A network constrained bi-level model for optimal generation expansion planning and optimal determination of feed-in tariffs for renewable energy resources

S.A.Rafiei[1], S.Goldani[2], and H.Falaghi[3]

[1, 2, 3] *Faculty of electrical and computer engineering University of Birjand*
[*] *Corresponding author: arash.rafiei@birjand.ac.ir*

Manuscript received 19 July, 2018;Revised 29 August, 2018, accepted 31 August,2018. Paper no. JEMT-1811-1138.

This paper presents a new model for strategic generation expansion planning as well as investor decision making. The generation expansion planning in this paper is including the purchase of a guaranteed power, which is discussed at HL2. The existing problem has a target year (30 years later), which consists of several steps. Regarding time periods and strategic behavior of investors, a bi-level model is presented. The upper-level issue involves investment decisions and strategic products with the goal of maximizing investor profit and the lower-level includes market clearing equations aimed at maximizing social welfare. The bi-level model presented using the KKT conditions is converted into a problem of mathematical programming with equilibrium constraints (MPEC). In this paper, the contract price of the guaranteed purchase, the market price and the strategic offers as a variable in the problem that are in the output of the problem. The proposed model is implemented on a 6-bus network.

keywords: *Generation expansion planning, Bi-level problem, Contract pricing, Strategic offering.*

http://dx.doi.org/10.22109/jemt.2018.14337.1110

PARAMETERS AND VARIABLES OF PROBLEM:

i Index for existing units

k Index for other units

o Index for load levels

d Index for consumers

t Index for planning periods

a, b Index for system buses

r Interest rate

a_{ct} Contract price in period t

λ_{at} Market price of bus a in period t

IC_{wt} Investment cost of wind units in period$t$

$OC_w t$ Operation cost of wind unit in period t

x_{wt} Price offer of wind unit in period t

x_{eit} Price offer of existing unit i in period t

x_{okt} Price offer of other unit k in period t

y_{dt} Price bid of consumers in period t

P_{wt} Construction capacity of wind unit in period t

P_{cwt} Contractual power of wind unit in period t

P_{mwt} Market power of wind unit in period t

P_{eit} Capacity of existing unit i in period t

P_{ceit} Contractual power of existing unit i in period t

P_{meit} Market power of existing unit i in period t

P_{okt} Capacity of other unit k in period t

P_{cokt} Contractual power of other unit k in period t

P_{mokt} Market power of other unit k in period t

P_{dt} Supplied power of consumer d in period t

$P_{d(D,max)}$ Demanded power of consumer d in period t

B_{ab} Susceptance of line a - b

θ_a Voltage angle of bus a

ρ_o Probability of load level o

1. INTRODUCTION

Due to the limits of energy resources and environmental issues, in order to reduce environmental pollution and reduce the use of fossil fuels, various approaches have been proposed in international societies. Among these approaches, renewable energy sources can be mentioned. In 2007, the EU approved a plan to provide 20% of energy from renewable sources, reducing 20% of emissions and increasing 20% of energy efficiency by 2020. This project became known worldwide as 20/20/20 [1]. According to these existing laws and restrictions, authors of [2–5] have used renewable sources of solar and wind in a monopoly environment. However, the need for accurate planning in the field of renewable resource development is felt more and more. Changing the structure of the electricity industry and the advent of a competitive market in this industry requires actors in this market to consider different investment options in expansion planning in order to make the best decision. Today, one of the options for investing is the use of renewable sources that are mostly related to wind and solar resources that have been discussed in a restructured environment [6–8]. In references [9,10], the 6-bus Network is used to implement the proposed model. Reference [11], [12] and [13] chose the Iranian network, the Chilean network and the Canary Islands as a case study system for implementing its proposed model, respectively.

In order to persuade investors to invest in the renewable resource industry, due to the uncertainty in these resources, incentives should be considered. In [14], a guaranteed power purchase contract is considered by the independent operator of the system (ISO) as an incentive to invest. Capacity payment readiness is one of the incentives to invest in [15].

