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Research paper

An Approach for Evaluating Incentive Policy of Wind Resources Considering the Uncertainties in the Deregulated Power Market

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Abstract

Background and Objectives: Development of intermittent wind generation has necessitated the inclusion of several creative approaches in modeling the deregulated power market with presence of wind sources. The uncertain nature of wind resources will cause the private companies meet several risks in their medium and long term planning in a restructured power market. In addition to considering the uncertainties such as load, fuel costs, wind power generation and technical actions of rivals for modeling the restructured power market, the regulatory policies i.e. incentive policy for wind resources and Carbon tax should be assumed in this approach.
Methods: The first contribution of this article is to propose a developed mathematical model in order to evaluate the medium term deregulated power market by assuming the hybrid wind-thermal power plants. The second contribution is to evaluate the impact of different types of Feed in Tariff supports on Market Clearing Price, Expected Cost for Government, profits and contribution of each firm in electricity generation in the restructured power market. Also, the scenario based method has been used to generate the scenarios for wind uncertainties and then their reliability validate based on the statistical methods.
Results: The proposed mathematical model in the first contribution is calculated for each season and load levels based on the proposed wind scenarios. The functionality and feasibility of this model is demonstrated by simulation studies.
Conclusion: The proposed model in this article can be so useful for evaluating the different types of incentive policies for renewable energies. Moreover, this study confirms the previous researches that selected the Feed in Tariff as an efficient approach for developing the wind resources.

Introduction

Wind power plants, because of the various regulatory policies as well as their uncertainties, are among the risky investment in the deregulated power market. Thus, it is essential to provide a comprehensive model to investigate the effect of different types of incentive policies in the deregulated power market. In this model, all uncertainties in the electricity market, market regulatory policies and incentives of renewable power plant should be considered.

European Union (EU) countries have prepared several incentive policies to increase renewable resources [1]. Among renewable sources, the perfection rate of wind technology is higher than the others. The development has happened in consequence of several advantages of wind such as minimum environmental effects [2]-[5]. Furthermore , the wind has been developed very quickly rather than the other renewable technologies because of the low R&D expenditure [6]. In the late 1990s, around 70% of wind generators had been installed in Europe, 19% in North America and just 9% in Asia [7]. Besides the expansion of wind technologies, the structure of the power market has reformed from the centralized to the decentralized power market [8], [9]. In this article, competitive power market has been mentioned as restructured power market. However, these changes have a serious effect on the goals of the various power markets. The main purpose of the players in restructured markets are not the same as the objectives explained by the government in regulated markets. The main aims of planning in the regulated power market is to respond the demand through the acceptable reliability [10], [11]. While, maximize the profit is the goal of the investors in the deregulated power market [12]-[15]. In the restructured power market the decision makers of wind resources are encounter with several challenges. These challenges related to the volatility of wind speed, uncertainties in the restructured power market, regulatory policies (such as incentive policies, CO2 taxation, etc.) and high capital investment of this technology. These challenges are barriers against the development of wind resources [16]. Moreover, the wind power plants could not compete with other conventional power plants in the restructured power market because of the intermittent nature of wind. Therefore, incentive policies need to expand the wind power plants [3], [17]. There are four main policies for developing the renewable energies which are including the auctions and fiscal incentives, tax credits, quotas and tradable green certificates and Feed-in tariffs (FIT). However, the FIT is the most effective incentive to develop the renewable resources [15], [21]. Feed-in tariffs are incentive mechanism suggested to speed up the investment in renewable energy by providing them reward (a "tariff") above the retail or wholesale rates of electricity. Spain is one of the first countries that have developed specific incentive mechanisms for implementing the renewable energies. They established the first FIT in 1994 through the fixed FIT. Then, Spain encouraged the renewable firms to sell their generation through the wholesale market and received premium in a restructured power market. Also, distribution utilities had been obliged to buy the whole renewable generation. Germany has supported the renewable energies by developing the technologies in order to decrease the generation cost of renewable energies. In addition to Research and development subsidies, the Feed in supports motivated the development of renewable in Germany [23], [24]. The other countries such as United States, Canada and Denmark are developing the renewable sections by considering the different types of supportive policies. Although FIT supports are effective policy to develop the renewable energies in developed countries, it exposes excessive cost to the government and costumers.

In addition, the wind resources' investors encounter more uncertainties rather than the conventional companies. These stochastic uncertainties are including the wind velocity, electricity demand and fuel price. Also, these stochastic parameters as well as the technical actions of rivals fluctuate the market clearing price. Therefore, the investors in the deregulated power market and governments should equip themselves with powerful and flexible decision making tools in order to investigate the effect of these uncertainties as well as the effect of various types of FIT on their, market clearing price (MCP), profits and contribution of each firm in electricity generation in the restructured power market. This decision tools should capable to model the uncertainties (such as demand, fuel price, wind and rational uncertainties) and the CO2 tax and bilateral contracts in addition of the FIT. Due to these uncertainties, modeling and planning in the restructured power market has encountered more risks. Different methods are available to evaluate the uncertainties. Usually, these methods are based on the probability and statistical methods. Accordingly, the decision problems such as planning and risk management should be solved by considering the stochastic uncertainties such as load and fuel price uncertainties and rational uncertainties that is the operational strategic behaviour of participants in the restructured environment. Moreover, the realities and the regulator policies should be considered in medium term planning.

A mathematical model has been suggested in [25] for evaluating the effect of fix FIT. In this model, uncertainties and also the realities of the deregulated power market has been neglected. In [26], a review paper has been given for assessing the policy in power market. It has been illustrated that policy assessment and Generation expansion planning are the most important issues [26]. furthermore, an approach has been given in [27]. Although this model provide useful data about the incentive mechanism for renewable sources in the deregulated power market, the CO2 tax has been dismissed [27].

In this article, a developed mathematical model is proposed to investigate the impact of FIT on the profit, MCP, Expected Cost for Government and contribution of each firm in the restructured power market. The main contribution of this paper is to propose a mathematical model in order to investigate the effect of different types of FIT by considering the hybrid wind-thermal power plants, rational and stochastic uncertainties and realities such as bilateral contracts and carbon tax for thermal units in a restructured power market. Also, the uncertainty of output power of wind power plants has been considered in this study based on the scenario based method. The reliability of these scenarios validate based on the statistical methods. The developed mathematical model is examined with fixed FIT, variable FIT for different levels of demand and without FIT.

The rest of this paper is structured as follows: Section 2 illustrated the description of the proposed structure and describes the modeling of wind generation. Section 3 demonstrate the proposed mathematical model to simulate the deregulated power market. Section 4 implements the developed model on a power market and the results are discussed in Section 5. Finally, the last section is focused to the conclusion.

