marzooni and Hoseini in [12] have proposed a dynamics system model for analyzing the long run behavior of investment in generation capacity. They defined an index for the market power to show the level of competition in the market. The effect of CO_2 emission regulations on the long run behavior of capacity expansion in Australia is analyzed by Chattopadhyay in [13]. He has focused on the coal-fired technology and compared the effectiveness of pursuing the renewable expansion policies instead of the emission limiting rules in this paper. Eager has modeled the Britain market as control loop for analyzing the long run effect of reliability policies in an energy-only market in [14]. Gary and larsen have developed a feedback model for analyzing the strategic policies in out-of-equilibrium markets in [15]. Stability of market in autonomous power networks is analyzed by Wittebol *et.al* in [16].

The influence of the reliability policy on the price increment in the power market has been analyzed in [17]; in this paper a dynamics system model is developed for long run analysis of the capacity expansion in the restructured power market under different reliability policies. The results in this article show that continuous policies can decrease the magnitude of the price increment in the energy only market.

Besides the system dynamics and market restructure, natural gas export and its relevance to the electricity are studied by researchers. Authors in [18] studied the effect of natural gas export from the U.S. on the economy via Market Allocation Macro model. The results show that export of natural gas has a small effect on the economic parameters in the U.S. and more export increases the price of electricity. Moreover, the export affects the transport and its costs in the U.S.. Reference [19] has reviewed different ways for exporting the natural gas; it hasn't represented analytical results for comparing the methodes. The long-term (up to 2050) scenarios of Russian natural gas exports to Europe and Asia was explored in [20]; the author uses the MIT Emissions Prediction and Policy Analysis (EPPA) model for analysis. The results has represented some predictions about natural gas export from Russia to Europe and Asia. Reference [21] analyzes the Nash equilibrium for trilateral game in Iran's gas transit from Turkey and Iraq in 2030 perspective under two cooperative and noncooperative strategies. The authors concluded that if the three countries participate in a trilateral cooperation the Nash equilibrium will take place and their profits will be maximized.

By comparing the investment cost of combined cycle gas turbine (CCGT) with coal-fired, Ford has described the importance of natural gas based technologies in a deregulated power system in [22]. The analysis of different options for investment in a restructured power market was addressed by Zambujal in [23]; the author has suggested the CCGT as a suitable choice for investing in the new structure using Monte-Carlo simulations. Reference [24] has described the role of natural gas in the future of the electricity generation in Spain and has introduced the CCGT as tie point between the power and gas systems. In [25] an empirical long run simulation model for the European electricity and natural gas market was described; the authors modeled the markets by dynamic linear programming and analyzed the interrelationship between power generation and gas market.

Abadie *et.al* in [26] have evaluated the energy investment related to natural gas using the real options method; they have evaluated natural gas combined cycle power plant and a liquefied natural facility and several investment options in a realistic setting. The natural gas price which is an uncertain parameter is estimated is estimated by Inhomogeneous Geometric Brownian Motion (IGBM) in this paper. The results of the research show that risks are in the short term and the regulatory changes may have a deeper effect in long term result of an investment.

Reference [27] has focused on the stochastic models for the spot market of natural gas by including the oil price as an exogenous factor. The authors have shown that associating the natural gas price to the oil price explains its behavior better than other factors such as temperature do. The uncertainty of natural gas price together with the upstream emissions and climate policy is modeled in a two-stage stochastic programming approach in [28]. The results show that climate policies are stronger drivers of greenhouse gas emission trajectories than new natural gas are. Anderea *et.al* in [29] have focused on the pricing of gas swing options by Monte Carlo method in a free natural gas market. They have computed the price of an arbitrarily chosen gas swing option in accordance with the concept of risk-neutral expectations.

Published books by different scholars are helpful in long run analysis of different events in the power market. Sterman in [30] has described the concepts of system dynamics and its implementation in different systems. Reference [31] is helpful in understanding the concept of power market structure and its design. Stoft has focused on the basic economics and engineering of the power markets such as price spikes, revenue of the firms and reliability. Many advances in random number generation and Monte Carlo methods was incorporated in [32]; Gentle has discussed methods for generation of sequences of pseudorandom numbers in the book. Different technologies for extracting the energy from the wind, some techniques for modeling the wind generation and useful data about the operation and maintenance of the wind systems are presented in [33]. Moreover, the published reports by established institutes give useful information about the cost of power generation, life data of different technologies and forecasts of natural gas price [35], [36].

This paper applies the system dynamics to analyze exporting the natural gas from Iran to Turkey as a case study. In this regard, different scenarios including direct export of natural gas, converting into the electricity and exporting via the power market is considered; sale at forward and real time prices and the expansion of renewable resources are different studied situations. The real time price of natural gas is modeled by MCMC with considering the rate of return. Different technologies such as coal-fired, CCGT, gas turbine (GT) and wind participate in the market at the third scenario. The research analyzes some parameters such as present profit, profitability index and power market condition. The results are explanatory that exporting the natural gas and electricity at a suitable forward price not only compensates the costs but also generate profit, while exporting via the market decreases the profit and cannot make up for investment in transmission lines. Without affecting on exportation, expansion of renewable technologies decreases the total fuel cost. The rest of the paper is organized as follows. Section 2 describes the developed model; it describes the process of estimating the real time price of natural gas, direct export of natural gas, converting into the electricity and exporting via the power market. Section D models different parts of a restructured power market for analyzing the capacity expansion via the system dynamics. The results are represented and analyzed in section 3 for different scenarios and are summarized in section 4 as conclusion. Appendix A represents the detail of MCMC algorithm for estimating the natural gas price.

