Policy Making for Generation Expansion Planning by means of Portfolio Theory; Case Study of Iran

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Abstract-

The complex structure of the power system and the pivotal role of electrical energy in determining the socio-economic indicators of any countries lead the policy makers of power industry to take into account the expansion planning of generation system with high priority. Considering the intense fluctuations of costs in electrical energy generation (particularly due to variation of fuel prices within the recent years in the Middle East), finding an optimal generation portfolio, regardless of the costs variations risk looks impossible. The portfolio theory, as an efficient tool for risk management, provides a proper solution to materialize the optimal generation portfolios with the following properties: maximizing the expected return for any given level of risk, while minimizing risk for every given level of expected return. Determining an optimal generation technologies portfolio in Iran by the above-mentioned theory is the main aim of this study. To do so, two scenarios have been conducted and optimal generation portfolios have been determined considering the past 10 years recorded data and 10 upcoming years predicted data. Meanwhile, in each scenario the effect of renewable energy resources on optimal generation mix will be studied. According to the results, in both scenarios, presence of renewable energy generation is attractive and portfolio risk can be reduced significantly through diversification with a key role for renewables. Also for every given level of expected return and for each scenario, the natural gas and the oil have the maximum and minimum share in optimal portfolio, respectively. The studied problem is a non-linear optimization problem, and the GAMS and MATLAB software have been implemented to extract the final results.

Keywords: Power Industry Policy-making, Portfolio Theory, Renewable Energy Resources, Risk Management.

1. Introduction

Power industry policy-makers have assorted tools at their disposal to determine the framework of optimally conducting investments to develop the electrical power-generating plants. Because of the intense fluctuation of the generation costs in recent years, it looks impossible to decisively formulate such a framework for Iran, regardless of cost uncertainties. The main reasons of such costs variations can be summarized as follow:

1. Volatility of fossil fuels price due to the political and security issues especially in the Middle East
2. Aftermath of “Subsides Target-orientation Act” enforcement in 2010
3. Increase of the foreign exchange rates against the Iranian currency in 2012.

One of the most practical tools to deal with the risk management is the modern portfolio theory (MPT). This theory is about finding an “efficient frontier" of optimal portfolios which “maximize expected return considering a maximum acceptable level of risk” or “minimize the investment risk for a given expected return”.

MPT was founded by Harry Markowitz in 1952[1]. The most outstanding role of MPT is to offer a risk-return framework for investors’ decision-makings. Having quantitatively defined investment risk, Markowitz provided a mathematical model for portfolio management. This model was awarded a Nobel Prize after 38 years[1-3]. Markowitz' theory major hypotheses are as follows [4, 5]:

- Investors attempt to increase the return.
- Investors are risk averse.
- Returns distribution functions are normal.

An old application of this theory in electricity sector was conducted by Bar-Lev and Katz in 1976[6]. In that study, the Portfolio Theory's concepts to study the contribution share of each fossil fuel in the US electrical power industry was employed. The authors suggested that, utilities could move towards the efficient frontier by purchasing more the higher-priced fuels that however exhibit smaller price fluctuation. It was mentioned in [7-9] that, in energy planning, in addition to generation costs, the "risk minimization" should be considered as the other objective. They found that by diversification, while total costs remain constant, portfolios with lower risk can be achieved. Also, the impact of renewable energies became evidently substantive in decreasing the optimal portfolio risk.

One of the preliminary application of MPT principles in power systems planning and policy-making, presented by Awerbuch-Berger [5]. The authors formulated an MPT based model to analyze existing and projected generating mixes in the European Union. Four conventional technologies, i.e. nuclear, coal, oil and natural gas, along with wind energy are considered. Besides, four types of costs including investment cost, fixed and variable operation and maintenance (O&M) costs and fuel costs are addressed in the pproposed model. A secondary type of modelling was provided in [10]. The main difference of their model and the above mentioned one, shows that the return and the risk of return were replaced by costs and the risk of costs. Moreover, installed power capacity was replaced by generated power within a certain period of time. This method led to extension of limited accessibility to renewable energy resources. Another example of using cost instead of return is presented in[11]. The Portfolio Theory was used in [12] for determining the energy consumption portfolio in the US. Based on that study, this portfolio has changed toward a more optimal one since 1980. Furthermore, it is imperative that, the share of natural gas in the portfolio would increase from 1990. In [13], the product portfolio was introduced, where the objective function simply consists of the weighted sum of total costs and the related variations (the risks) and uses a risk-averse factor. Meanwhile, the distinction between the capacity and the generated electrical energy was made during a long period of time. This quantitative method developed more in[14], where a new objective function was introduced by the use of generation costs and its related risks with the aim of formulating an optimal fossil fuel portfolio in Taiwan. They used a Load Duration Curve (LDC) to define different demand blocks. Gotham et al. introduced a Portfolio Theory-based method through which they had categorized the loads (on the basis of load factor) into three groups. In fact, taking into account the importance of load variations, the initial portfolio theory is later harmonized and updated in accordance with loads classification [15].

In [16], concentrating on private investors' investment, Application of MPT in liberalized market environment is investigated. In that study, three scenarios (according to different correlation coefficients between fuel, CO2 and electricity prices) have been considered based on net present value of three base load technologies, i.e. nuclear, coal and combined cycle gas turbine. A sample of using Portfolio Theory in purchasing electricity is addressed in[17].

A short-term market risk model based on Portfolio Theory presented in [18]. While transaction costs and contractual constraints were considered, authors proposed a covariance matrix which reflects different developments of fuel prices across regional electricity markets.