Description of the Proposed Structure

The flowchart of the proposed model is revealed in Fig. 1. It presents four main blocks, which are explained in the next paragraphs. In this study, a new method has been proposed to generate the wind scenarios according to the scenario-based method. The wind scenarios together with their probabilities have been generated based on the data mining algorithm. Then, their results are validated with the statistical method. The proposed method has been applied for a standard system in order to reveal the effectiveness of this approach. This section is presented in block 1. In the second block, a model has been developed to evaluate and analyze the medium term restructured power market with the presence of the hybrid wind-thermal firm. In this model, electricity demand and fuel costs as short term uncertainties are simulated through Monte-Carlo method annually. In addition, the wind generation's scenarios with probabilities of their occurrence have been calculated through the outcomes of block 1. These uncertainties are called the stochastic uncertainties which are considered in the proposed model to simulate the medium term power market. Besides the stochastic uncertainties, the strategic behavior of investors, as an effective parameter on the MCP, is analyzed based on the concept of Cournot game theory. This concept has been used in order to determine the MCP in the restructured power market. Also, regulatory interventions such as the CO2 tax, FIT, and bilateral contracts are assumed in this model as the exogenous parameters.

Then, the proposed model has been examined with various types of FIT which are represented in the third block. Finally, the output results of this model are given for each type of FIT. These results are represented in the fourth block. The details of these blocks are described in the next sections.

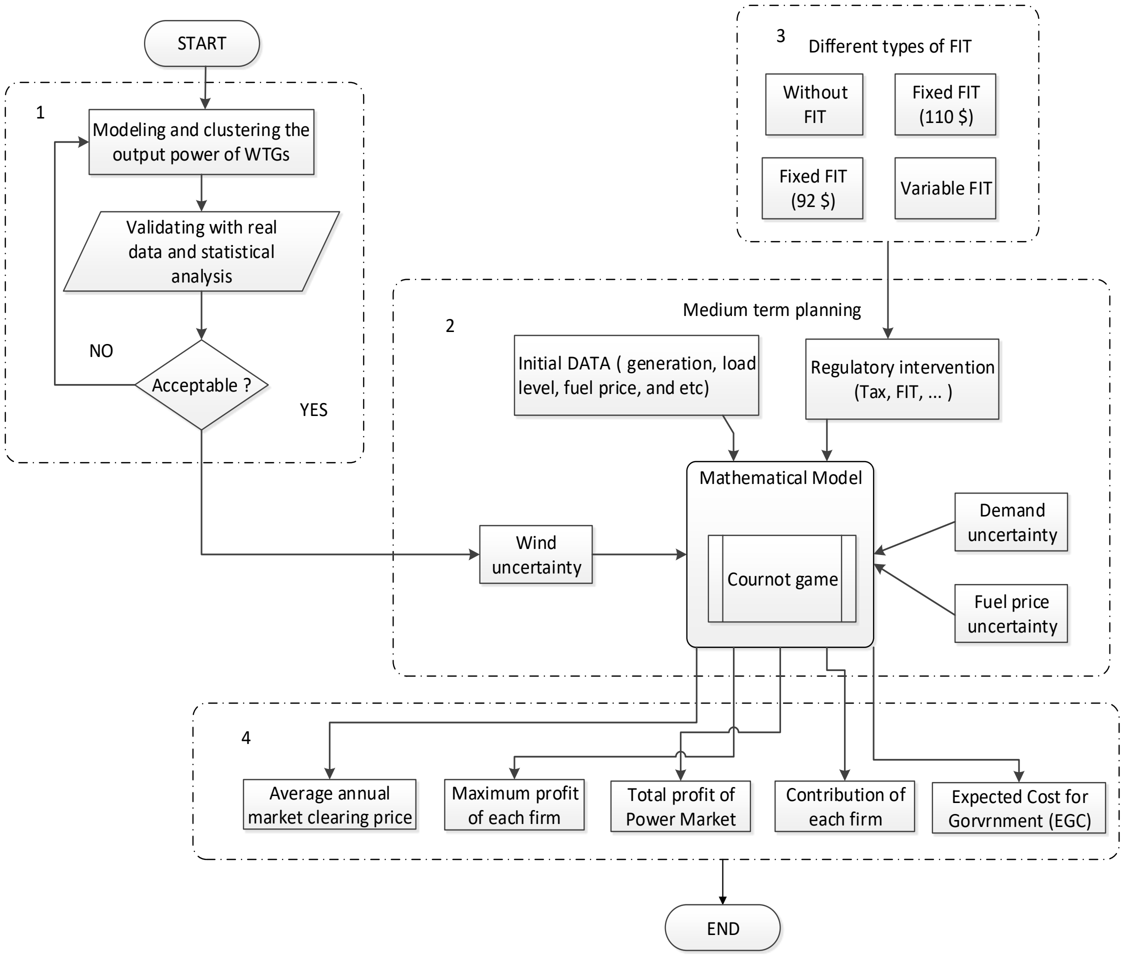


Fig. 1: Flowchart of the proposed structure.

Scenario Reduction Algorithm for Output Power of Wind Power Plants

Although, various methods have been implemented to decrease the generated scenarios for the velocity of wind, the precision of them were not justified through a scientific method [15], [28], [29]. In this article, the proposed method has been validated and justified based on the real data and Weibull probability plot test. In this article, the generated scenarios for wind power plants are selected based on data mining. The basis of this method is to classify the real wind speed data that have certain characteristics in a specific group. Data mining have various methods that in this article the K-means method is used to generate wind scenarios. The main purpose of scenario reduction algorithm is to downsize the data set whereas holding the stochastic data as intact as possible [30], [31]. In this paper, the clustering method is given to generate scenarios for the velocity of wind. In the proposed method, each year is divided into four seasons and then the acceptable number of scenarios determined for each season. Several scenarios can be generated for wind speed data in each season, but choosing the optimal number of scenarios can greatly help to increase the speed of the program. For this reason, a method should be proposed to select the appropriate number of scenarios in each season. In this article, after the wind scenarios have been generated, the parameters of the Weiball distribution function (scale and shape) are determined for these scenarios. Then, the scale and shape parameters compared for both Weibull distribution functions before and after the scenario generation. These steps are tested for the cases with different number of scenarios and reconciled with the Weibull parameters of real wind speed data. Finally, scenarios that are closer to the distribution function of real wind speed data in terms of scale and shape have been used for the next stage of this research. However, it is possible that the values of shape and scale parameters for each generated scenarios are very close to each other. Therefore, in order to avoid inaccurate selection, the authors of this article suggest a statistical method in addition to the previous method. In other words, in order to validate and justified the generated scenarios, an Anderson-Darling statistic test is applied according to Fig. 3. This test was done using Minitab software. Accordingly, if the scatter points are located between two references lines it means that the data set conform the Weibull distribution. Furthermore, if the P-value is higher than the significance level, for instance 0.05, then the Weibull probability plot test is meaningful and the data fit a Weibull distribution. Also, less AD values demonstrate a better fit. In this article, the Weibull distribution functions for real wind data and wind scenarios data for each season together with the Weibull probability test have been applied to validate the number of scenarios which is selected for each season. This is because the Weibull distribution gives the best fit for the wind speed data that have been used in this study [4], [32].

The k-means clustering algorithm which is proposed for this approach is as follows:

Step 1: To calculate the number of clusters based on the mean and standard deviation.