2. MODEL DESCRIPTION

A model is developed for analyzing the long run behavior of exporting the natural gas by Iran using the concept of system dynamics. Three different scenarios, namely direct export of natural gas, converting into electricity and export via the power market are considered in the paper. The real time price of natural gas is estimated by MCMC method. The first and second scenarios analyze the sale of natural gas and electricity via a forward contract and the third scenario studies the effect of renewable expansion in the market. The export of natural gas to Turkey is chosen as a case study and is analyzed using the published reports by EIA [37] and [38] about the export targets and its costs.

A. Natural Gas Price

Natural gas price is a source of uncertainty in the power system [24]. Markov chain is a sequence of random variables such that for a given X_t, the distribution of X_{t+1} is independent from X_{t-1}, X_{t-2}, ... There are various ways of using a Markov chain to generate random variables from some distribution related to the chain. Such methods are called MCMC. Following engineering terminology for sampling sequences, the techniques based on these chains are generally called samplers. The objective in the Markov chain samplers is to generate a sequence of auto

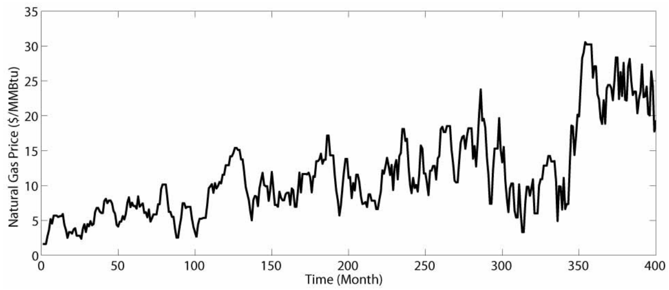


Fig. 1. The samples of natural gas price generated by Markov chain Monte Carlo

correlated points with a given stationary distribution. Appendix A describes the process of MCMC method in creating samples.

For estimating the future price by the Metropolis-Hastings sampler, the initial price of natural gas and its variance is chosen from Ref. [36], summarized in table 1. The price is estimated for 400 months by using Normal distribution for the target stationary distribution of natural gas price, p_X, and Uniform distribution for the proposal distribution, $g_{Y_{t+1}|Y_t}$ in the flowchart 13. Figure 1 shows the natural gas price, Γ_{NG}, during the studied time horizon that increases with a constant rate of return according to table 1 [35].

B. Direct Export of Natural Gas

The first scenario analyzes the direct export of natural gas as base condition, considering export at real time and forward prices as shown in Fig. 2. Due to its profit in the present situation expressed by Eq. (1), investment on transfer of the specified amount of gas from Iran to Turkey [37] has decreased. Table 1 summarizes the information on the direct export of natural gas such as amount, prices and costs.

$$\Pi_{NG}(t) = \int_0^t (\Phi_{NG}(\tau) \cdot \Omega_{NG}(\tau)) \times (1+rr)^{-y} d\tau - \Upsilon_{NG} \quad \textbf{(1)}$$

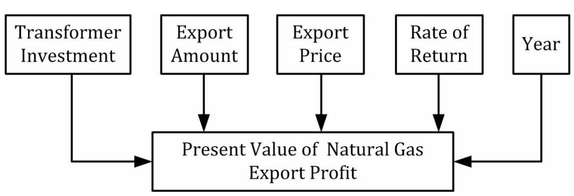


Fig. 2. The causual procedure of natural gas direct export

C. Export of Natural Gas by Converting into Electricity

Because of its higher efficiency, lower pollution *etc.*, the CCGT converts natural gas into electricity. The fuel used in energy conversion process could be free of charge or at pre-set price of Γ_{NG}.

Figure 3 represents the process of exporting the generated electricity by the CCGT technology. The generation costs such as the fuel, O&M and pollution together with the generation investment are added to the costs in this scenario.

Equation Eq. (2) represents the present profit of exporting the electricity. The fuel cost affects the profit through the heat rate of the CCGT technology in the first condition, which is dissipated in the energy conversion. The amount of exported electricity is equivalent to the volume of planed natural gas export in table 1, taking into account the heat rate of the CCGT. The investment in the CCGT and infrastructure for transmission of electricity is subtracted from the income of export as expressed in Eq. (2).

$$\Pi_{Elec}(t) = \int_0^t (\Phi_{Elec}(\tau) \cdot \Omega_{Elec}(\tau) - \Gamma_{NG} \cdot HR_{CCGT} - OM_{CCGT} - CO_{CCGT}) \times (1+rr)^{-y} d\tau - I_{CCGT} - \Upsilon_{Elec} \quad \textbf{(2)}$$

D. Export of the Converted Natural Gas via the Power Market

In the third scenario the natural gas is converted into the electricity and is exported at the price of power market. The expansion of capacity for supplying the demand, including the exported energy, is influenced by the profit that is made by active firms in the liberalized power market. Four technologies including coal-fired, CCGT, GT and wind turbine compete in the power market and the natural gas based technologies allocate a part of their capacity to the exported electricity.

Figure 4 illustrates the process of capacity expansion in a restructured power market in this scenario. In order to clear the price and amount of generation, the firms offer their marginal cost to the market, which has uniform price structure. The market determines the profit of each firm considering the investment costs and capacity payment. The profit affects decision about the investments by firms and creates the generation capacity by passing the construction time. The capacity is offered to the market, which forms the main feedback loop in this process; it is retired after its life time and changes the investment rate in the expansion process. The market price determines the profit of the export based on the amount of planned export and investment in infrastructure for transmission of electricity.