In [16], the point pricing is formulated to reduce the cost of the economic distribution problem. Authors of [17] has modeled the load uncertainty with the locational marginal price approach for unit pricing. Similar work has been done in this field by [18]. In [19], the optimal contract pricing has been studied. In [20], the market price of electricity energy is determined, and since predict of price is often error-prone, it uses bidding and offering strategy for energy storage system to offset the error. Authors of [21] predicted the market price using the meta-heuristic method. In modeling of the electricity price predicting problem in the competitive market of this reference, the characteristics of non-storage capacity, low tensile and seasonality of demand are considered. Also authors of [22] using the storage system in their research due to the security limitations. In [23], a bi-level optimization method was used for optimal contract pricing for a distributed generation (DG). In this reference, the upper-level of planning is the maximization of the total profit of the unit produced by itself, while at the lower-level the wholesale company is thinking of minimizing its payments. In this case, a mathematical program with equilibrium constraint (MPEC) is created. In [24], a bi-level problem has been solved, which looking for the investment of strategic units. This reference maximizing the strategic units profit in upper-level problem, and in lower-level social welfare is maximized by ISO, and its output is the optimal determination of the proposed price of strategic units and the market price. In the present study, the contract price of the guaranteed power purchase is as a variable which the contracting market is not available in [24], and the distinction between the present paper and the reference [24] is the existence of a guaranteed purchasing contract market. The reference [25] has been strategically priced in offering and has benefited from a competitive learning method for market participation. The market clearing process in this reference is based on locational marginal pricing. The results of [25] suggest that decision making of strategic offering could be more profitable.

The reference [26] is intended to strike a balance between the distribution company (DisCo) and the distributed generation unit. This research is also a bi-level problem that target of the upper-level is DG's profits maximization and the lower-level goal is DisCo's cost minimization. In this reference, the bilateral contracts between DGs and DisCo are optimal pricing. The divergence of the advance paper with [26] is that [26] is contract pricing in a competitive market merely, and there is no discussed about generation expansion planning.

According to the reviewed papers, it can be seen that the models presented in the above mentioned are not complete and do not consider all aspects of the market. The shortcomings in the above are the lack of use of the contract pricing along with the market price to solve the problem of development of production, and the contract pricing in the existing market regardless of the expansion issue. This paper tries to provide a complete model for the generation expansion planning with fixing defects. In this paper, a novel framework is presented for solving generation expansion planning problem considering an investment in a wind power units in a bi-level model. In the upper-level problem, the profit of wind units investor is maximized and in the lower-level problem, the social welfare is maximized. Investment incentives include guaranteed power purchase contracts. The bi-level problem is converted into an MPEC single-level problem using a mathematical program with equilibrium constraints, which utilizes Karush-Kuhn-Tucker (KKT) conditions. Regarding the investigated references, the novelties of this paper are as follows:

- Presenting a mathematical model for generation expansion planning of wind units, considering simultaneous determination of guaranteed purchase price and spot market.
- Similar papers consider the contract price as the input; however, in this paper, the guaranteed purchase contract price, market price simultaneously are assumed as internal variables of the problem, which exist in the output of the problem.
- Presenting a new algorithm for solving the generation expansion planning problem.

In the following, the Section 2 is dedicated to the features of the proposed model. In the Section 3, the mathematical formulation of problem is taken into account, and in the Section 4, numerical studies are included. Section 6 presents a conclusion about the findings of current work.

2. FEATURES OF MODEL

In this section of the paper, the general features of the problem are explained.

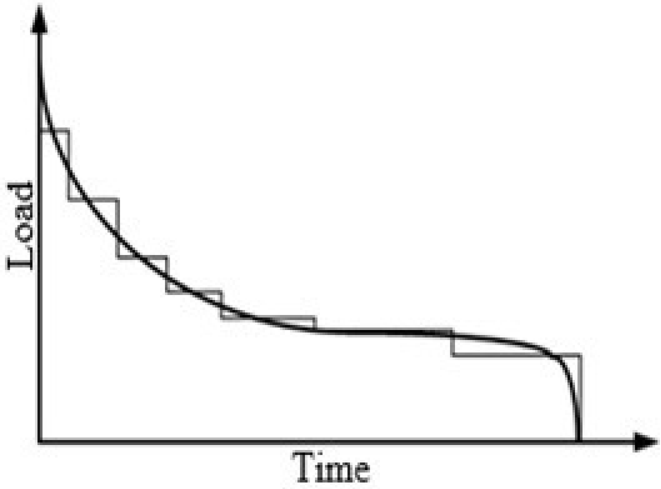

Fig. 1. Load duration curve

A. Planning horizon, load demand and wind characteristics

The planning horizon in this paper is considered 30 years with five-year periods. In this horizon, the planning can be performed entirely for future 30 years, which is known as static method. However, here the target year is intended to be five years later, and every five years, the generation expansion studies are repeated. As the period of the studies is shorter, the results become more accurate and reasonable; because any prediction about network contains errors and uncertainties.

Demanded load for each target year that is obtained through prediction is dealt with step by step using a load duration curve (LDC). Fig. 1 shows an example of a load curve. Wind characteristics is obtained via prediction, weather conditions and previously recorded data.