Jun Xu et al. presented a midterm time horizon portfolio optimization strategy with risk management for New England electricity market [19]. The aim of that paper was maximizing the profit while the risk was minimized and different time scales of different markets were coupled through load obligation constraints. The numerical results show the effectiveness of proposed framework.

Another example of applying MPT based approach to electricity market presented in [20]. This paper concentrated on optimal allocation of generation portfolio in Indian electricity market. As the market prices are not distributed normally, a 3-objective optimization framework was proposed. While Markowitz assumed periodic returns of the different investments could be defined with the first two moments (namely mean and variance), the authors used the third moment (skewness) of returns as another objective. So, MVS (mean-Variance-Skewness) framework was proposed in contrast with initial Markowitz Mean-Variance framework. In this way, optimal portfolios maximize the expected return and skewness and minimize the variance, simultaneously. Also, in [21] MVS optimization problem for electricity market was solved by a novel proposed algorithm which was named as multi-objective genetic algorithms (MOGAs). The results validate the effectiveness of proposed algorithm.

In this research, in accordance with Iran's economy condition, an MPT based model is adopted for generation expansion planning. In order to investigate the effects of the above-mentioned three economic shocks, two various scenarios have been studied based on the collected data since past 10 years and the predicted data in next 10 years, as well. It should be noted that, the fixed and variable O&M costs fluctuations is considered in the proposed model. Also, the effects of renewable energy resources in Iran generation mix are addressed. Due to the geographical limitations, the maximum capacity of wind, hydro-electric and nuclear technologies is surveyed in the proposed model.

2. Portfolio Theory Foundations

Two major principles of an investment are the "returns" and the "risks" [18]. The investors desire to maximize the expected returns. However, they intend to minimize the risk in the meantime. Risk may interpret as "the measurable potential loss of an investment". Weston and Brigham defined the risk of an asset as "the future probable change in the return gained from the asset"[19]. According to the Portfolio Theory, the possible return dispersion from the expected return could be measured by variance and may be taken as a risk criterion.

If the portfolio includes "n" assets, the return and the general risk of the portfolio can be extracted from (1) and (2) [5]:

$$E(r_p) = \sum_{i=1}^{n} W_i E(r_i) \quad (1)$$

$$\sigma_p^{\,2} = \sum_{i=1}^{n} \left(X_i \sigma_i\right)^2 + \sum_{i=1}^{n}\sum_{j=1}^{n} W_i W_j COV_{ij} \left(i \neq j\right) \quad (2)$$

In the equation (1), $E(r_p)$, $E(r_i)$, and W_i are the total portfolio expected return, the expected return of the portfolio for i[th] asset, and the weight of i[th] asset in the portfolio, respectively. Also, in equation (2), σ_p and σ_i are the total risk (standard deviation) of the portfolio and the i[th] asset return risk. Meanwhile, COV_{ij} represents the covariance between the i[th] and j[th] asset where it can be calculated as in (3)):

$$COV_{ij} = \rho_{ij}\sigma_i\sigma_j \quad (3)$$

Here, the item ρ_{ij} is the correlation coefficients between the returns of i[th] and j[th] asset, whose value ranges between –1 and +1. It should be noted that, in the equations (1) and (2), the sum of the weights in the portfolio must equal 1 ($\sum_{i=1}^{n} W_i = 1$). According to the equations (1) and (2), and paying attention to the fact that the weight of any technologies in the portfolio is variable, the infinite number of portfolios might be resulted with certain risks and returns. As shown in Fig. 1, the portfolios on the red–colour line, would be the optimal ones. It's noteworthy to mention that for any feasible point on the risk-return page, there is a point on the red–colour line which has either less risk or more return. In this figure, the red–colour line is called the "efficient frontier".

According to the above-mentioned explanations, the problem of the optimal generation mix determination based on the Portfolio Theory is described as follows:

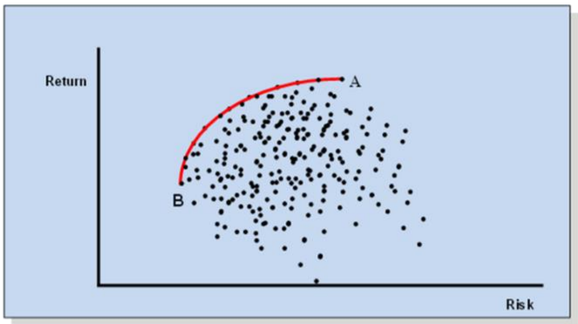

Fig. 1. The efficient Frontier in the Portfolio Theory

This problem is a multi-objective non-linear optimization one.

$$\begin{cases} Maximize\ E(r_p), \quad Minimize\ \ \sigma_p \\ subject\,to: \sum_{i=1}^{n} W_i = 1 \end{cases} \quad (4)$$

3. Modelling the Optimal Energy Portfolio for Iran Generation mix

As mentioned previously, regarding to the intense fluctuations of fossil fuels prices, it looks impossible to determine the contribution share of each energy resource in the power generation mix without considering the costs variations. It is supposed initially that, the changes in the fossil fuels are the only risk resource of power generation costs. In order to analyse the risk-return and pinpoint the efficient frontier in Iran, it is imperative to get access to the information on the costs of various sections of electrical energy generation. Such information is presented in two different ways, i.e. 1) the information on historical data within the recent 10 years, and 2) the data on the horizon of next 10 years.

It should be noted that kilo Rial (kR) is used for cost unit. So, the return which is the ratio of the output/yield to the input/cost, can simply obtain by inverting the generation cost. In this way, the unit of the expected return for the generation assets becomes kWh/kR.