Step 2: To initialize the centroids of each cluster

Step 3: To optimize the following objective function:

$$\min_{\{C_1, C_2, \ldots, C_j\}} \sum_{j=1}^{K} \sum_{i=1}^{n} \left\| x_i^{(j)} - C_j{}^2 \right\| \quad (1)$$

The k-means method is shown in Fig. 2.

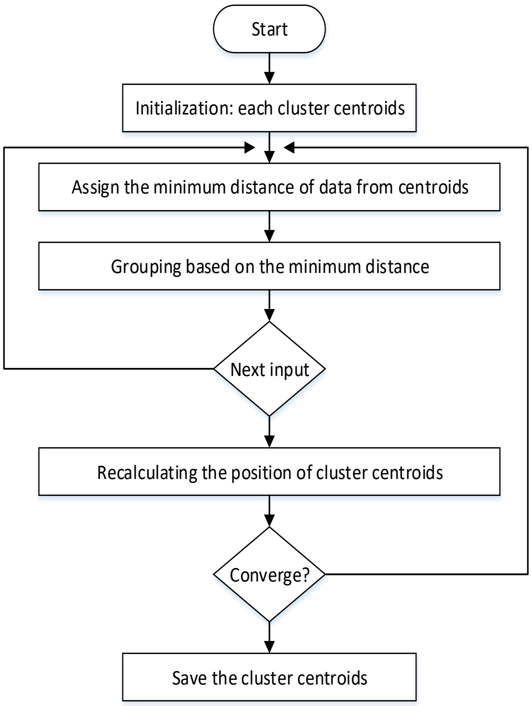


Fig. 2: Flow chart of K-means method.

The wind speed data were gathered from Swift Current in the Saskatchewan state-Canada [33]. Finally, the proposed scenarios for all seasons are shown in Table 1.

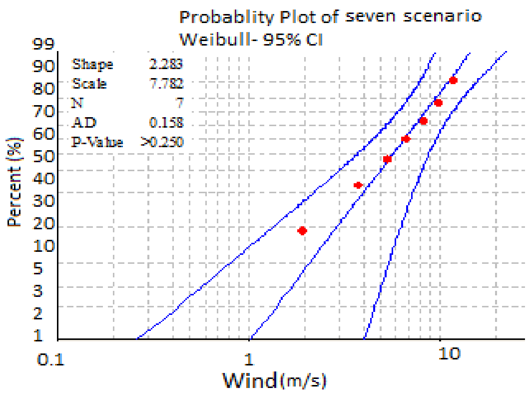


Fig. 3: Sample of Weibull probability plot test for first season.

Table 1: seasonal generated scenarios for wind farm

Proposed Scenarios for electricity generation								Weibull parameters for each scenario		Weibull parameters from simulated data		Statistical results	
								Shape	Scale	Shape	Scale	P-value	AD
S1	Output [MW]	0	3.31	10.02	16.63	24.66	34.93	2.184	7.251	2.1522	6.5248	>0.25	0.149
	Prob [%]	14	23	24	19	14	6						
S2	Output [MW]	0	1.41	5.92	12.42	26.05		2.291	6.361	2.1695	5.1198	>0.25	0.166
	Prob [%]	24	22	17	26	11							
S3	Output [MW]	0	5.13	11.71	19.61	27.17	38.24	2.279	7.671	2.5788	6.9993	>0.25	0.138
	Prob [%]	20	29	30	11	8	2						
S4	Output [MW]	0	2.73	11.48	28.31			2.432	8.44	2.8548	8.0269	>0.25	0.195
	Prob [%]	20	23	35	22								

Mathematical Formulation for Deregulated Power Market

The main goal of the proposed objective function is to maximize the profit of each players in the deregulated power market. The objective function is presented in (2) to (4). Also, the constraints are shown in (5) to (9).

$$\begin{aligned}
Max\ Benefit = & \sum_{e}^{Ne}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left((\sum_{u}^{Nu} N_{e,u}\times P_{e,u,sl}) - Q_{e,sl}\right)\times SP_{sl} \\
& + \sum_{e'}^{Ne'}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left((\sum_{u'}^{Nu'} N_{e',u'}\times P_{e',u',sl}) - Q'_{e',sl}\right)\times SP_{sl} \\
& + \sum_{e}^{Ne}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times Q_{e,sl}\times BP_{sl} \\
& + \sum_{e'}^{Ne'}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times Q'_{e',sl}\times BP_{sl} \\
& + \sum_{e'}^{Ne'}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left(\sum_{uw}^{Nuw} N_{e',uw}\times PW_{e',uw,sl,n}\right)\times (SP_{sl}+inc)" \\
& - \sum_{e}^{Ne}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left(\sum_{u}^{Nu} N_{e,u}\times FP_{u}\times\left(a_u + b_u\times P_{e,u,sl} + c_u\times (P_{e,u,sl})^2\right)\right) \\
& - \sum_{e}^{Ne}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left(\sum_{u}^{Nu} N_{e,u}\times Tax\times\left(a_u + b_u\times P_{e,u,sl} + c_u\times (P_{e,u,sl})^2\right)\times EM_u\right) \\
& - \sum_{e'}^{Ne'}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left(\sum_{u}^{Nu} N_{e',u'}\times FP_{u'}\times\left(a_{u'} + b_{u'}\times P_{e',u',sl} + c_{u'}\times (P_{e',u',sl})^2\right)\right) \\
& - \sum_{e'}^{Ne'}\sum_{s}^{Ns}\sum_{l}^{Nl} d_{sl}\times\left(\sum_{u'}^{Nu'} N_{e',u'}\times Tax\times\left(a_{u'} + b_{u'}\times P_{e',u',sl} + c_{u'}\times (P_{e',u',sl})^2\right)\times EM_{u'}\right)
\end{aligned} \quad (2)$$

$$g_{e,sl}=\sum_{u}^{Nu}N_{e,u}\times P_{e,u,sl} \tag{3}$$

$$g_{e',sl}=\sum_{uw}^{Nuw}N_{e',uw}\times PW_{e',uw,sl}+\sum_{u'}^{Nu'}N_{e',u'}\times P_{e',u',sl} \tag{4}$$

Subject to:

$$BP_{sl}=SP_{sl,t-1}\left(1+GP\right) \tag{5}$$

$$g_{e,e',sl}\le D_{sl} \tag{6}$$

$$P_{e,u.min}\le P_{e,u}\le P_{e,u,max} \tag{7}$$

$$P_{e',u'min}\le P_{e',u'}\le P_{e',u'max} \tag{8}$$

$$PW_{e',uw,nmin}\le PW_{e',uw,n}\le PW_{e',uw,nmax} \tag{9}$$

The main objective function which is represented in (2) is made up of two main sections. The revenue of renewable and traditional power plants as well as the income for each firm in contractual markets is shown in the first section. Also, the incentive policy for wind firms is given in first section. Then the costs such as the CO2 tax and costs for heat power plants are shown in the second part of the proposed model. The amounts of generations of traditional and hybrid traditional-renewable private firms are shown in (3), and (4), respectively.

Electricity price for bilateral contract in each season and each load level is represented in (5). The demand constraints is shown in (6), because the private firms are not responsible to response the all request of the power market. Upper and lower limit of the generation capacity of each firms and units are represented in (7), and (8). Furthermore, the generation restriction in renewable units of hybrid firm is shown in (9).