D.1. Electricity Generation Cost

Marginal and investment costs are the main expenses for generating the electrical energy. Some costs such as fuel, pollution and operation, presented in [34], [35], form the marginal cost of the firms, which shows the cost of electricity generation per MWh. The marginal cost increases with constant rate of return every year as expressed in Eq. (3); the HR_j denotes the required thermal energy for generating electric energy by a certain technology in Btu/KWh and decreases every year [35]. The natural gas based technologies pay the Γ_{NG} for fuel cost.

$$MC_j = \left(F_j.HR_j + OM_j + CO_j\right)(1+rr)^y. \quad \textbf{(3)}$$

The investment cost is paid over the construction period and must be recovered during the operation of the firms. Recovering the investment cost is important for providing the reliability in the uniform price markets, especially about the peak technologies [17], [31]. The firms cannot add the investment costs to

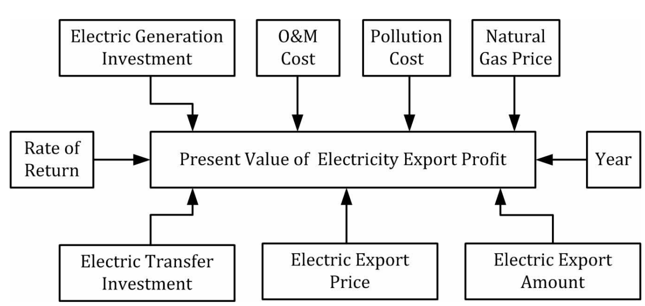


Fig. 3. The causal procedure of natural gas export by converting into electricity

Table 1. The Parameters of the simulation [35]- [38]

Parameter \ Technology	Coal Fired	C.C.G.T	G.T	Wind
Fuel Cost	65 ($/ton)	Γ_{NG}	Γ_{NG}	
Heat Rate (Btu/KWh)	9200	6752	9289	
O&M Costs ($/MWh)	7.7	3.3	4.3	3.4
CO_2 Costs ($/MWh)	24	10.5	16	
Investment Costs ($/KW)	1923	877	604	1797
Construction Time (months)	48	36	24	6
Life Time (months)	720	360	360	240
Planned amount of natural gas export (MMBtu/Month)	112.5×10^6			
Natural gas transfer investment ($)	5.1×10^9			
Forward price of natural gas export ($/MMBtu)	14.65			
Planned amount of electricity export (MW)	23000			
Forward price of electricity export ($/MWh)	130			
Electricity transfer investment ($)	2.8×10^9			
Rate of Return (%/year)	5%			
Peak Demand (MW)	52000			
Peak Duration	0.2			
Middle Demand (MW)	40000			
Middle Duration	0.6			
Base Demand (MW)	28000			
Base Duration	0.2			
Demand Growth Rate (%/year)	5%			
Rated Wind Speed (m/s)	7			
Product Wind Speed (m/s)	4			
Cut Out Wind Speed (m/s)	13			

their offers. These costs are recovered due to the market pattern and capacity payment to the firms that have not the fortune of generation [31].

D.2. Electric Demand

The electric demand is modeled by load duration curve (LDC) for the base, middle and peak sections of the demand, which are supplied by the coal- fired, CCGT and GT, respectively. The demand grows in each section with a constant growth rate every year and its average, expressed in Eq. (4), is offered to the market. The planed export demand is added to the interior demand, which is supplied by the natural gas based technologies at first. The total of interior and exported demand forms the market demand in Eq. (4).

$$D(t) = \sum_{i=1}^{k} \delta_i \cdot L_i \cdot e^{g \cdot y} + E_d. \quad \textbf{(4)}$$

D.3. Power Market

In this paper, it is assumed that the market structure is uniform. Thus the price and generation of each firm is determined based on the minimum cost criterion. The firms bid their marginal cost in Eq. (3) and the offers are sorted from low to high. Market price is specified by the last bid that supplies the demand completely.

The investment cost does not influence the bid of the firms directly, but it must be recovered during the operation period. Wining the high bids is profitable for the firms with lower marginal cost. The reliability of the power system is provided by capacity payment to the losers or free capacities [31].

D.4. Profitability

Clearing the market specifies the firms generation, , which can be used for computing their costs and profit. Total generation cost is the sum of expenses paid by the firms for generating electrical energy until the studied time, expressed by Eq. (5).

$$GC_j(t) = \int_0^t \Phi_j(\tau) \cdot MC_j(\tau) d\tau \quad \textbf{(5)}$$

As expressed in Eq. (6), firm's income is calculated by subtracting the generation and investment cost from their income, where $\Phi_j \cdot MC_j$, $CP_j \cdot I_j$ and $\Phi_j \cdot \Omega_j$ are generation cost, investment cost and income of firms respectively.

$$\Pi_j(t) = \int_0^t \Phi_j(\tau) \cdot \Omega_j(\tau) - \Phi_j(\tau) \cdot MC_j(\tau) - CP_j(\tau) \cdot I_j(\tau) d\tau \quad \textbf{(6)}$$

The profit of the firms can be normalized to the same quantity by defining the profitability index. It is the ratio of profit to generation cost in Eq. Eq. (7) [30]. This parameter is helpful in decision about investing in a technology.

$$PI_j = \frac{\Pi_j}{GC_j} \quad \textbf{(7)}$$

D.5. Capacity Expansion

The PI of the firms is converted into the investment rate by the S-shaped curves as defined by Eq. (8). The curves limit the rate of variation and final value [30]. Each technology has different amounts of m_{jmax}, α_j and β_j, but the m_j is equal to 1 for $PI_j = 1$ in all of the firms. The coefficient m_j is influenced by the reliability policy and the profitability for providing enough capacity.

$$m_j = \frac{m_{jmax}}{1 + e^{-(\alpha_j PI_j - \beta_j)}} \quad \textbf{(8)}$$

The investment rate in each technology is a function of demand growth rate and the retirement rate of the firms, which is weighted by the coefficient m_j as indicated in Eq. (9).