B. Bi-level investment model

Decision making for investment and strategic price offering is described by the generation unit in the form of a bi-level model. The upper-level problem indicates decision making of investment of the generation unit and its strategic offer is related to each scenario. The purpose of this part of the problem is to maximize the investor's profit.

This upper-level problem is restricted by a set of lower-level problems, implying that market clearing is done for each scenario. The lower-level problem intends to increase social welfare, which is planned by independent system operator. Locational marginal price (LMP) for such problems as dual variables is obtained from power balance constraint. The desired region of each lower-level problem are shown via KKT conditions. Taking into account the upper-level problem and substituting lower-level problems for KKT conditions, an MPEC problem is formed. The balance constraints are a set of KKT conditions that indicate market clearing in each scenario.

C. Uncertainty in price offering and rivals investment

Selling price offered by rival producer units is shown using scenarios. These scenarios can be formed on the basis of previous data related to rivals offers.

Engaging in investment by rival producers is also modeled as scenarios. Since there are not too many investment options, a sizeable number of alternative scenarios can correctly demonstrate rival's investment in the planning target year.

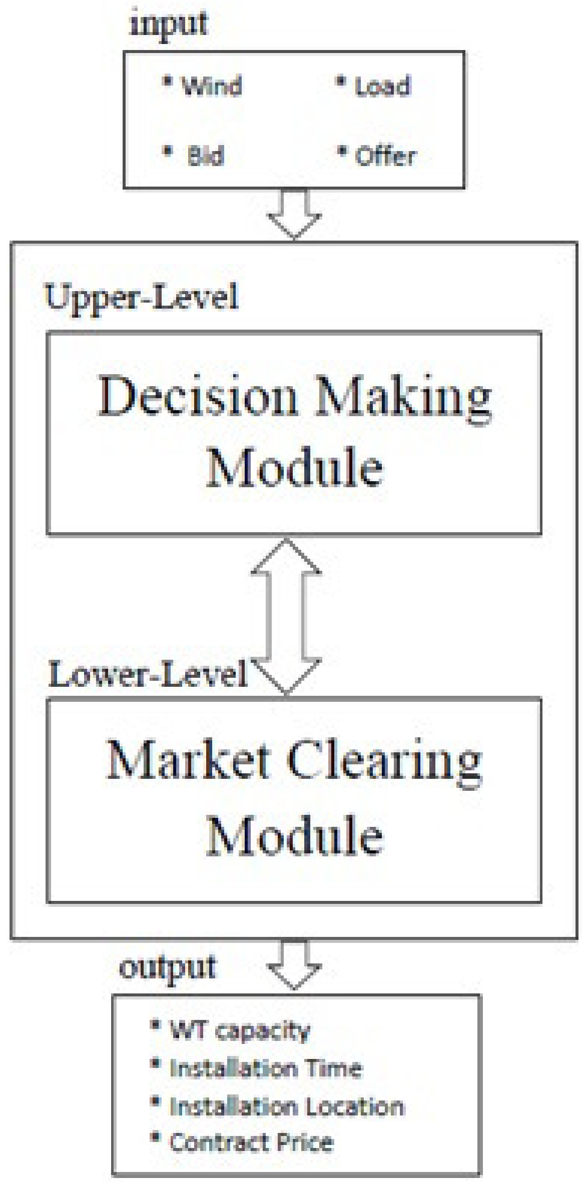

Fig. 2. Proposed framework of bi-level problem

3. MATHEMATICAL FORMULATION

Fig. 2 illustrates the schematics of the proposed framework. The main block of the proposed framework includes a bi-level model in which the problems related to each level are shown. The upper-level problems include investment problems intended to maximize the profit of generation unit in the presence of investment incentives along with restrictions imposed in planning period. The mechanism of guaranteed contract and preparedness are also considered in the upper-level problem. The lower-level problem is solved by the independent system operator, in which the improvement of social welfare is intended considering dominant restrictions. Some items in the output of the framework are as follows: capacity invested in the wind unit, profit of owners of the wind unit, energy purchased from the wind unit, market price and the guaranteed purchase contract price.