The outputs of the proposed model are including the whole energy generated in market, electricity produced by each company, profit of power market, and profit of each company. For this situation, investors in the power market with lower expenses as opposed to different firms will amplify their benefits by incrementing their generations. On the other hand, different individuals with excessive generating costs decide on not to take part in this type of power market or they will take part with minimum generation. Therefore, the equilibrium price and equilibrium quantity will no longer be provided.

In the balance condition the amount of electricity load is equivalent with the amount of supply, which is the main characteristic to pursue choice in the deregulated market. In addition, the investors in the deregulated market has less data about the decision of rivals and they need a consistent model to make their operational decisions. Game theory is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers" [34].

There are three famous games to evaluate the competitive power market which are including Cournot, Bertrand, and van Stackelberg. In the first game theory model, each company picks a result amount to maximize benefit. Firms are accepted to deliver homogeneous merchandise that are non-storable. The equilibrium price is calculated based on an auction process. The mannequin additionally assumes that all corporations in the enterprise can be recognized at the beginning of the game, and decision-making by way of companies happens simultaneously [35]-[37].

Subsequently, on account of numerous likenesses between Cournot game model and the deregulated power market, the idea of Cournot game has been implemented in this paper to decide the Market Clearing Price (MCP). The concepts which is used in this paper in order to calculate the MCP by considering the uncertainties of demand and fuel costs are shown in Fig. 4 and Fig. 5.

In order to clarify the issue, the steps of the proposed algorithm are explained in 8 steps as follows:

Step 1: Calculate the power generation of each company using the proposed objective function based on the initial electricity price.

Step 2: Update the electricity price using the following linear demand function.

$$D_{sl}\left(SP_{sl}\right)=-A_{sl}\times SP_{sl}+B_{sl} \tag{10}$$

where D_{sl} is the total generation of power market in each season and load levels. Also, A and B are constant value which are determined based on (11) and (12) respectively.

$$A_{sl}=\frac{B_{sl}}{pc.\pi_{base,sl}} \tag{11}$$

$$B_{sl}=dc.D_{base,sl} \tag{12}$$

Step 3: The calculated price is compared with the initial price. If these 2 values are equal, the program is saved and the results are shown. Otherwise, steps 1 and 2 are repeated until the Nash equilibrium is reached. These three steps show in internal loop of Fig. 4.

Step 4: The above three steps are implemented for all the wind scenarios generated in the previous section of this article. This step represents in external loop of Fig. 5.

Step 5: Simulating the demand and fuel costs for each firm based on the Monte Carlo technique. In this paper, normal distribution function is considered to generate random data for these uncertainties. The proposed algorithm shows in Fig. 5.

Step 6: Save the output results which are including the average market clearing price (AMCP), annual average market clearing price (AAMCP), expected cost for government (ECG), average annual profit (AAP) for each firm and total profit of power market.

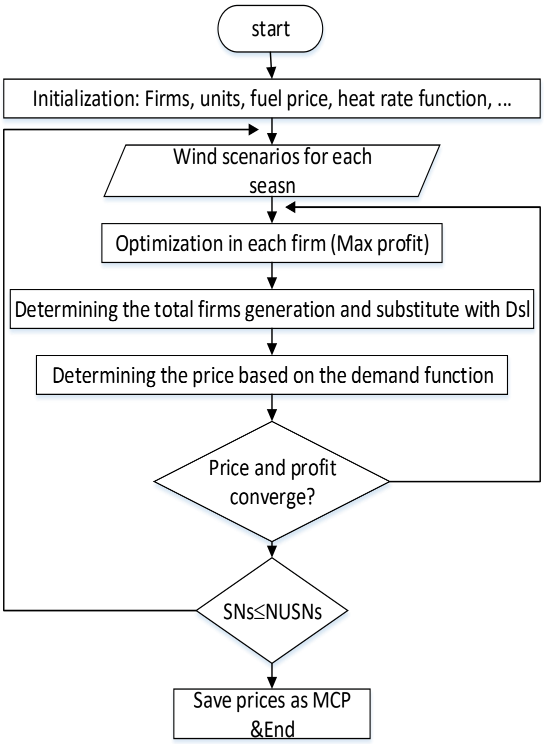


Fig. 4: Proposed algorithm to determine the MCP.

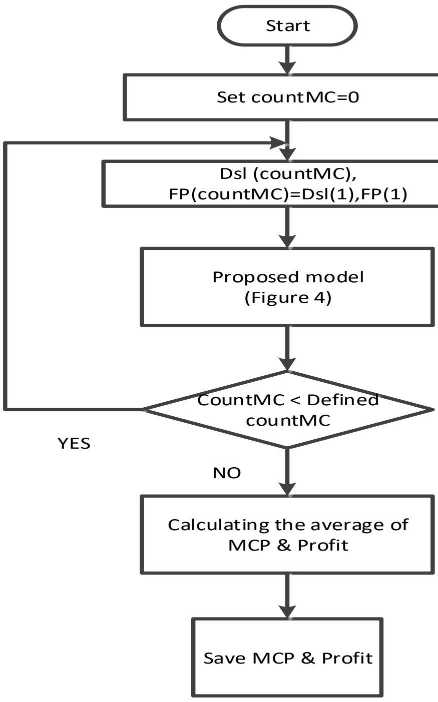


Fig. 5: Monte-Carlo for simulating the uncertainties (Demand and fuel costs).

Case Study

The proposed approach in this study is tested by applying IEEE RTS1 [38]. The whole installed capacity and the peak load of the study system are 2850 and 2500 MW, respectively. Characteristics regarding the firms in this system are revealed in Table 2. The study system includes five price maker investment companies.

The fuel costs and the information related with the producing units of these investment companies are taken from sources [39], [40] and are shown in Table 3. It is considered one year for the period of this study. Four windy seasons were considered for each year. Also, three load levels (off-peak, medium and peak levels) were assumed in this study for each season. The results of simulating wind scenarios are shown in Table 1.

The load duration data have been gathered from [41] and illustrated in Table 4. The amounts of CO_2 emission for candidate units are illustrated in Table 5. The percentages of FIT for each load level are illustrated in Table 6.

Table 2: specifications of units

	Type of units			
	Oil/steam	Coal/steam	Wind	Nuclear
Firm 1	2	2	-	-
Firm 2	3	3	-	1
Firm 3	4	4	-	-
Firm 4	1	2	-	-
Firm 5	1	2	6	-

Table 3: Fuel cost and power limitation for each unit

Types of unit	Oil/steam	Coal/steam	Wind	Nuclear
Fuel[$/MBTU]	5.27	1.68	-	1.65
Max P [MW]	12-197	76-350	50	400
Min P [MW]	2.4-68.95	15.2-140	0	100

Table 4: Load duration data for each season and each load level

Season	Load level and duration [MW]&[hrs]		
	Off-peak (Duration)	Medium (Duration)	Peak (Duration)
1	950(876)	1800(985.5)	2300(328.5)
2	1200(876)	1650(985.5)	2370(328.5)
3	1300(766.5)	1900(876)	2500(547.5)
4	1000(876)	1550(985.5)	2250(328.5)

[1] Reliability test system

Table 5: CO2 emission [lb/MMBTU]

	Oil/steam	Coal/steam	Wind	Nuclear
CO2 EM	170	210	0	0

Table 6: Percentages of FIT for each load level

	Base (%)	Medium (%)	Peak (%)
SN1	50	60	70
SN2	70	80	90
SN3	110	120	130
SN4	120	130	140

Results and Discussions

In this section, the findings of this research are examined. These results will be analyzed in three parts. The first part related to the generated scenarios for wind power plants.