3.1. historical Data

Tables 1, illustrates the necessary information on a span of 10 past years on the basis of present technologies in Iran, i.e. the power plants with the fuels of natural gas, gasoil, oil, nuclear, wind, and hydroelectric power plants. This table demonstrate the information on the average investment, fuel cost, fixed and variable O&M costs.

In addition to average return of costs, the information on risk and correlation coefficient should be available. Tables 2 and 3 introduce such information[1].

3.2. Data on the Horizon of Next 10 Years

In terms of fossil fuels resources, Iran is one of the richest countries in the Middle East and the globe. Therefore, in past, the main portion of the real price of such energy resources have been paid as subsidies by the government in domestic consumptions. Such a policy caused certain faulty patterns of the consumption management, lead to higher energy consumption per head in Iran than that of the world average. In recent years, in order to facilitating the country's economic development, reforming consumption patterns, the environmental concerns, and the imminent depletion of fossil fuels reservoirs the Subsidies Target-orientation Law was enforced by Islamic Consultative Assembly (Iran's parliament) in 16 December 2010.

[1] . The risk and correlation coefficient are zero in renewable energy power plants as they have no fuel costs.

Table 1. The annual costs of the technologies for historical data within the recent 10 years [1]

LEVELIZED Cost (KR/KWh)	Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
Investment	0.6	0.8	0.7	6	3.514	5.314
Fuel	0.042	0.082	0.091	0.253	0	0
Variable O&M	0.019	0.149	0.014	0.014	0.24	0
Fixed O&M	0.022	0.039	0.042	0.038	0.548	0.185
Total cost	0.683	1.107	0.847	6.305	4.302	5.319
Return(kWh/kR)	1.46	0.93	1.18	0.16	0.232	0.188

Table 2. The risk of different technologies for historical data within the recent 10 years

Natural Gas	Gasoil	Oil	Nuclear
0.489	0.581	0.929	0.356

Table 3. The correlation coefficients of different technologies for historical data within the recent 10 years

Correlation Coefficient	Natural Gas	Gasoil	Oil	Nuclear
Natural Gas	1	0.513	0.616	0.37
Gasoil	0.513	1	0.617	0.33
Oil	0.616	0.617	1	0.47
Nuclear	0.37	0.33	0.47	1

Table 4. The annual costs of the technologies for the horizon of next 10 years

LEVELIZED Cost (KR/KWh)	Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
Investment	0.6	0.8	0.7	6	3.514	5.314
Fuel	0.182	0.195	0.208	0.3	0	0
Variable O&M	0.019	0.149	0.014	0.014	0.24	0
Fixed O&M	0.022	0.039	0.042	0.038	0.548	0.185
Total cost	0.823	1.183	0.847	6.305	4.302	5.319
Return(kWh/kR)	1.21	0.84	1.03	0.16	0.232	0.188

Table 5. The risk of different technologies for the horizon of next 10 years

Natural Gas	Gasoil	Oil	Nuclear
0.23	0.3	0.38	0.18

Thereupon, there was a sharp rise in the prices of energy carriers, having caused a hefty standard deviation and risks of the energy carriers than those in the past. On the other hand, Subsidies Target-orientation Law, in the second phase of enforcement, causes the prices liberalization of the energy carriers by the end of Islamic Republic of Iran's Sixth Development Plan.

Table 6. The correlation coefficients of different technologies for the horizon of next 10 years

Correlation Coefficient	Natural Gas	Gasoil	Oil	Nuclear
Natural Gas	1	0.43	0.49	-0.27
Gasoil	0.43	1	0.51	-0.1
Oil	0.49	0.51	1	-0.21
Nuclear	-0.27	-0.1	-0.21	1

Hence, the resulted domestic variations would coincide with those in the world. Therefore, in this section, the studies of the previous section are conducted, through the use of the Persian Gulf FOB prices of the energy carriers, taking into account the sudden and sharp hike in the foreign exchange parity against the Iranian Rial in 2011. These facts are illustrated in the Tables 4-6.

4. Simulation

In this section, the application of the proposed model for determining the optimal generation mix of Iran will be presented. The input data are the same as the previous section. The GAMS software by the Barons solver employed to solve the problem. The results of simulation are presented in two parts; for historical data as well as for the horizon of the next 10 years. It should be noted that, in this section, the fuel price fluctuations are assumed as the sole cause of the generation costs risk. Later in the section 5, the effect of O&M price volatility will be considered in the model

4.1. Efficient Frontiers, based on historical Data

Based on the historical data, given in the section 3.1, the problem in the equation (4) is solved for the fossil fuel-based (traditional) technologies where the results are presented in Fig.2. In this figure, for each pairs of technologies, the efficient frontier is displayed. For example, the blue-colour dashed line represents the efficient frontier of portfolios consist of just natural gas and gasoil. The final efficient frontier considering all conventional technologies is presented in red colour. Fig. 3, shows the nuclear-gas line with more detail so that the efficient frontier becomes more clearly visible. This enlargement shows that, the lower section of the efficient frontier lies to the left of the nuclear-gas line. This result is of particular interest because it shows that by adding the other riskier technologies to the nuclear-gas mix, the risk of the resulting portfolio would be reduced. In this figure, the green-coloured spots are some of the feasible points which are not located on the efficient frontier. Whereas, the renewable energy technologies have no fuel price, these technologies are considered as the "risk-free assets". To evaluate the effects of the risk-free assets, the point "M" where the conventional technologies efficient frontier meets the renewables efficient frontier, should be found. Equation (5) is used to determine this point [5]:

[1] All the figures and data presented in this article have been cited either from Iran's Energy Affairs of Plan and Budget Organization or Iran's Planning Bureau of the Ministry of Energy.