A. Bi-level model

The mathematical model for problem are presented below:

$$\max : (1+r)^{-t} \left\{ \begin{array}{l} -[IC_{wt}*P_{wt}] + \\ \sum\limits_{o\in O} \rho_o \sum\limits_{t\in T} \left\{ \begin{array}{l} [a_{ct}*P_{cwt}] + [\lambda_{mt}*P_{mwt}] \\ -[OC_{wt}*(P_{cwt}+P_{mwt})] \end{array} \right\} \end{array} \right\} \quad (1)$$

$$0 \le P_{wt} \le P_{wt}^{max} \quad (2)$$

$$max : \sum_{t\in T} \left\{ \begin{array}{l} -[a_{ct}*P_{cwt}] - [x_{wt}*P_{mwt}] - \\ \sum\limits_{i\in I} ([a_{ct}*P_{ceit}] + [x_{eit}*P_{meit}]) - \\ \sum\limits_{k\in K} ([a_{ct}*P_{cokt}] + [x_{okt}*P_{mokt}]) + \\ \sum\limits_{d\in D} [y_{dt}*P_{dt}] \end{array} \right\} \quad (3)$$

$$\sum_d P_{dt} + \sum_b B_{ab}(\theta_{at}-\theta_{bt}) - \left(P_{cwt} + P_{mwt} + \sum_i [P_{ceit}+P_{meit}] + \sum_k [P_{cokt}+P_{mokt}] \right) = 0; \lambda_{at} \quad (4)$$

$$0 \le P_{cwt} \le A*P_{wt}; \mu_{cwt}^{min}, \mu_{cwt}^{max} \quad (5)$$

$$0 \le P_{mwt} \le (1-A)*P_{wt}; \mu_{wt}^{min}, \mu_{wt}^{max} \quad (6)$$

$$0 \le P_{ceit} \le B*P_{eit}; \mu_{ceit}^{min}, \mu_{ceit}^{max} \quad (7)$$

$$0 \le P_{ceit} + P_{meit} \le P_{eit}; \mu_{eit}^{min}, \mu_{eit}^{max} \quad (8)$$

$$0 \le P_{cokt} \le C*P_{okt}; \mu_{cokt}^{min}, \mu_{cokt}^{max} \quad (9)$$

$$0 \le P_{cokt} + P_{mokt} \le P_{okt}; \mu_{okt}^{min}, \mu_{okt}^{max} \quad (10)$$

$$0 \le P_d \le P_d^{D,max}; \mu_{dt}^{min}, \mu_{dt}^{max} \quad (11)$$

$$-F_{ab}^{max} \le B_{ab}(\theta_{at}-\theta_{bt}) \le F_{ab}^{max}; v_{abt}^{min}, v_{abt}^{max} \quad (12)$$

$$-\pi \le \theta_{at} \le \pi; \xi_{at}^{min}, \xi_{at}^{max} \quad (13)$$

$$\theta_{at} = 0, a = 1; \xi_t^1 \quad (14)$$

Objective function (1) of the upper level problem indicates the profit of wind investor and consists of four terms. The first term is investment cost of wind turbine. The second term show the revenue derived from selling power by wind turbine through guaranteed contract and the third term show the revenue derived from selling power by wind turbine in spot market. The fourth term is current cost of wind turbine. Equation (2) shows the maximum amount of investment in wind turbine at each time. Objective function (3) of the lower-level problem deals with maximizing social welfare by independent system operator and includes eight terms. In the lower-level objective function, the quantities that are received for selling power are shown by plus sign, and the quantities related to power purchase, acting as payments, are shown by minus sign. First and second terms are the cost of purchasing power from the wind unit as a guaranteed contract and participating in the spot market, respectively. The third and fourth terms are contract costs and the spot market for purchasing power from existing units. Fifth and sixth terms refer to the payment cost to the competitor units in a contractual market and spot market by the independent system operator. The seventh term is received cost from consumers by ISO.

Constraints and restrictions of the lower-level problem are explained by (4) to (14). For solving bi-level problems, as mentioned in Section 2-2, KKT conditions are used and the use of these conditions requires the help of dual problems. Accordingly, the duals of problem constraints are also specified (for each constraint, a dual is defined) that are further explained. Equation (4) is known as power balance constraint for each bus; in each hour, with regard to market clearing, the power delivered to the market must be equal to the amount of power purchased from the market. The dual of power balance constraint in the market is denoted by λat, which is identical to locational marginal price (LMP) for each bus. Equation (5) show the maximum amount of participation of the wind unit in the contractual market against the total capacity of the unit. The terms μ_{cwt}^{max} and μ_{cwt}^{min} are upper limit and lower limit duals of (5). Equation (6) indicates the limitation of power output at the wind unit, which should not be greater than the total capacity. The terms μ_{wt}^{max} and μ_{wt}^{min} show the upper and lower limit duals of (6). Constraints (7) and (8) indicate the maximum amount of participation of existing power plants in the contractual market and the maximum amount of generation of existing power plants, respectively (which should not be greater than their capacity). Phrases μ_{ceit}^{max} and μ_{ceit}^{min} are the dualities of the upper and lower limits of (7) and the phrases μ_{eit}^{max} and μ_{eit}^{min} are the dualities of the upper and lower limits of (8). Constraints (9) and (10) are the same as those in (7) and (8), concerning the new power plants and generation units. Equation (9) indicates the maximum level of participation in the contractual market of the newly created generation unit rate as the total capacity of the unit that it plans to invest. The clause of these constraint are represented by theμ_{cokt}^{max} and μ_{cokt}^{min}, which are related to the upper and lower limits of equation (9). Equation (10) represents the maximum power generated by the new generation unit, which should not exceed the total capacity of the unit. The μ_{okt}^{max} represents the upper limit dual and the μ_{okt}^{min} of the lower limit dual of the constraint (10). Equation (11) is the demanded load constraint that is provided in the market clearing operation. The maximum value in this equation is the same as the total demanded load. The terms μ_{dt}^{max} and μ_{dt}^{min} are the dualities of the upper and lower limits of (11).