$$IR_j = m_j.(\dot{L_i} + \dot{RE_j}) \quad \textbf{(9)}$$

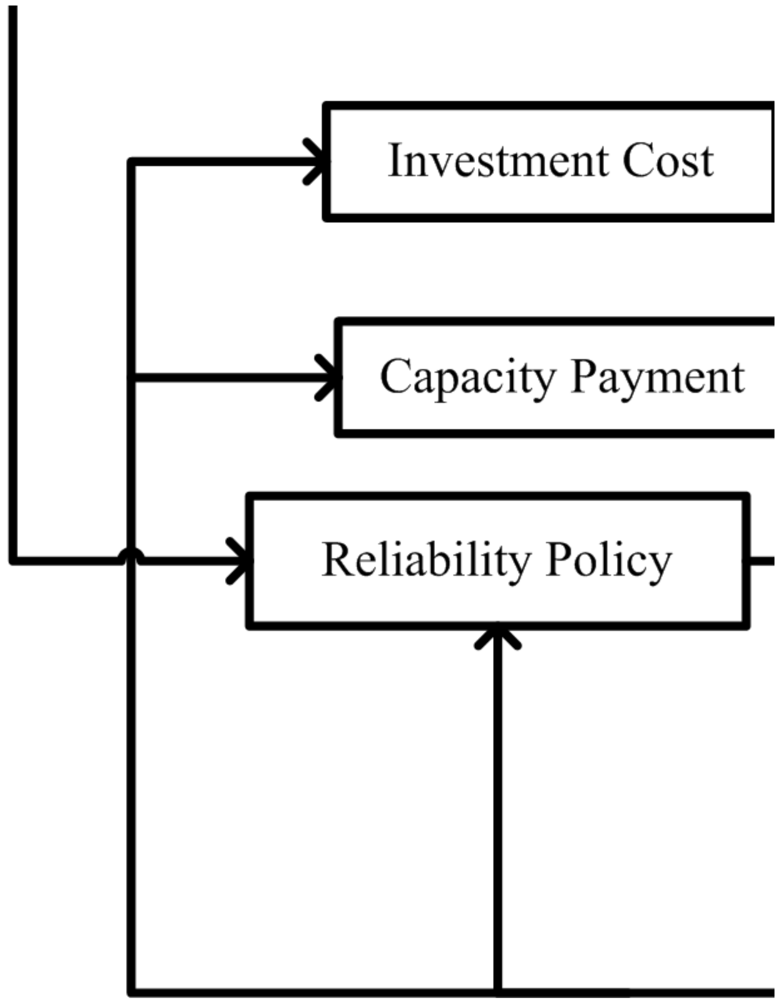


Fig. 4. The causal procedure of natural gas export via the restructured power market

The reliability policy in Eq. (10) is an internal loop in launching process, named as launch scale [1]. It changes the rate of investment in each technology for holding the ratio of the reserve to the demand at a proposed level.

$$Res.Rat = \frac{TCP - D(t)}{D(t)} \tag{10}$$

The investment rate is converted into the under construction capacity during the construction time in Eq. (11), which is the difference between the investment rate and the construction rate in each technology. The capacity in operation is the difference between the constructed and the retired capacity in Eq. (12). The exploited capacity is declared to the market and creates the main feedback loop in this process; besides, it is used for providing the reliability as an internal loop.

$$UC_j = \int_0^t IR_j - IR_j(\tau - CT_j)d\tau \tag{11}$$

$$CP_j = \int_0^t CN_j - CN_j(\tau - LT_j)d\tau \tag{12}$$

D.6. Wind Technology

The wind technology participates in the market besides the thermal technologies. Different effective factors such as generation and investment costs, construction time and life time are considered for analyzing the long run behavior of the wind technology in the market [35], [34]. The output power of the wind technology is perturbed by the wind speed, which is modeled by the Weibull probability distribution function in Eq. (13).

$$V_w(t) = \frac{\gamma}{\eta}.\left(\frac{t}{\eta}\right)^{\eta-1}.e^{-\left(\frac{t}{\eta}\right)^{\gamma}} \tag{13}$$

The wind generation in Eq. (14) is affected by the wind perturbation and the restriction of the infrastructures in low and high wind speeds, which eliminates the generation from the nominal amount [33]. The GT increases its income by compensating the lack of planed generation by wind, due to its fast response and free capacity [24].

$$\Phi_w = \begin{cases} 0 & V_w < V_{ci} \\ \left(\frac{V_w}{V_r}\right)^3 CP_{rw} & V_{ci} \leq V_w < V_r \\ CP_{rw} & V_r \leq V_w < V_{co} \\ 0 & V_w \geq V_{co}. \end{cases} \tag{14}$$

3. SIMULATION AND RESULTS

This section studies different presented situations in section 2 for exporting the natural gas from Iran to Turkey during 400

Fig. 5. The present profit of natural gas export

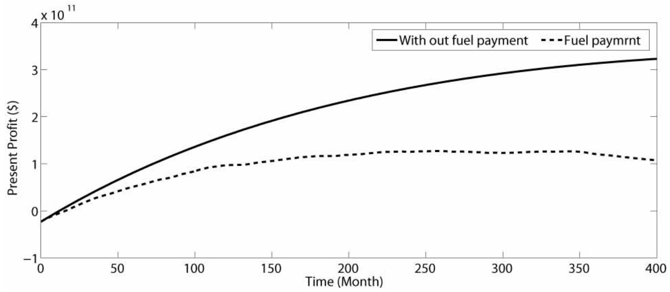


Fig. 6. The present profit of electricity export

months as a case study. The results are obtained by simulating different scenarios using the published reports by EIA about the natural gas and the costs of electricity generation [35]- [38]. The analyses consider the export of natural gas and electricity via a forward contract in table 1 and real time price of natural gas, Γ_{NG}.