Then the robustness of the proposed mathematical model is examined in the second part based on the sensitivity analysis technique. Finally, the proposed model is investigated for different types of FIT in the last part.

A. Wind Scenario Gereration

In this section, the results of the Weibull distribution functions of wind speed data as well as the clustering wind data for each season are shown in Fig. 5 and Fig. 12.

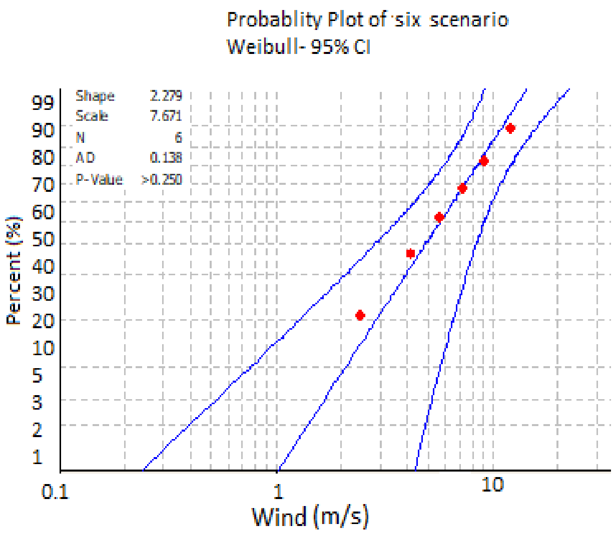


Fig. 5: Weibull probability plot test – first season.

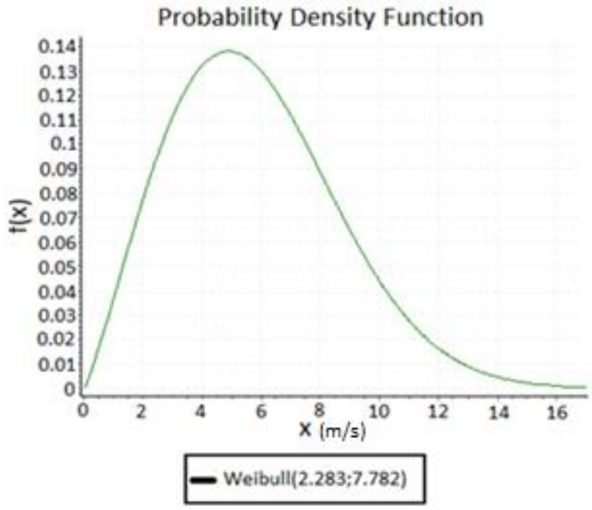


Fig. 6: Weibull distribution function - first season.

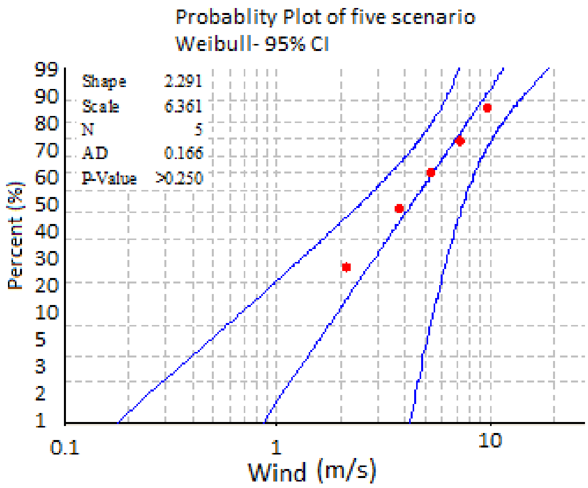


Fig. 7: Weibull probability plot test - second season.

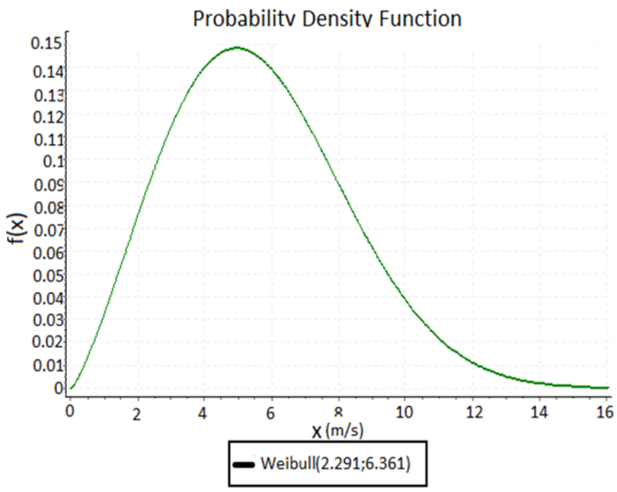


Fig. 8: Weibull distribution function for second season.

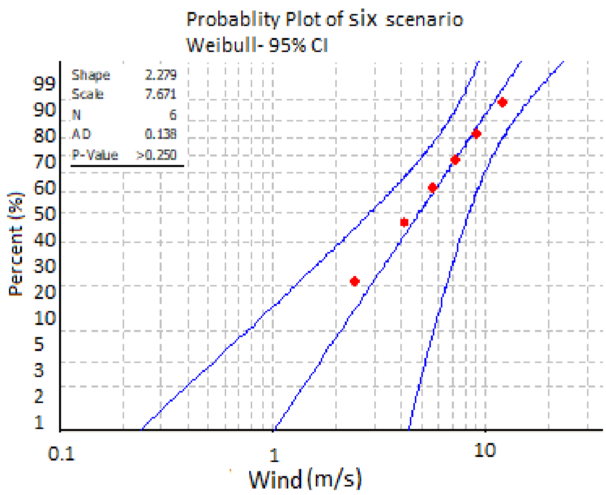


Fig. 9: Weibull probability plot test for third season.

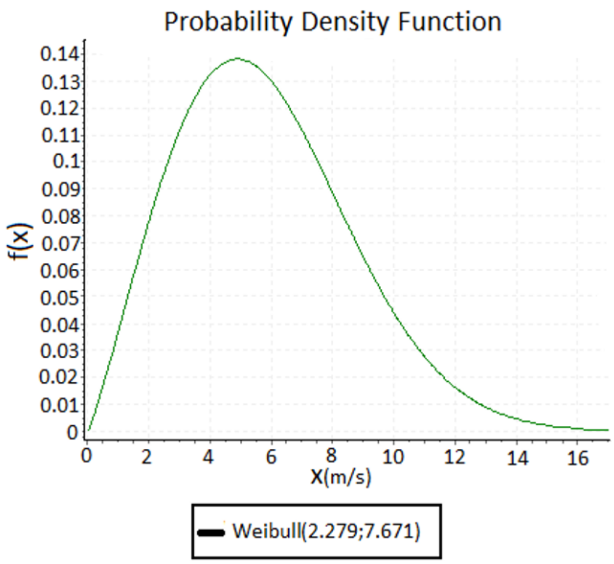


Fig. 10: Weibull distribution function for third season.