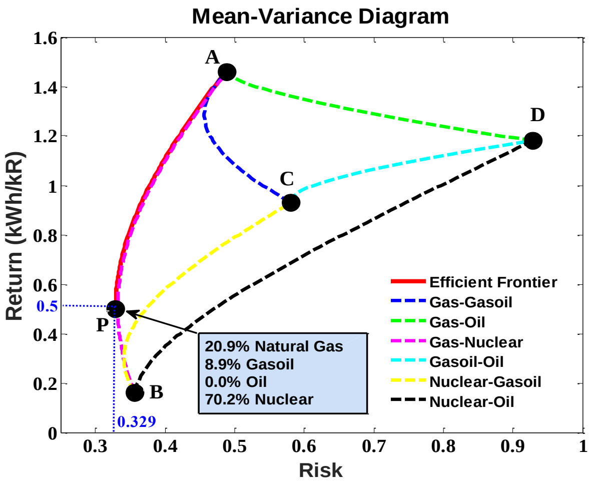

Fig.2. The efficient frontier for the traditional technologies; A: 100% natural gas, B: 100% nuclear, C: 100% gasoil, and D: 100% oil.

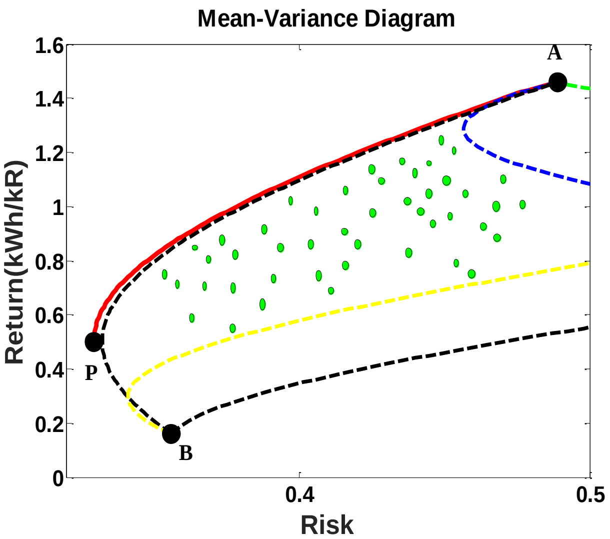

Fig.3. The regional zoomed zone of the efficient frontiers.

$$Max\ \frac{r_p - r_f}{\sigma_p} \quad (5)$$

Where, r_p and σ_p are the return and the risk of each portfolios on the risky assets efficient frontier, respectively. Also, r_f represents the return of the risk-free asset. For the efficient frontier which is shown in Fig. 2, the point M rests on point A which represents a portfolio consist of the only natural gas.

By supposing a couple of technologies (one with the specifications of the point M and the other with the specifications of the risk-free technology), their efficient frontier has to be drawn. It should be added that, since the wind (and hydroelectric) power plants are risk free assets, their covariance with point "M" are zero. So, the equation (2) would turn to be in the shape of a line which is characterised as follows:

$$\sigma_p^2 = X_M^2 \sigma_M^2 \rightarrow \sigma_p = X_M \sigma_M \quad (6)$$

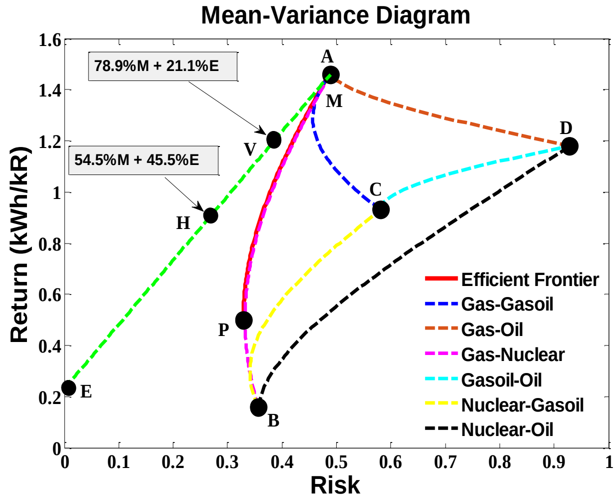

Fig.4. The efficient frontier considering all technologies; A: 100% natural gas, B: 100% nuclear, C: 100% gasoil, D: 100% oil, and E: 100% risk-free.

As shown in Fig. 4, the efficient frontier between the point "M" and the risk-free point is a line which is drawn in green colour. The located points on this line represent the portfolios, which are consist of a portion of the point "M" related technologies, and the remain is related to the risk-free assets. For instance, the point "V", represent a portfolio with 1.2 of the return and 0.3856 of the risk. 78.9% of this point is related to the point "M" (here, natural gas) and the rest for risk-free assets (here, wind energy). Also, the point "H" represents a portfolio with 0.9 of the return and 0.2664 of the risk which is consists of 54.5% of the point "M" and 45.5% of risk-free assets.

In such case, the optimal efficient frontier is composed of a combination of the portfolios, situated on the fossil fuel based efficient frontier and the green line. Whereas, no limitations have been imposed on the amount of the power capacity of the hydro-electric and the wind power technologies, both technologies are risk free, and the wind has higher return, the optimal generation mix contain just wind energy as the risk-free asset. However, taking into account the geographical and environmental constraints of the nuclear, the wind and the hydro-electric technologies, it is impossible to utilize such technologies to cover the full generation capacity of the network. Thus, according to the collected information from the Iran's Energy Affairs of Plan and Budget Organization, the maximum attainable capacity for the nuclear, the wind and the hydro-electrical power plants are 5, 8 and 12 percent of the full capacity of the generation system, respectively. Fig. 5, illustrates the resulted optimal efficient frontier. In this figure, the bold red-colour curve illustrates the efficient frontier of all traditional technologies and the bold green- colour curve illustrates the total efficient frontier by considering the wind and the hydro-electric technologies. As it can be seen, adding the renewable technologies improves the efficient frontier. To cite a proof, the point "N" in this figure, lies on the efficient frontier before considering the renewable resources. However, it gets to the point "H" after having added the renewable resources, which has less risk for the same amount of return.