The voltage angle (θ_a) of each network bus is obtained from the run of the DC power flow on the desired network. Each time the lower-level problem is run, according to the network information, at the same time, the DC power flow is run and gives the value of θ_a. The cause for the use of DC power flow is to ignore losses (because the used network is the transmission network and the problem is discussed at HL2). Constraint (12) relates to the transmission power of the network lines, and F_{ab}^{max} is the maximum capacity of the lines between the buses a and b. The $_{abt}^{min}$ shows the lower limit dual and $_{abt}^{max}$ the upper limit dual of (12). Constraint (13) indicates the voltage angle range of each bus, which can be between $-\pi$ and π. The expressions ξ_{at}^{max} and ξ_{at}^{min} are the dualities of the upper and lower limits of (13).

B. Converting bi-level problem into MPEC

The present bi-level problem that is presented by (1) to (11) can be converted into a single-level mathematical problem with equilibrium constraints or MPEC, by applying KKT conditions to the lower-level problem. In this conversion, it should be considered that the objective function of MPEC problem is the same upper-level objective function. In addition to the sum of product of constraints and their duals, the lower-level objective function of the primal problem forms a Lagrange equation, which is obtained in (12) as follows [24]:

$$\mathcal{L} = (\text{Lower\_LevelProblem}) + \sum \lambda * h + \sum \mu * g \qquad (15)$$

Derivatives of the Lagrange equation with respect to the variables of lower-level problem are assumed as a part of variations of KKT conditions, which are given in (16) to (23).

$$\frac{\partial \mathcal{L}}{\partial P_{cwt}} = a_{ct} - \lambda_{at} - \mu_{cwt}^{min} + \mu_{cwt}^{max} - \mu_{wt}^{min} + \mu_{wt}^{max} = 0 \qquad (16)$$

$$\frac{\partial \mathcal{L}}{\partial P_{mwt}} = x_{wt} - \lambda_{at} - \mu_{wt}^{min} + \mu_{wt}^{max} = 0 \qquad (17)$$

$$\frac{\partial \mathcal{L}}{\partial P_{ceit}} = a_{ct} - \lambda_{at} - \mu_{ceit}^{min} + \mu_{ceit}^{max} - \mu_{eit}^{min} + \mu_{eit}^{max} = 0 \qquad (18)$$

$$\frac{\partial \mathcal{L}}{\partial P_{meit}} = x_{eit} - \lambda_{at} - \mu_{eit}^{min} + \mu_{eit}^{max} = 0 \qquad (19)$$

$$\frac{\partial \mathcal{L}}{\partial P_{cokt}} = a_{ct} - \lambda_{at} - \mu_{cokt}^{min} + \mu_{cokt}^{max} - \mu_{okt}^{min} + \mu_{okt}^{max} = 0 \qquad (20)$$

$$\frac{\partial \mathcal{L}}{\partial P_{mokt}} = x_{okt} - \mu_{okt}^{min} + \mu_{okt}^{max} = 0 \qquad (21)$$

$$\frac{\partial \mathcal{L}}{\partial P_{d}} = -y_{dt} + \lambda_{t} - \mu_{dt}^{min} + \mu_{dt}^{max} = 0 \qquad (22)$$

$$\sum_b B_{ab}\left(\lambda_{at} - \lambda_{bt}\right) + \sum_b B_{ab}\left(v_{abt}^{max} - v_{bat}^{max}\right) + \sum_b B_{ab}\left(v_{abt}^{min} - v_{bat}^{min}\right) + \xi_{at}^{max} - \xi_{at}^{min} + \begin{pmatrix} \xi_t^1 \\ a = 1 \end{pmatrix} = 0 \qquad (23)$$