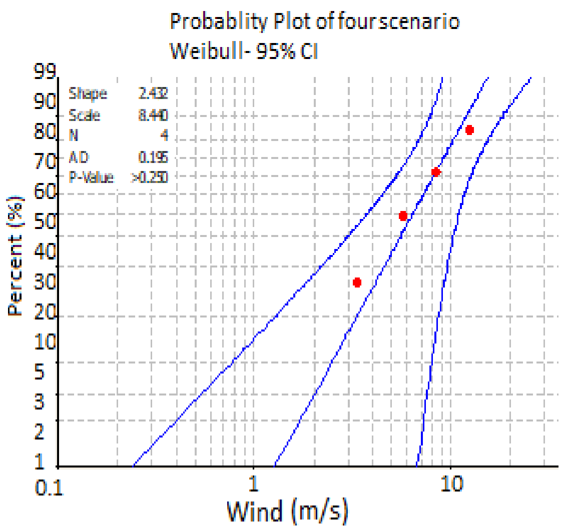


Fig. 11: Weibull probability plot test for forth season.

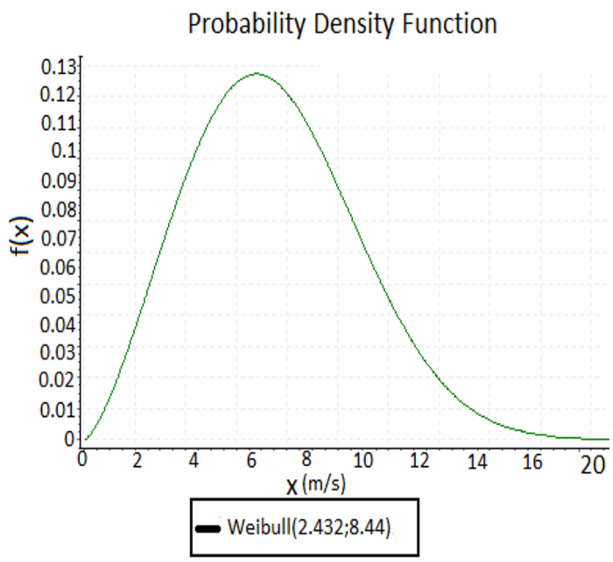


Fig. 12: Weibull distribution function for forth season.

B. Sensitivity Analysis of Proposed Model

The main purpose of this section is to validate and verify the proposed model. In fact, sensitivity analysis is used to examine the relationship between a specific dependent variable and independent variables. In this article, the effect of fuel price changes on the profit of each company and also the whole market is investigated. The results are given in Table 7. Accordingly, with the increase in the fuel price, the total profit of the power market decreases. These results show the correctness of the proposed model in which the profit of firms decrease as their costs increase.

Table 7: Sensitivity analysis of proposed model

Growth of fuel price	Profit [M$]					
	Firm1	Firm2	Firm3	Firm4	Firm5	Total
2%	25.56	78.99	51.11	62.95	29.66	248.3
4%	24.55	75.29	49.1	62.06	27.59	238.6
6%	24.18	73.96	48.36	61.33	25.35	233.2

C. Investigating the Different Types of FIT

The developed model is tested for four types of FIT and their results are illustrated in Table 7 and Table 8. Each case study is described as below:

Case study No. 1: In this case study, the FIT is not considered for wind resources.

Case study No. 2: The proposed model for simulating the restructured power market is solved with fixed FIT. Two different scenarios have been considered for this case study. These scenarios are including the FIT lower than the average fixed FITs in European countries (92

$/MWh), and FIT higher than the average fixed FITs in European countries (110 $/MWh).

Case study No. 3: In this case study, the FIT changes for different load levels. But these variations are considered fixed for each load level. Three different scenarios are imagined for solving the proposed model. In the first scenario, 80% of the MCP for each load levels (Low, Medium, and High) is paid to wind resources as FIT. In the second and third scenario 100% and 120% of the MCP for each load levels is considered for wind resources as FIT, respectively.

Case study No. 4: The MCP is increased by growing the electricity demand. Accordingly, the more FIT can be proposed in peak load level and it reduces to lower level. In case study No. 4, the proposed model solves for four different types of scenarios. The percentages of FIT for each load level are illustrated in Table 6. In scenario No.1, For instance, 50%, 60% and 70% of the MCP will be paid to wind resources as FIT for base, medium, and peak load levels, respectively. The average market clearing price (AMCP), annual average market clearing price (AAMCP) and expected cost for government (ECG) are illustrated in Table 8. ECG is mentioned as a factor in order to determine the cost that the government should pay as incentive. It calculates according to (13). According to Table 7, the AAMCP increases by growing the rate of fixed FIT from zero to 110 $/MWh. Also, The ECG increases through these variations.

$$ECG_{e'} = \sum_{s}^{Nn}\sum_{l}^{Nl}(g_{e',sl} \times inc) - (g_{e',sl} \times MCP_{sl}) \tag{13}$$

Table 8: Simulation results for investigating the effect of type of FIT on MCP and ECG

Cases	Types of FIT	AMCP [$/MWh]			AAMCP [$/MWh]	ECG[$]
		L	M	H		
No. 1	W/out FIT	22	42.924	90.748	51.891	0
No. 2	Fixed FIT (92)	22.028	42.96	90.743	51.91	93141.95
	Fixed FIT (110)	22.033	42.972	90.748	51.918	135734.6
No. 3	F/V SN1	22.02	42.915	90.547	51.827	99307.1
	F/V SN2	22.02	42.975	90.501	51.832	122898.8
	F/V SN3	22.036	42.913	90.788	51.912	148283.9
No. 4	V/V SN1	22.028	42.979	90.793	51.933	79625.51
	V/V SN2	22.013	42.982	91.074	52.023	105031.9
	V/V SN3	22.019	42.954	90.847	51.94	155961.7
	V/V SN4	22.008	42.99	90.481	51.826	167411.8

The results for investigating the effects of different case studies on the average annual profit (AAP) for each firm and total profit of power market have been represented in Table 9.

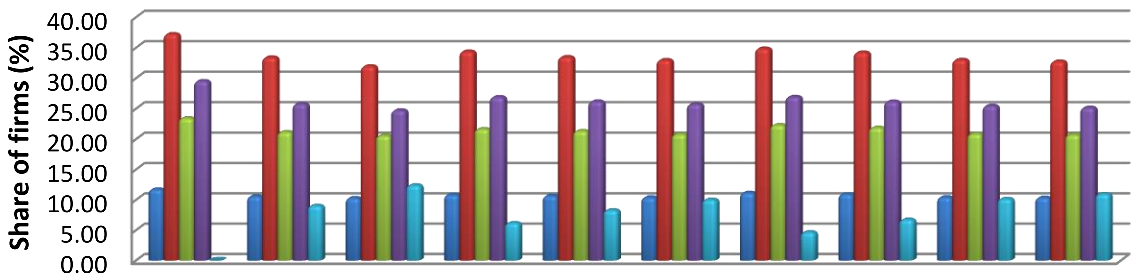
Accordingly, the firm No. 5 as a hybrid wind-thermal firm could not compete with conventional firms without FIT. Also, it will gain the maximum profit in case study No. 2. Since the demand and fuel price are considered as uncertain parameters in the proposed model, the standard deviation (SD) of each case study is shown in the following table.