Fig. 6, illustrates the contribution share for each technology as a percentage of the total generation on the efficient frontier portfolios for different returns after imposing limitations on the nuclear, the wind and the hydro electrical power plants.

2.1. Efficient Frontier, horizon of next 10 years

In this section, as the first step, the introduced problem of equation (4) is solved for fossil fuel-based technologies with respect to the presented data in section 3-2. When the point “M” is located, the efficient frontier would entail all the existing technologies as presented in Fig. 7. In this figure, the black curve represents the efficient frontier of the fossil fuel based technologies. Same as the previous section, the point “M” would be localized using equation (5), and the efficient frontier between the point “M” and the point “E” could be drawn using equation (6) as presented in red colour. In this case, the final efficient frontier for the points with higher and lower returns respect to the point “M” would be equal to that of the points on the black and red curves, respectively. Also, the combination of portfolio related to the point “M” is changed in comparison with the former section. Here, the point “M” consists of natural gas (77.8%), gasoil (3.1%), oil (0.2%), and nuclear fuel (18.9%). This result is obtained due to the small differences between the return of point “A” and other points related to fossil fuel bases technologies regarding the previous scenario. For the risks, lower than risk of point “M” (0.177), the presence of the renewable resources will improve the generation mix and lead to some portfolios with lower risk for a specified amount of return, or higher return for a specified amount of risk. As an instance, the point “P” on the efficient frontier of fossil fuel technologies is an optimal portfolio before considering the renewable technologies. By adding renewable resources to this portfolio, the points “V” and “H” with enhanced characteristics can be reachable.

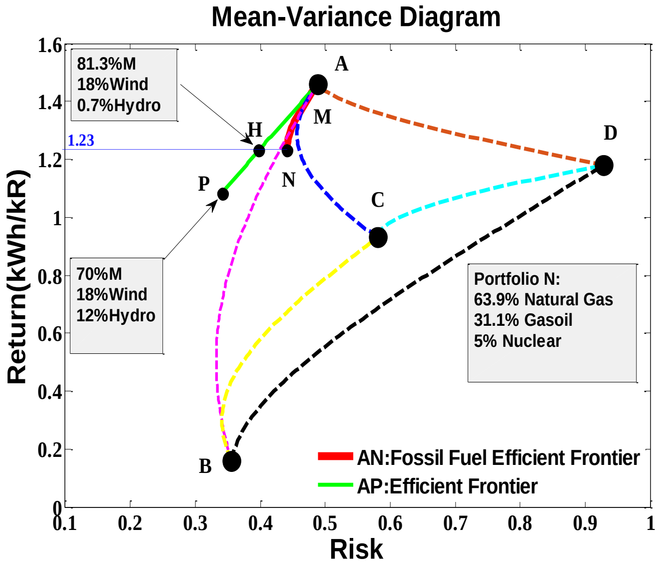

Fig.5. The efficient frontier, considering limitations on the renewable and nuclear technologies capacity.

The efficient frontier in Fig. 7 is obtained without considering any capacity constraint, while as mentioned before, because of geographical and environmental issues, the maximum amount of installable capacity for nuclear and renewable resources technologies is limited. By applying the mentioned limitations (see section 4.1), the modified efficient frontier can be obtained as in Fig. 8. Furthermore, the contribution share of considered technologies for the efficient frontier in different returns is presented in Fig. 9 as a percentage of the total capacity. In Fig. 8, the black-colour dashed line, is the fossil fuel based efficient frontier and the red-colour bold line is the final efficient frontier considering the renewables and maximum capacity limitations.

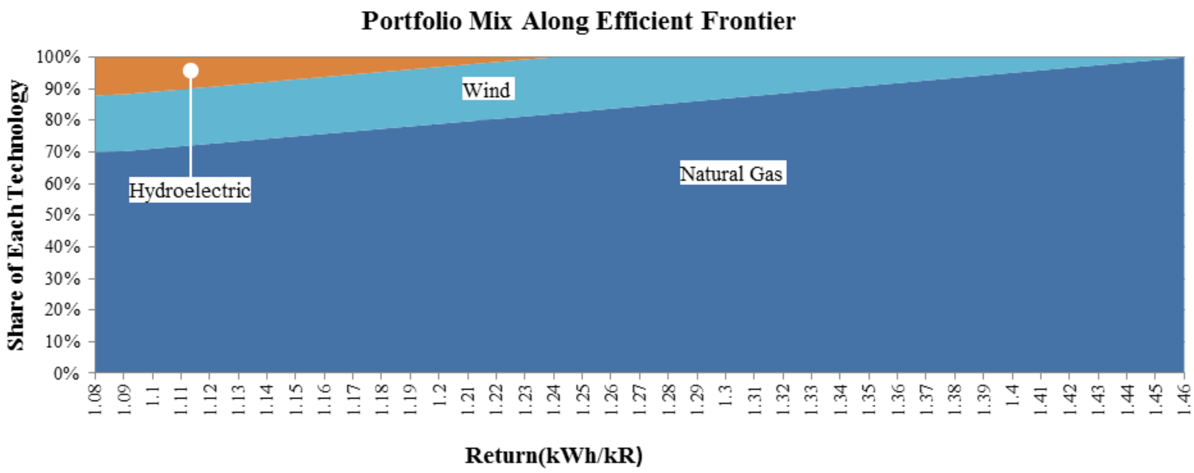

Fig.6. The contribution share of all technologies on the efficient frontier for historical data, after having considered capacity constraints shown as a percentage of the total generation