Figure 5 represents the present profit of exporting the planned amount of natural gas in table 1 at the forward and real time prices. The final profit in forward price is 3.3×10^{11}\$, while it decreases to 2.1×10^{11}\$ in the real time price. The exportation with suitable forward price recovers the investment costs during 4 months and it takes 1 year to be recovered in the real time price scenario.

The second scenario studies export of electricity in a forward price instead of natural gas and considers the energy conversion with and without fuel cost. The CCGT technology is chosen for the conversion due to its distinguishing characteristics [24]. In this scenario the costs of operation and maintenance and pollution should be taken into account. Moreover, the natural gas price should be considered in costs, while the natural gas price, Γ_{NG}, is added to the costs in the second situation. The investment in generation and transmission is deducted from the income of exportation. Table 1 summarizes the applied data for simulating the situations.

Figure 6 represents the present profit of electricity export in this scenario. The present profit of exportation without fuel cost is 3.2×10^{11}\$, equivalent to direct export of natural gas with forward price. Taking into account the fuel cost, profit will reduce to 1.07×10^{11}\$. The investment costs is recovered after 1 year at the first situation, while it increases to 16 months by fuel payment as shown in Fig. 6.

By restructuring of the power system the price of electricity is determined in a competitive market, which can be applied to the exported electricity. Figure 7 presents the market price, which grows with a constant rate of return and is influenced by the natural gas price, Γ_{NG}; the coal-fired technology determines the lower limit of the price in this figure.

The profitability index of the firms changes by the variation of natural gas price as indicated in Fig.8. As the greatest value, the PI of CCGT is about 0.4; it is due to fact that the efficiency of energy conversion in this technology is comparatively high. On the other hand, the high marginal cost of GT reduces its efficiency, leading to the lowest PI for this technology in the market. High price natural gas increases the PI of the coal-fired due to higher electricity price and increases the costs of the GT and CCGT, which decreases their profitability in Fig. 8.

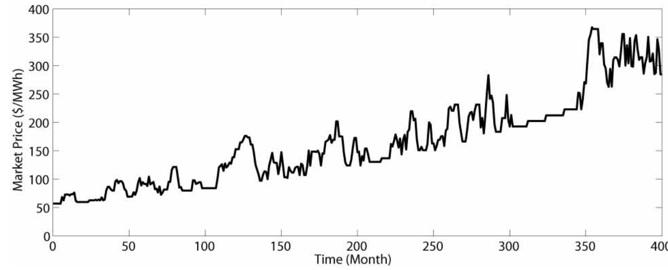


Fig. 7. The market price of the electricity

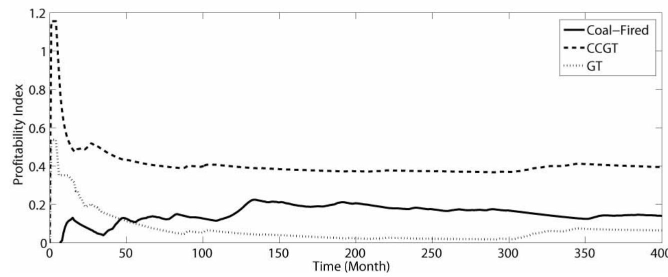


Fig. 8. The profitability index of the thermal technologies in the power market

The present profit of electricity export at the market price for different firms is summarized in table 2. The profit of the CCGT in the market decreases to 3.2×10^8, compared with the electricity generation with considering fuel cost in the second scenario. However, The CCGT earns the most profit and operates at the full capacity in comparison to other firms. Electricity exportation at the market price does not recover the invested resources in transmission and causes loss as the income from market is 6.2×10^8.

The variation of natural gas price and the profitability affects the pattern of capacity expansion by the firms as shown in Fig. 9. Increasing the natural gas and market prices provides the opportunity for capacity expansion by the coal-fired to the maximum capacity of 13.8×10^4 MW. The rate of capacity expansion by the CCGT and GT is less than the coal-fired and their capacity is 7.5×10^4 MW and 6.4×10^4 MW at the end of the period, respectively. The power market provides the reliability of domestic and foreign demand as indicated in Fig. 10, in which the ratio of power system reserve remains about 20%.

The presence of the wind technology bsides the thermal firms changes the pattern of generation without influence on the market price and profit of the exportation. Figure 11 represents the profitability index of the firms by the presence of the wind turbines in the market. The PI of the coal-fired and CCGT does not change, but the PI of GT increases compared with Fig. 8, due to

Table 2. The present profit of the firms and electricity export via the market

Firm	Profit ($)
Coal- Fired	1.9×10^8
CCGT	3.2×10^8
GT	0.26×10^8
Exportation	-21.8×10^8