In order to complete the discussion, the share of each private company in the market are compared for different case studies. These results are represented in Fig. 6.

This figure represents that the share of the generation of firm 5 as hybrid wind-thermal firm increases by considering the fixed FIT (110 $) rather than others. This analysis is referred to evaluate the incentive policy on the proposed model to simulate the deregulated power market.

Table 9: Simulation results for investigating the effect of type of FIT on AAP and total profit of power market

Cases	Types of FIT	AAP for each firm [M$]					Total profit [M$]	SD
		firm 1	firm 2	firm 3	firm 4	firm 5		
No. 1	W/out FIT	26.01	82.61	52.02	65.49	-4.36	221.79	3.94
No. 2	Fixed FIT (92)	26.43	83.45	52.87	64.40	22.56	249.72	5.50
	Fixed FIT (110)	26.67	82.85	53.35	64.11	32.16	259.16	4.48
No. 3	F/V SN1	26.08	82.75	52.16	64.76	14.89	240.65	6.49
	F/V SN2	26.08	81.83	52.17	64.01	20.28	244.38	8.78
	F/V SN3	26.20	83.04	52.41	64.78	25.28	251.74	7.54
No. 4	V/V SN1	26.48	82.71	52.96	63.92	11.09	237.17	6.79
	V/V SN2	26.52	82.92	53.05	63.39	16.35	242.26	7.23
	V/V SN3	26.27	83.09	52.54	64.10	25.57	251.59	8.78
	V/V SN4	26.29	83.15	52.59	63.90	27.86	253.82	7.48



	Without FIT	Fixed FIT 92	Fixed FIT110	F/V SN1	F/V SN2	F/V SN3	V/V SN1	V/V SN2	V/V SN3	V/V SN4
Firm 1	11.73	10.586	10.293	10.84	10.68	10.41	11.17	10.95	10.44	10.36
Firm 2	37.25	33.418	31.969	34.39	33.48	32.99	34.87	34.23	33.03	32.76
Firm 3	23.46	21.173	20.586	21.68	21.35	20.82	22.33	21.90	20.88	20.72
Firm 4	29.53	25.788	24.74	26.91	26.19	25.74	26.95	26.17	25.48	25.18
Firm 5	0.00	9.034	12.412	6.19	8.30	10.05	4.68	6.75	10.17	10.98

Fig. 13: Contribution of each firm in different types of FIT.

Conclusion

The first contribution of this article is to propose a developed model in order to simulate the medium term deregulated power market by assuming the hybrid wind-thermal firm. The second contribution is to evaluate the impact of different types of FIT on MCP, ECG, profits and contribution of each firm in electricity generation in the restructured market of energy. To this end, the wind power generation has been evaluated based on the scenario based method.

The wind scenarios are generated based on the data mining technique. Besides the wind uncertainty, the demand and fuel price uncertainties are assumed in this approach based on the Monte-Carlo technique. Also, the strategic behavior of other participants in each tactical period evaluates based on the Cournot game theory. The findings affirm that the wind resources could not compete with conventional firms. Furthermore, the proposed model in this article can be so useful for evaluating the different types of incentive policies for renewable energies. Moreover, this study confirms the previous researches that selected the FIT as an efficient incentive policy for developing the wind resources. For future work this model can be examined with quota or other incentive policies in the restructured power market.

Author Contributions

Mohammad Tolou Askari: Programmer, Software, Validation, Conceptualization, Visualization, Investigation, Writing - Reviewing and Editing, Conceptualization, Methodology, Visualization, Investigation, Writing - Original draft preparation.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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List of Variables and Parameters in the Model

i.Indices

l	Load level
s	Season
e	Traditional generation firm
e'	Hybrid traditional and renewable generation firm
u	Thermal unit of traditional firm
u'	Thermal unit of hybrid traditional and renewable generation firm
uw	Wind unit of hybrid traditional and renewable generation firm

ii. parameters

d_{sl}	Duration of time [hours]
$N_{e,u}$	Number of thermal units in e
$N_{e',u'}$	Number of thermal units in e'
$N_{e',uw}$	Number of wind units in e'
$Q_{e,sl}$	Total generation contracted by firm e in sl [MW]
$Q_{e',sl}$	Total generation contracted by firm e' in sl [MW]
SP_{sl}	Average electricity price of power market in sl [$/MW]
BP_{sl}	Contracted electricity price in sl [$/MW]
FP_u	Fuel price of unit u [$/MBtu]
a_u, b_u, c_u	Constant coefficients of heat rate function for unit u
$a_{u'}, b_{u'}, c_{u'}$	Constant coefficients of heat rate function for unit u’
Tax	CO2 tax rate [$/lbCO2]
EM_u	CO2 produced by unit u[lb/MMBTU]
GP	Percentage of electricity price
D_{sl}	Average demand in sl [MW]
$P_{e,u\min}$	Minimum generation of thermal unit u of firm e [MW]
$P_{e,u\max}$	Maximum generation of thermal unit u of firm e [MW]
$P_{e',u'\min}$	Minimum generation of thermal unit u’ of firm e' [MW]
$P_{e',u'\max}$	Maximum generation of thermal unit u’ of firm e' [MW]
$PW_{e',uw,n\min}$	Minimum generation of wind unit uw of firm e' for scenario n [MW]
$PW_{e',uw,n\max}$	Maximum generation of wind unit uw of firm e' for scenario n [MW]

iii. Decision variables

$P_{e,u,sl}$	Power generation by thermal unit u of firm e in sl [MW]
$P_{e',u',sl}$	Power generation by thermal unit u’ of firm e’ in sl [MW]
$PW_{e',uw,sl,n}$	Power generation by wind unit uw of firm e’ in sl for scenario n [MW]
$g_{e,e',sl}$	Total power generation of firms e, e' [MW]
MCPsl	Market clearing price in sl [$/MW]

References

[1] P. Brown, "European Union Wind and Solar Electricity Policies: Overview and Considerations," 2013.

[2] C.-D. Yue, C.-M. Liu, E. M. Liou, "A transition toward a sustainable energy future: feasibility assessment and development strategies of wind power in Taiwan," Energy Policy, 29: 951-963, 2001.

[3] R. Saidur, M. Islam, N. Rahim, K. Solangi, "A review on global wind energy policy," Renewable Sustainable Energy Rev., 14: 1744-1762, 2010.

[4] M. Askari, M. Ab Kadir, H. Hizam, J. Jasni, "A new comprehensive model to simulate the restructured power market for seasonal price signals by considering on the wind resources," J. Renewable Sustainable Energy, 6: 023104, 2014.