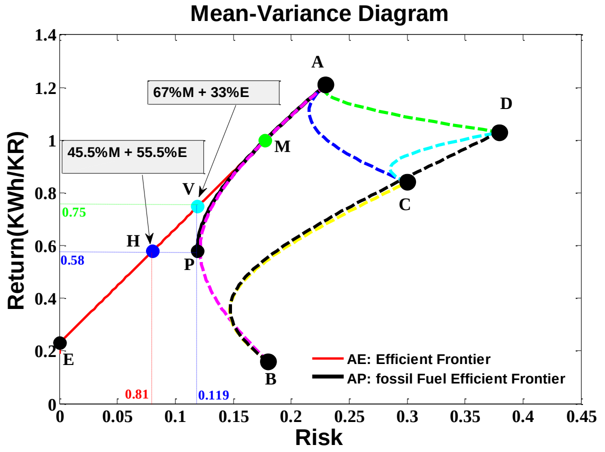

Fig. 7. The efficient frontier on the horizon of next 10 years without considering any capacity constraint

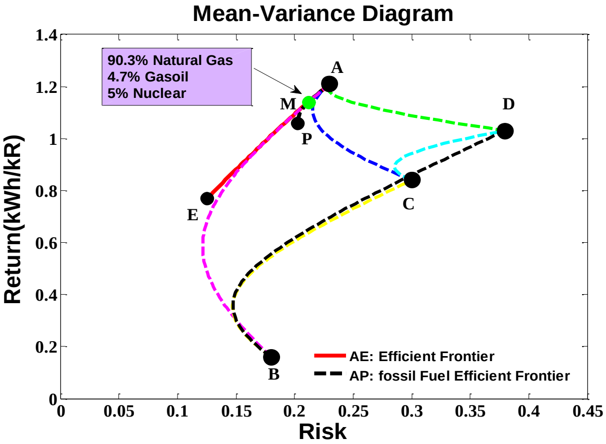

Fig. 8. The efficient frontier, after having considered capacity constraints on the horizon of next 10 years

5. Extending the Model by Considering the Risks of O&M Costs

It was supposed in the previous section that the risk of any technology resulted from the fluctuations in the fuel prices. In the other words, the risks of other cost streams of each technology were not considered. Nevertheless, considering Iran's economic conditions in recent years (especially intense fluctuations of foreign exchange parity prices against Rial), the fixed and variable O&M costs have changed considerably. In this situation, it sounds impossible to finalize the reliable results without considering this costs volatility. In this section, to consider the risks of fixed and variable O&M costs, the introduced model of the previous section is improved in an attempt to achieve more accurate results.

To determine the risks and correlation coefficient of the fixed and variable O&M costs, having access to authoritative resources for surveying the changes of such costs would be imperative. To evaluate the fixed O&M costs, considering the nature of this costs, the insurance premium tax variations have been used. On the other hand, the human resources and machinery parts of the Adjustment Indexes, authorized by Iran's Plan and Budget Organization were considered to measure the risk of the variable O&M costs. These indexes are seasonally announced to be enforced in the area of Iran's development projects where they indicate the costs variation. Consequently, the risks of fixed and variable O&M costs have been considered as 0.2 and 0.3, respectively. Accordingly, the total risk for any technologies could be measured through the equation (7).

$$\sigma_A = \sqrt{\sum_k \sigma_{A,k}^2} \tag{7}$$

Where, σ_A is the total risk of technology "*A*" and $\sigma_{A,k}$ represents cost streams of technology "*A*", i.e. fuel, fixed and variable O&M costs. Therefore, the renewable technologies are no longer considered as the risk-free technologies. Besides, the correlation coefficient between the technologies "*A*" and "*B*" are calculated regarding the fluctuations in the fixed and variable O&M costs as in equation (8).

$$\rho_{AB} = \frac{\sum_k \sum_j \rho_{kj,AB}\, \rho_{A,k}\, \sigma_{B,j}}{\sigma_A \sigma_B} \tag{8}$$

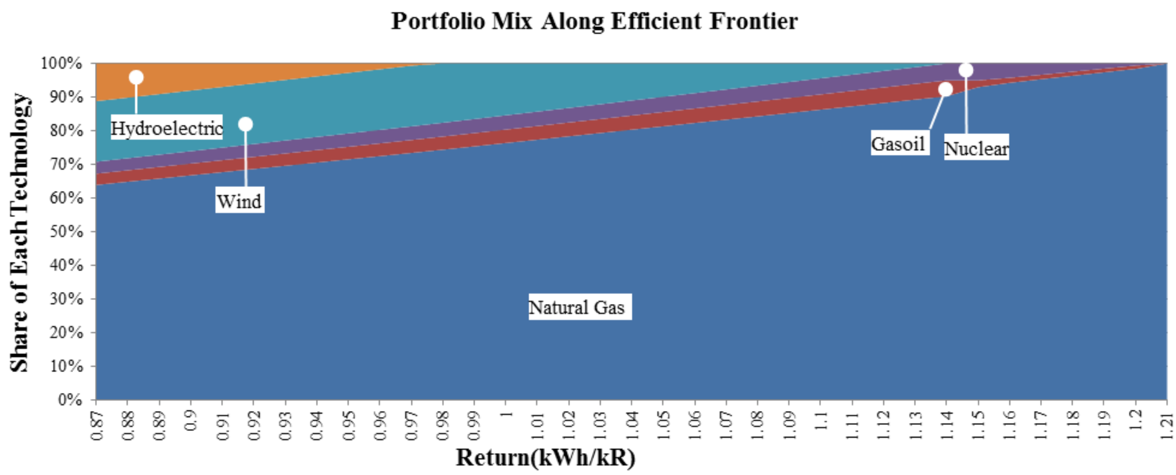

Fig.9. The contribution share of all technologies on efficient frontier on the horizon of next 10 years, after having considered capacity constraints shown as a percentage of the total generation

Here, $\sigma_{A,k}$, $\sigma_{B,j}$ and $\rho_{kj,AB}$ are the K[th] cost component of the technology "A", the J[th] cost component of the technology "B", and the cross-correlation coefficient between these two components, respectively. These cross correlations are presented in Table 7.