Besides the derivatives of Lagrange equation, in MPEC, constraints (3) and (5) to (13) retain their current form, and all constraints corresponding to lower-level are influenced by KKT variations [24]. After applying the KKT conditions, each constraint in the primal problem is converted into two constraints in the dual problem, which are shown in the following, in (24) to (41).

$$0 \le P_{cwt} \perp \mu_{cwt}^{min} \ge 0 \qquad (24)$$

$$0 \le A * P_{wt} - P_{cwt} \perp \mu_{cwt}^{max} \ge 0 \qquad (25)$$

$$0 \le P_{cwt} + P_{mwt} \perp \mu_{wt}^{min} \ge 0 \qquad (26)$$

$$0 \le P_{wt} - \left(P_{cwt} + P_{mwt}\right) \perp \mu_{wt}^{max} \ge 0 \qquad (27)$$

$$0 \le P_{ceit} \perp \mu_{ceit}^{min} \ge 0 \qquad (28)$$

$$0 \le B * P_{eit} - P_{ceit} \perp \mu_{ceit}^{max} \ge 0 \qquad (29)$$

$$0 \le P_{ceit} + P_{meit} \perp \mu_{eit}^{min} \ge 0 \qquad (30)$$

$$0 \le P_{eit} - \left(P_{ceit} + P_{meit}\right) \perp \mu_{eit}^{max} \ge 0 \qquad (31)$$

$$0 \le P_{cokt} \perp \mu_{cokt}^{min} \ge 0 \qquad (32)$$

$$0 \le C * P_{okt} - P_{cokt} \perp \mu_{cokt}^{max} \ge 0 \qquad (33)$$

$$0 \le P_{cokt} + P_{mokt} \perp \mu_{okt}^{min} \ge 0 \qquad (34)$$

$$0 \le P_{okt} - \left(P_{cokt} + P_{mokt}\right) \perp \mu_{okt}^{max} \ge 0 \qquad (35)$$

$$0 \le P_d \perp \mu_{dt}^{min} \ge 0 \qquad (36)$$

$$0 \le P_d^{D,max} - P_d \perp \mu_{dt}^{max} \ge 0 \qquad (37)$$

$$0 \le F_{ab}^{max} + B_{ab}\left(\theta_{at} - \theta_{bt}\right) \perp v_{abt}^{min} \ge 0 \qquad (38)$$

$$0 \le F_{ab}^{max} - B_{ab}\left(\theta_{at} - \theta_{bt}\right) \perp v_{abt}^{max} \ge 0 \qquad (39)$$

$$0 \le \pi + \theta_{at} \perp \xi_{at}^{min} \ge 0 \qquad (40)$$

$$0 \le \pi - \theta_{at} \perp \xi_{at}^{max} \ge 0 \qquad (41)$$

4. NUMERICAL STUDIES

In this section, the performance of the proposed framework is examined in a 6-bus network as shown in Fig. 3. In this Figure, N shown the buses and D shown the loads on the buses. The existing power plants in Fig. 3 shown by ES and O that indicant of strategic types and the other types respectively.

A. Case study

In this paper, a HL2 model has been used for planning, and the DC power flow equations are considered with the neglect of network losses. The network under study is a 6-bus test system, with loads and units are shown in Fig. 3. According to Fig. 3, N indicates the buses, the ES indicates the existing strategic generation units, O indicates other generation units, and D indicates the load points in the network of case study.

The load information is shown in Table 1, which has four load points (MW) and seven steps, and is offered for each step of the proposed price (£/ MW) from the consumers side (load points) [24]. Table 2 contains information on the generation units available in the network, including the type, capacity, and marginal cost of the generation units [24]. The data of new generation units for investment in development planning is presented in Table 3, which is similar to Table 2 with three columns of type, capacity and marginal cost [24]. Table 4 specifies different scenarios for solving this problem. The characteristics of the wind in this paper are clustered randomly and correlated with demand. Wind data in each bus is shown in Table 5 and shows the probability of occurrence of each level of wind [24]. In this paper, Figure 4 is used to convert wind speed to wind turbine output, which is wind turbine according to its characteristics [27]. The Weibull distribution function can model wind speed behavior, more accurately. Therefore, in this paper, wind speed is modeled as Weibull function.