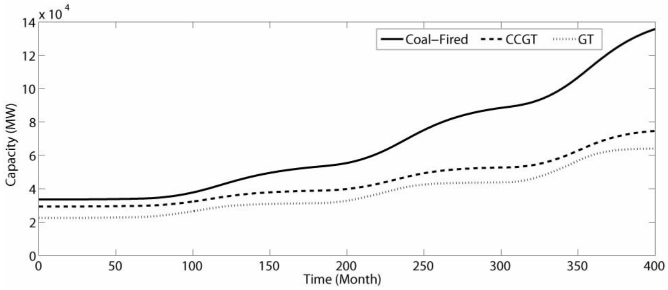


Fig. 9. The capacity of the thermal technologies in the power market

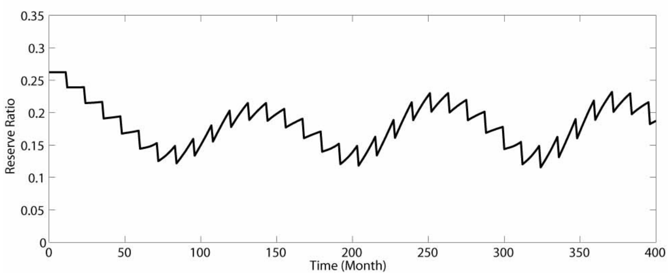
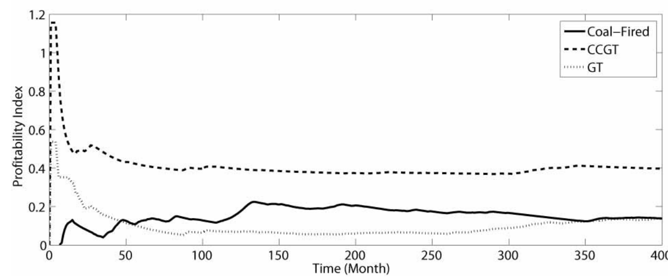
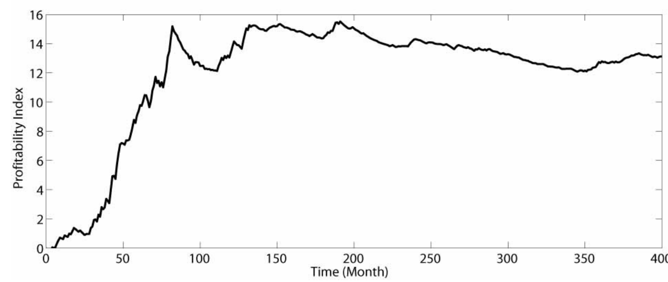


Fig. 10. The reserve ratio of the power system



(a) Thermal firms



(b) Wind

Fig. 11. The profitability index of the firms with the presence of the wind

compensation of the difference between generated power and nominal power. Free capacity of the GT and its fast start up and fast response to the changes made the GT suitable for making up the wind lack.

Table 3 summarizes the profit of the firms and electricity exportation via the power market. The present profit of the coal-fired and CCGT decreases compared with table 2, while the present profit of GT is increased through compensating the lack of wind generation.

Table 3. The profit of electricity export via power market in the presence of wind turbines for different firms

Firm	Profit ($)
Coal- Fired	1.6×10^8
CCGT	2.9×10^8
GT	0.7×10^8
Wind	0.69×10^8
Exportation	-21.7×10^8

The wind participation in the market changes the generation pattern as shown in Fig. 12. The capacity of the thermal firms reduces to 10.2×10^4 MW, 5.9×10^4 MW and 5.2×10^4 MW for the coal-fired, CCGT and GT, respectively as the wind capacity gets to 2.7×10^4 MW. The new generation pattern decreases the total fuel cost of electricity generation from 2.34×10^7\$ to 1.93×10^7\$.

4. CONCLUSION

In this paper, the long run export of natural gas is analyzed by the system dynamics method. In this regard, the exportation from Iran to Turkey is studied using the published data by the EIA about the natural gas price and its forecast, the situation of natural gas resouces around the world and the costs of electricity generation. The real time price of natural gas is estimated by the Markove Chain Monte Carlo, considering the present price and variation and rate of return.

Three different scenarios is considered for transferring the energy including direct export of natural gas in forward and real time prices, conversion of natural gas into electricity before export and export the electricity via the power market with considering the renewable resources. Direct export of natural gas in the real time price is profitable and recovers the investment in transfer infrastructure. Also, exporting the natural gas in a suitable forward price increases the earned profit.

The second scenario analyzes the conversion of natural gas into the electricity by the CCGT. Converting the energy for exportation in a forward price without fuel payment creates profit equivalent to the direct export of natural gas in a forward price. On the other hand, paying the real time price of natural gas used by the CCGT and selling the electricity in a forward price decreases the profit, but recovers the investment costs of generation and transmission.

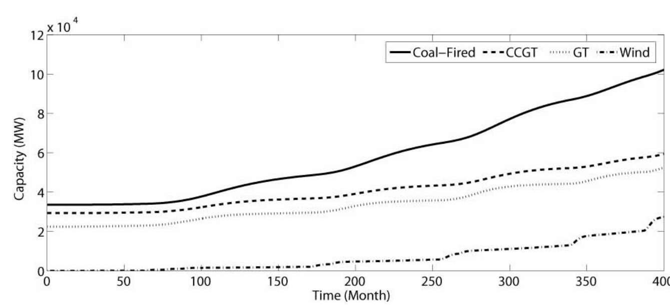


Fig. 12. The capacity of different technologies with the participation of the wind

Export of electricity in the real time price is investigated in the third scenario. The electricity price is cleared in the power market with uniform price structure. The firms including coal-fired, CCGT and GT technologies supply the demand and export electricity, given that they expand their capacity according to the earned profit from the market. Exporting via the market price is not profitable and does not recover the investment in transmission. Therefore, the costs of transmission in this scenario have to be appropriately considered by planning for transmission right. Participation of the exported electricity besides the demand in the market can be provided by the capacity expansion of the firms for keeping the reliability of the power system. The expansion of renewable technologies in the power market does not affect the continuity of export. Although the expansion of renewable energy decreases the costs of fossil fuel during the studied period, it does not make a profit for export, due to its high investment in transmission.

All in all, the export of natural gas in a suitable forward price makes a good profit in direct and electricity export scenarios. The export of natural gas in the real time price is profitable but selling the electricity in the market price cannot recover the investment costs.