The risk of each technologies and the correlation coefficients based on the historical data are calculated in Tables 8 and 9, using equations (7), and (8) as well as the values of tables 2 and 3. Meanwhile, the risks of each technologies and the correlation coefficients in the horizon of the next 10 years are according to Tables 10 and 11, taking into account the values of Tables 5 and 6. Fig. 9 and Fig. 10 show the efficient frontier in the basis of the historical data in the horizon of next 10 years, respectively. Likewise, the contribution share of each technologies in the efficient frontier of the optimal portfolios were illustrated for both scenarios in Fig. 11 and Fig. 12, respectively. It should be noted, the efficient frontier is determined by imposing 5%, 12%, and 18% constraints on the maximum capacity of the nuclear, the hydro-electric and the wind technologies, respectively.

As stated before, by considering the fixed and the variable O&M costs risk, the hydro-electric and the wind technologies are no longer deemed as the risk-free assets. So, the share of these technologies are decreased in comparison with the presented results of section (4).

6. Conclusion

In this paper considering the uncertainities of the price volatility, the application of modern portfolio theory on Iran's power generation mix is presented. In comparision with the conventional solutions, the different generation cost components are not considered deterministic. To do so, the risk of price variations are measured via standard deviation and considered as the second objective function in the presented model. The proposed model were solved for two scenarios. In the first scenario, the historical data related to the recent 10 years were employed as the model entries, while in the second scenario, considering the future developments of Iran, the predicted data for the next 10 years were used.

In order to extend on the applied model, the risks of the O&M costs are included in the proposed model. Also, due to geographical and environmental limitations, the maximum capacity constraints for the nuclear, the wind and the hydroelectric technologies were considered as 5 %, 18 %, and 12 % out of the total generation capacity, respectively. Next, to determine the policy making framework for Iran's generation planning, the related data which had been received from Iran's Plan and Budget Organization is used. The results indicats that, by considering the characteristics of the natural gas, the majority of the contribution share in the optimal portfolios are belonged to this technology in either scenario.

Table 7. Cross-correlations for the cost streams of technologies[1]

		Technology A		
Technology B		Fuel	Fixed O&M	Variable O&M
	Fuel	Tables 3&6[2]	0	o.1
	Fixed O&M	0	o.7	o.2
	Variable O&M	o.1	o.2	o.7

Table 8. Risk of technologies on the basis of historical data

Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
0.6076	0.6838	0.9965	0.5067	0.3606	0.2

Table 9. Correlation coefficients on the basis of historical data

Correlation Coefficient	Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
Natural Gas	1	0.705	0.675	0.3	0.525	0.329
Gasoil	0.705	1	0.683	0.579	0.466	0.292
Oil	0.675	0.683	1	0.591	0.32	0.201
Nuclear	0.3	0.579	0.591	1	0.629	0.395
Wind	0.525	0.466	0.32	0.629	1	0.555
Hydro Eelectric	0.329	0.292	0.201	0.395	0.555	1

Table 10. Risk of technologies on the horizon of next 10 years

Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
0.4277	0.469	0.5238	0.403	0.3606	0.2

Table 11. Correlation coefficients on the horizon of next 10 years

Correlation Coefficient	Natural Gas	Gasoil	Oil	Nuclear	Wind	Hydro Electric
Natural Gas	1	0.8	0.786	0.673	0.745	0.467
Gasoil	0.8	1	0.787	0.656	0.68	0.426
Oil	0.786	0.787	1	0.556	0.608	0.381
Nuclear	0.673	0.656	0.556	1	0.791	0.496
Wind	0.745	0.68	0.608	0.791	1	0.555
Hydro Eelectric	0.467	0.467	0.381	0.496	0.555	1

On the other hand, although the oil has relatively high return, because of the high volatility of it's price, the minimum contribution share is belonged to this technology. Morever, simulation results emphasis the key role of the renewable energy based technologies in the risk management of generation expansion policy making.

[1] The information of the table has been gathered from the afore-mentioned references as well as the standpoints of Plan and Budget Organization's experts through "engineering judgment".

[2] For historical data, table 3 and for horizon of next 10 years table 5 is applied.