Table 1. Load information of network

	D1		D2		D3		D4	
Level	Load(MW)	Price(£/MW)	Load(MW)	Price(£/MW)	Load(MW)	Price(£/MW)	Load(MW)	Price(£/MW)
1	400	38.75	340	36.48	280	35.75	230	33.08
2	350	33.69	290	30.09	230	28.72	180	28.52
3	310	30.66	250	28.30	190	27.36	140	26.20
4	280	28.08	220	26.22	150	25.21	110	23.47
5	240	25.69	180	24.34	110	23.55	70	22.71
6	220	23.49	160	21.98	90	21.33	50	21.58
7	190	22.76	120	21.35	70	20.71	40	20.61

Table 2. Information of existing units

Technology	Capacity (MW)	Type	Bus no.
Coal	350	Strategic	1
Oil	100	Strategic	2
Coal	76	Strategic	3
Oil	20	Strategic	6
Coal	350	Other	1
Oil	197	Other	2
Coal	155	Other	3
Oil	100	Other	5

Table 3. Information of new units

Type	Capacity (MW)	Marginal price (/MW)
Base	0, 500, 750, 1000	6.16
Peak	0, 200, 250, 300, 350, . . . , 1000	14.96

Table 4. Simulated scenarios

Scenario no.	Power market	Guaranteed contract	Strategic offering
1	*	-	-
2	*	*	-
3	*	*	*

Table 5. Wind information

Wind speed	Probability (%)					
(m/s)	Bus 1	Bus 2	Bus 3	Bus 4	Bus 5	Bus 6
0	23	21	24	23	19	18
(0,2)	19	20	20	18	21	22
(2,4)	13	15	12	15	16	15
(4,6)	9	7	10	8	10	9
(6,8)	14	16	12	14	14	16
(8,10)	12	11	13	13	13	10
(10,12)	7	6	6	7	5	5
(12,14)	3	4	3	2	2	5

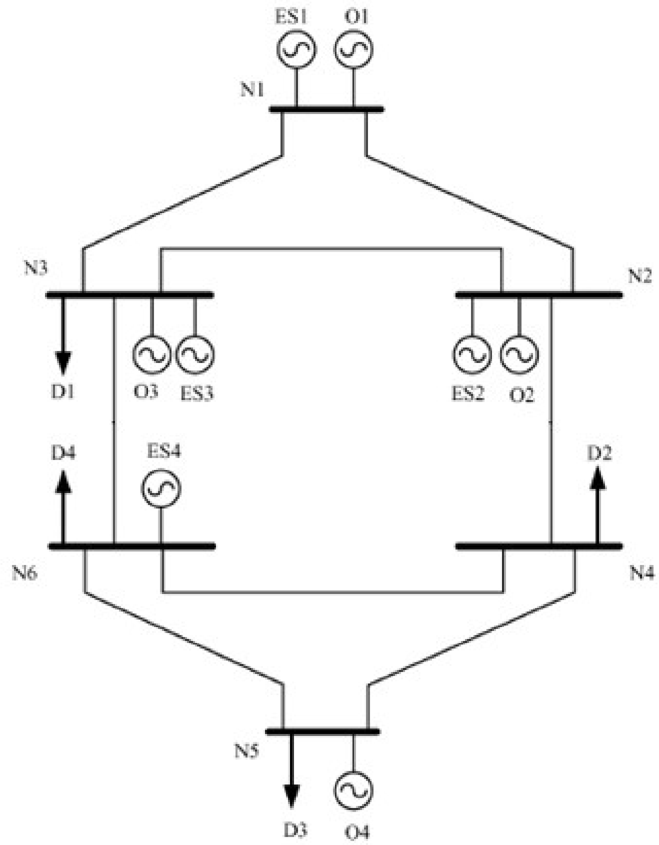

Fig. 3. The 6-bus network

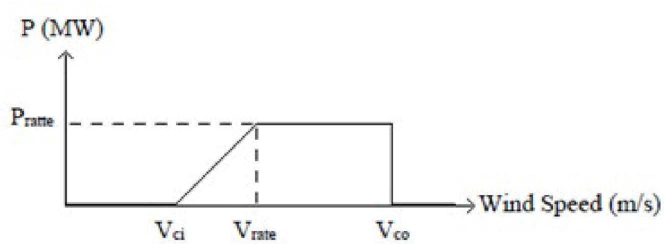

Fig. 4. Relation between wind speed and output power of wind unit

B. Analysis of simulation results

To validate the results, the proposed model was first implemented based on one of the scenarios in reference [24], which achieved best results (Table 7 shows comparison of results.). The results of each scenario are reviewed in the following.

Scenario 1: In this scenario, the wind generation unit can participate in the competitive market as well as other generation units and supply its own goods and subsequently manage its profits and capital. According to the results, in the third period, a wind unit with a capacity of 50 MW has been invested in Bus 4. Also, in the fifth period, capacity of 30 MW in Bus 4 and in the sixth period, capacity of 30 MW in Bus 4 and 20 MW, in Bus 6, was invested in wind unit. The total capacity invested in this scenario is about 170 MW. According to Table 6, with investment of around 113 M€, profit of 175 M£can be earned in the 30-year period.