APPENDIX A

Inequality Eq. (15) expresses the criteria for acceptance or rejection of a sample in a distribution with the density p_X, which generates the walk moves from the point y_i to a candidate point $y_{i+1} = y_i + s$, where s is a realization from U(-a, a) and u is an independent realization from U(0, 1). If the new point is at least as probable (that is, if $p_X(y_i + 1) \geq p_X(y_i)$), the condition Eq. (15) implies acceptance without the need to generate u [32].

$$\frac{p_X(y_i + 1)}{p_X(y_i)} \geq u. \quad (15)$$

The Metropolis-Hastings sampler uses a more general chain for the acceptance/rejection step, instead of just basing the decision on the probability density p_X as in the inequality Eq. (15). The Hastings technique uses deviates from a Markov chain with density $g_{Y_{t+1}|Y_t}$ for generating deviates from a distribution with a probability density p_X as shown in flowchart 13.

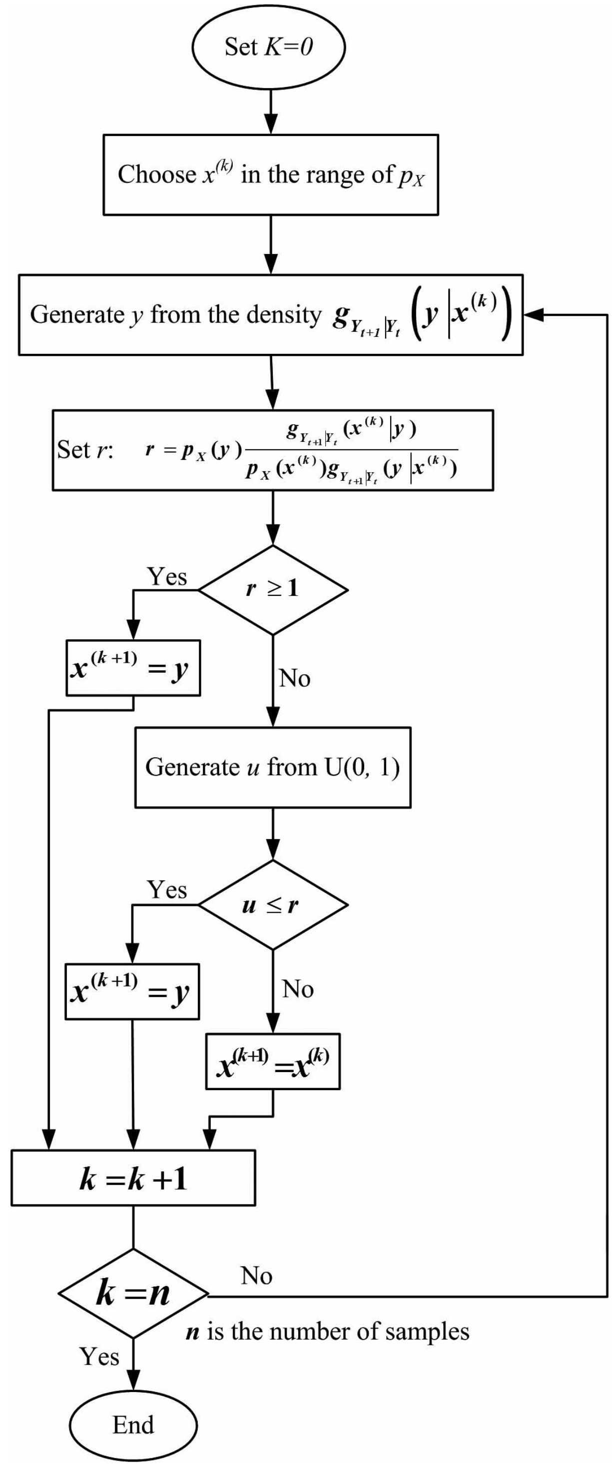


Fig. 13. The flowchart of estimating the natural gas price

REFERENCES

1. Anna Shaojie Cui, Meng Zhao, and T. Ravichandran," Market Uncertainty and Dynamic New Product Launch Strategies: A System Dynamics Model", IEEE Transactions on Engineering Management, v. 58, n. 3, p.530-550, Aug. 2011.

2. Fernando Olsina, Francisco Garce, H.J. Haubrich, " Modeling Long-Term Dynamics of Electricity Markets", Energy Policy, n. 34, p.1411-1433, 2006.

3. M. Assili, M. Hossein Javidi D.B., Reza Ghazi, "An improved mechanism for capacity payment based on system dynamics modeling for investment planning in competitive electricity environment", Energy Policy, vol. 36, p. 3703-3713, 2008.

4. Masoud Hasani-Marzooni, Seyed Hamid Hosseini, " Dynamic Analysis of Various Investment Incentives and Regional Capacity Assignment in Iranian Electricity Market", Energy Policy, n. 56, p. 271–284, 2013.

5. Jung-Yeon Park, Nam-Sung Ahn, Yong-Beum Yoon, Kyung-Ho Koh, Derek W. Bunn, " Investment Incentives in the Korean Electricity Market", Energy Policy, n. 35, p. 5819–5828, 2007.

6. Patricia Ochoa, " Policy Changes in the Swiss Electricity Market: Analysis of Likely Market Responses", Socio-Economic Planning Sciences, n. 41, p. 336–349, 2007.

7. M. Hasani-Marzooni and S.H. Hosseini, " Dynamic Inter-

actions of TGC and Electricity Markets to Promote Wind Capacity Investment", IEEE SYSTEMS JOURNAL, vol. 6, n. 1, p.46-57, MARCH 2012.