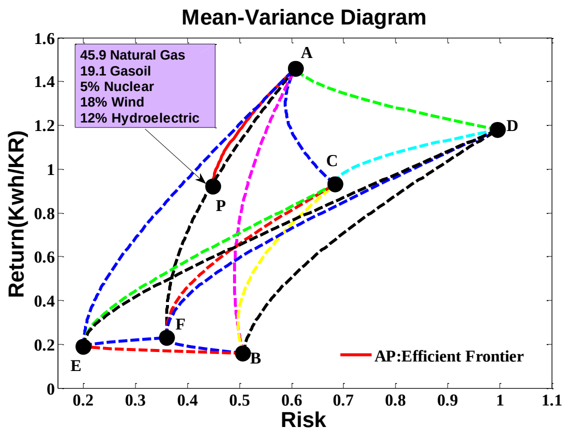

Fig. 9. Efficient frontier with the consideration of fixed and variable O&M costs, based on the historical Data

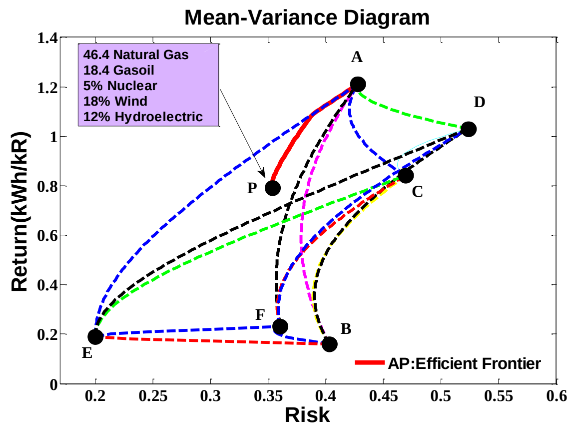

Fig. 10. Efficient frontier with the consideration of fixed and variable O&M costs, on the horizon of next 10 years

In case of the horizon of next 10 years, the contribution share of the gasoil and the nuclear technologies are higher than the scenario of the recent 10 years. Meanwhile, by including the risk of O&M costs in the model, the renewable energy based technologies are not considered as risk-free assets.

In this case, the contribution share of the gasoil and the nuclear technologies are decreased by increasing the expected returen of the portfolio. Finally, it can be concluded that, as the expected return of portfolio isincreased, the higher contribution share is belonged to natural gas.

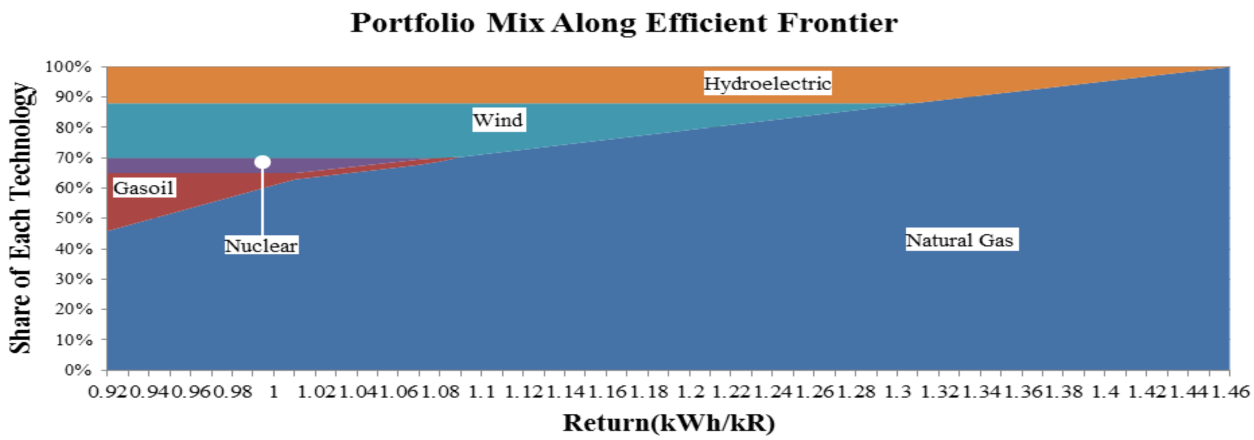

Fig. 11. Contribution share of all technologies on efficient frontier, with the consideration of fixed and variable O&M costs, based on the historical Data

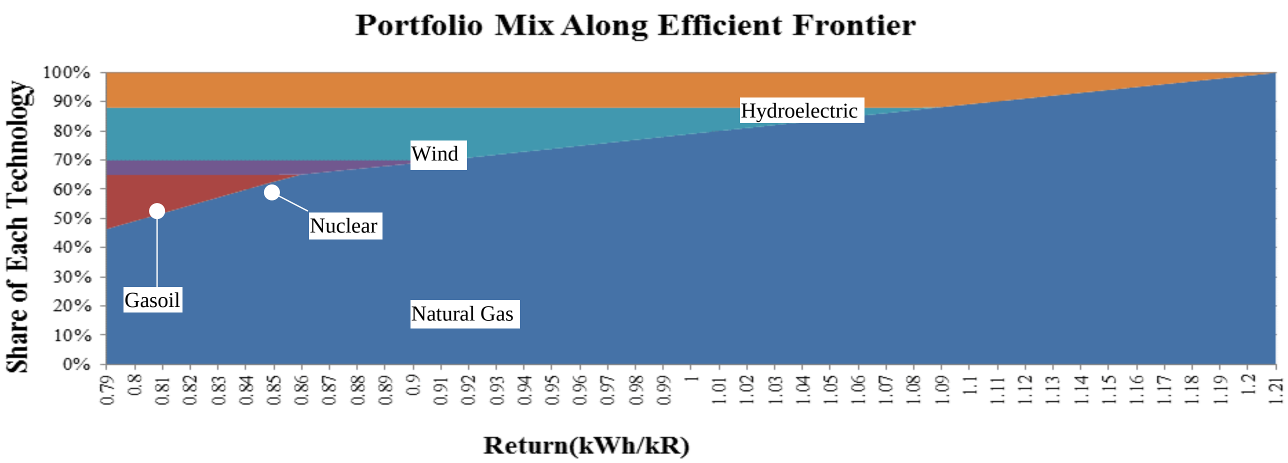

Fig. 12. Contribution share of all technologies on efficient frontier, with the consideration of fixed and variable O&M costs, based on the horizon of next 10 years

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