[5] M. Askari et al., “Modeling optimal long-term investment strategies of hybrid wind-thermal companies in restructured power market,” J. Mod. Power Syst. Clean Energy, 7: 1267–1279, 2019.

[6] P. Harborne, C. Hendry, "Pathways to commercial wind power in the US, Europe and Japan: The role of demonstration projects and field trials in the innovation process," Energy Policy, 37: 3580-3595, 2009.

[7] T. Ackermann, L. Söder, "An overview of wind energy-status 2002," Renewable Sustainable Energy Rev., 6: 67-127, 2002.

[8] T. Barforoushi, M. Parsa Moghaddam, M. Javidi, M. Sheik-El-Eslami, "A new model considering uncertainties for power market simulation in medium-term generation planning," Iran. J. Electr. Electron. Eng. (IJEEE), 2: 71-81, 2006.

[9] T. Barforoushi, M. P. Moghaddam, M. H. Javidi, M. K. Sheikh-El-Eslami, "Evaluation of regulatory impacts on dynamic behavior of investments in electricity markets: a new hybrid DP/GAME framework," IEEE Trans. Power Syst., 25: 1978-1986, 2010.

[10] D. Kothari, I. Nagrath, Modern power system analysis: McGraw-Hill Europe, 2003.

[11] A. S. Chuang, F. Wu, P. Varaiya, "A game-theoretic model for generation expansion planning: problem formulation and numerical comparisons," IEEE Trans. Power Syst., 16: 885-891, 2001.

[12] J. B. Park, J. H. Kim, K. Y. Lee, "Generation expansion planning in a competitive environment using a genetic algorithm," 3: 1169-1172, 2002.

[13] W. M. Lin, T. S. Zhan, M. T. Tsay, W. C. Hung, "The generation expansion planning of the utility in a deregulated environment," 2: 702-707, 2004.

[14] J. Zhu, M. Chow, "A review of emerging techniques on generation expansion planning," IEEE Trans. Power Syst., 12: 1722-1728, 1997.

[15] E. Alishahi, M. P. Moghaddam, M. Sheikh-El-Eslami, "A system dynamics approach for investigating impacts of incentive mechanisms on wind power investment," Renewable Energy, 37: 310-317, 2012.

[16] G. Richards, B. Noble, K. Belcher, "Barriers to renewable energy development: A case study of large-scale wind energy in Saskatchewan, Canada," Energy Policy, 42: 691-698, 2012.

[17] J. M. Kissel, S. C. Krauter, "Adaptations of renewable energy policies to unstable macroeconomic situations—Case study: Wind power in Brazil," Energy Policy, 34: 3591-3598, 2006.

[18] V. Di Dio, S. Favuzza, D. La Cascia, R. Miceli, "Economical Incentives and systems of certification for the production of electrical energy from renewable energy resources," in Proc. International Conference on Clean Electrical Power (ICCEP'07): 277-282, 2007.

[19] J. P. Painuly, "Barriers to renewable energy penetration; a framework for analysis," Renewable Energy, 24: 73-89, 2001.

[20] L. Ying, C. Yin, R. Yuan, H. Yong, "Economic incentive mechanism of renewable energy generation," in Proc. International Conference on Electrical Machines and Systems (ICEMS): 2689-2694, 2008.

[21] L. A. Barroso, H. Rudrick, F. Sensfuss, P. Linares, "The green effect," IEEE Power Energy Magazine, 8: 22-35, 2010.

[22] J. Sawin, "National policy instruments: Policy lessons for the advancement & diffusion of renewable energy technologies around the world," Renewable Energy, A Global Review of Technologies, Policies and Markets, 2006.

[23] J. Lipp, "Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom," Energy Policy, 35: 5481-5495, 2007.

[24] V. Lauber, L. Mez, "Three decades of renewable electricity policies in Germany," Energy & Environment, 15: 599-623, 2004.

[25] M. Askari, M. Ab Kadir, E. Bolandifar, "Evaluation of FIT impacts on market clearing price in the restructured power market," in Proc. 2015 IEEE Student Conference on Research and Development (SCOReD): 224-227, 2015.

[26] S. Ahmad, R. M. Tahar, F. Muhammad-Sukki, A. B. Munir, R. A. Rahim, "Application of system dynamics approach in electricity sector modelling: A review," Renewable Sustainable Energy Rev., 56: 29-37, 2016.

[27] A. Ibanez-Lopez, J. Martinez-Val, B. Moratilla-Soria, "A dynamic simulation model for assessing the overall impact of incentive policies on power system reliability, costs and environment," Energy Policy, 102: 170-188, 2017.

[28] F. Zia, M. Nasir, A. A. Bhatti, "Optimization methods for constrained stochastic wind power economic dispatch," in Proc. 7th IEEE International Power Engineering and Optimization Conference (PEOCO): 129-133, 2013.

[29] X. Liu, W. Xu, "Economic load dispatch constrained by wind power availability: A here-and-now approach," IEEE Trans. Sustainable Energy, 1(1): 2-9, 2010.

[30] L. A. Barroso, A. J. Conejo, "Decision making under uncertainty in electricity markets," in Proc. IEEE Power Engineering Society General Meeting, 2006.

[31] A. J. Conejo, M. Carriâon, J. M. Morales, Decision making under uncertainty in electricity markets , 153: Springer, 2010.

[32] R. Karki, P. Hu, R. Billinton, "A simplified wind power generation model for reliability evaluation," IEEE Trans. Energy Convers., 21: 533-540, 2006.

[33] (2006). Canada’s National Climate Archive [online].

[34] M. J. Osborne, An introduction to game theory vol. 3: Oxford University Press New York, 2004.

[35] A. S. Chuang, F. Wu, P. Varaiya, "A game-theoretic model for generation expansion planning: problem formulation and numerical comparisons," IEEE Trans. Power Syst., 16: 885-891, 2001.

[36] D. Kirschen, G. Strbac, Front Matter: Wiley Online Library, 2005.

[37] H. Singh, "Introduction to game theory and its application in electric power markets," IEEE Comput. Appl. Power, 12(4): 18-20, 1999.

[38] C. Grigg, P. Wong, P. Albrecht, R. Allan, M. Bhavaraju, R. Billinton, et al., "The IEEE reliability test system-1996. A report prepared by the reliability test system task force of the application of probability methods subcommittee," IEEE Trans. Power Syst., 14: 1010-1020, 1999.

[39] E. Gnansounou, J. Dong, S. Pierre, A. Quintero, "Market oriented planning of power generation expansion using agent-based model," in Proc. IEEE Power Systems Conference and Exposition: 1306-1311, 2004.

[40] M. Shahidehpour, H. Yamin, Z. Li, "Market operations in electric power systems, 2002," ed: John Wiley & Sons, Inc. New York.

[41] T. Barforoushi, M. P. Moghaddam, M. H. Javidi, M. K. Sheikh-El-Eslami, "Evaluation of regulatory impacts on dynamic behavior of investments in electricity markets: a new hybrid DP/GAME framework," IEEE Trans. Power Syst., 25: 1978-1986, 2010.

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