8. Andrew Ford, Klaus Vogstadb and Hilary Flynn, " Simulating price patterns for tradable green certificates to promote electricity generation from wind", Energy Policy, n. 35, p.91-111, 2007.
9. Andrew Ford, " Waiting for the boom: a simulation study of power plant construction in California", Energy Policy, n. 29, p. 847–869, 2001.
10. Andrew Ford, " Boom and Bust in Power Plant Construction: Lessons from the California Electricity Crisis", Journal of Industry, Competition and Trade, 2:1/2, p. 59-74, 2002.
11. Andrew Ford, " Cycles in competitive electricity markets: a simulation study of the western United States", Energy Policy, n. 27, p. 637–658, 1999.
12. Masoud Hasani-Marzooni and Seyed Hamid Hosseini, "Short-Term Market Power Assessment in a Long-Term Dynamic Modeling of Capacity Investment", IEEE Transactions on Power Systems, v. 28, n. 2, p. 626-638, MAY 2013.
13. Deb Chattopadhyay, " Modeling Greenhouse Gas Reduction From the Australian Electricity Sector", IEEE Transactions on Power Systems, v. 25, n. 2, p.729-740, MAY 2010.
14. Dan Eager, Benjamin F. Hobbs and Janusz W. Bialek, " Dynamic Modeling of Thermal Generation Capacity Investment: Application to Markets with High Wind Penetration", IEEE Transactions on Power Systems, v. 27, n. 4, p. 2127-2137, NOV. 2012.
15. Shayne Gary, Erik Reimer Larsen, " Improving firm performance in out-of-equilibrium, deregulated markets using feedback simulation models", Energy Policy, n. 28, p. 845–855, 2000.
16. A. Jokic, E. H. M. Wittebol, P. P. J. van den Bosch, " Dynamic market behavior of autonomous network-based power systems", International Transactions on Electrical Energy Systems, Volume 16, Issue 5, pages 533–544, September/October 2006.
17. Ali Movahednasab, Masoud Rashidinejad and Amir Abdollahi, " A system dynamics analysis of the long run investment in market-based electric generation expansion with renewable resources", International Transactions on Electrical Energy Systems, February 2017, DOI: 10.1002/etep.2338.
18. Kemal Sarıca, Wallace E. Tyner, " Economic Impacts of Increased U.S. Exports of Natural Gas: An Energy System Perspective", Energies, 2016, DOI:10.3390/en9060401.
19. Sydney Thomas, Richard A. Dawe, " Review of ways to transport natural gas energy from countries which do not need the gas for domestic use", Energy, n. 28, p. 1461- 1477, 2003.
20. Sergey Paltsev, " Scenarios for Russia's Natural Gas Exports to 2050", Energy Economics, n. 42, p. 262-270, 2014.
21. Hassan Yousefi, Davood Manzoor, " Iran's Gas Transit to Europe: A Game Theoretic Approch", Quarterly Energy Economics Review, n. 43, 2015.
22. Andrew Ford, " System Dynamics and the Electric Power Industry", System Dynamics Review, Vol. 13, No. 1, pages 57-85, Spring 1997.
23. João Zambujal-Oliveira, " Investments in combined cycle natural gas-fired systems: A real options analysis", Electrical Power and Energy Systems, n. 49, p.1-7, 2013.
24. José Gil, Ángel Caballero and Antonio J. Conejo, " CCGTs: The Critical Link Between the Electricity and Natural Gas Markets", ieee power & energy magazine, p.40-48, Nov./Dec. 2014.
25. C. C. von Weizsacker, J. Perner, " An Integrated Simulation Model for European Electricity and Natural Gas Supply", Electrical Engineering, Volume 83, Issue 5, pages 265-270, April 2001.
26. Luis M. Abadie, Jose M. Chamorro, " Monte Carlo valuation of natural gas investments", Review of Financial Economics, n. 18, p. 10–22, 2009.
27. Jan Muller, Guido Hirsch and Alfred Muller, " Modeling the Price of Natural Gas with Temperature and Oil Price as Exogenous Factors", Springer Proceedings in Mathematics & Statistics, n. 99, p. 109–128, 2015, DOI 10.1007/978-3-319-09114-3_7.
28. John E. Bistline, " Natural gas, uncertainty and climate policy in the US electric power sector", Energy Policy, n. 74, p.433-442, 2014.
29. Andrea Klimesova, Tomas Vaclavik, " GAS SWING OPTIONS: INTRODUCTION AND PRICING USING MONTE CARLO METHODS", ACTA OECONOMICA PRAGENSIA, Volume 24, Number 1, p. 15–32, 2016, DOI 10.18267/j.aop.496.
30. John D. Sterman, " Business Dynamics: System Thinking and Modeling Complex World", MC Graw-HILL, ISBN 007238915X, 2000.
31. Steven Stoft, " Power System Economics Designing Markets for Electricity", IEEE Press & WILEY-INTERSCIENCE, Copyright © 2002.
32. James E. Gentle, " Random Number Generation and Monte Carlo Methods", Springer, ISBN 0-387-0017-6, 2003.
33. Hermann-Josef Wagner, Jyotirmay Mathur, "Introduction to Wind Energy Systems: Basics, Technology and Operation", Springer, ISBN 978-3-642-32975-3, 2009.
34. "Projected Costs of Generating Electricity", INTERNATIONAL ENERGY AGENCY, 2010 Edition.
35. Rick Tidball, Joel Bluestein, Nick Rodriguez and Stu Knoke, "Cost and Performance Assumptions for Modeling Electricity Generation Technologies", ICF International Fairfax, Virginia, November, 2010.
36. Adam Sieminski, "Annual Energy Outlook 2015", U.S. Energy Information Administration, May, 2015.

37. John Conti, “International Energy Outlook 2016", U.S. Energy Information Administration, Washington DC 20585, May, 2016, .

38. “Natural Gas Exports from Iran", U.S. Energy Information Administration, Washington DC 20585, October 2012.

39. Steven Macmillan, Alexander Antonyuk, Hannah Schwind, “Gas to Coal Competition in the U.S. Power Sector", International Energy Agency, May, 2013.