Scenario 2: By adding investment incentives, such as a guar-

Table 6. Results of simulation

	Scenario 1 (base)	Scenario 2	Scenario 3
Period 1	-	-	-
Period 2	-	100(4)	120(4)
Period 3	50 (4)	60(4) 40(4)	100(4) 50(6)
Period 4	-	70(4)	70(4) 50(5)
Period 5	30(4)	50(5) 50(6)	30(5) 70(6)
Period 6	30(4) 20(6)	70(4) 50(6)	100(4) 30(5) 50(6)
Total power (MW)	170	490	670
Total capital (M£)	113	322	525
Total profit (M £)	175	500	790

anteed purchase contract to the market, there are a lot of investments made by wind farms. According to the results, it is shown in Table 6 that the wind generation unit made an investment of about 490 MW, which100 MW was at bus 4 in the second period, 60 MW at the bus 4 and 40 MW at the bus 6 during the Third period, 70 MW was invested in bus 4 in the fourth period, 50 MW in bus 5 and 50 MW in bus 6 in the fifth period and 70 MW in bus 4 and 50 MW in bus 6 in the sixth period. The result of this investment is a profit of about 500 M£. The initial cost of the unit in this scenario is about 322 M€. According to the above, a guaranteed power purchase contract can be a great incentive for investment in the wind turbine industry.

Scenario 3: In previous scenarios, the proposed sales price from the wind farm was presented as an input to the problem. But in this scenario, in addition to the market price and the price of a guaranteed purchase contract, offer of wind unit is also as a variable in the problem. According to the results in Table 6, the wind unit invested around 670 MW, which 390 MW is the share of Bus 4, 110 MW, the share of Bus 5 and 120 MW, the share of the bus 6. Investment in Bus 4 was carried out in the second, third, fourth and sixth periods with values of 120 MW, 100 MW, 70 MW and 100 MW, respectively. Bus 5 has been invested in terms of 50 MW, 30 MW and 30 MW for the three periods of the fourth, fifth and sixth periods, respectively. The investment in the bus 6 is 50 MW, 70 MW and 50 MW in the third, fifth, and sixth periods, respectively. Under this scenario, capital investment will require 525 M£, with a net profit 790 M€. In view of the results obtained, it can be seen that the presented model in this paper can be more profitable, and the investor, taking into account the aforementioned cases in this model, can Increase profit to considerable amount.

Table 6 with an annual load growth rate is 2% and factor of participation in the guaranteed purchase market is 50%. Table 8 shows the average market price and contract price across the network.

In the following, the effects of these two factors on the results

Table 7. Results comparison

	This Paper	Reference [24]
Total Power (MW)	670	500
Total Profit / Total Cost	1.5048	1.1247

Table 8. Market and contract price

	Market price	Contract price
Period 1 (£)	34.42	36.93
Period 2 (£)	35.18	38.74
Period 3 (£)	33.54	37.03
Period 4 (£)	32.83	36.24
Period 5 (£)	33.65	36.52
Period 6 (£)	32.76	35.78

of the problem, effect of changes in the marginal cost and effect of limiting the capacity of the transmission lines are discussed.

B.1. Effect of changes in load growth rate

Demand is an effective factor in the expansion strategy of generation units. In this research, the load growth rate is considered to be 2%, 4% and 7%, so that its effects on the results are examined. Table 9 illustrates these effects.

B.2. Impact of changes in participation factor in the contract market

In each market, guaranteed trade seems reasonable. Whatever amount of guaranteed contract is higher, the more investors will participate in the market. Making changes in the rate of participation of the wind unit in the guaranteed market and viewing the results is an affirmation of the said sentence. The results of these changes are shown in Table 10.

B.3. Effect of changes in the marginal cost variation of new units

Increasing the marginal costs of generation units will increase energy cost and reducing them will reduce energy cost. For this reason, with the increase of the marginal cost, the use of these units for investment is reduced and in order to meet the needs of the network, more wind units enter the network, and by reducing the cost of the new generation units, the demand for the use of these units will Increase in the network and using fewer wind units. Table 11 confirms this issue.

B.4. Effect of limiting the capacity of the transmission lines

If the power transmission capacity in lines 2-4 and 3-6 is limited to 300 MW and 100 MW, the results are modified in Table 12. According to the results obtained from the previous state, no

Table 9. Effect of changes in load growth rate

Load growth rate (%)	Investment capacity
2	670
4	720
7	770

Table 10. Impact of changes in participation factor in the contract market

Participation (%)	Investment capacity (MW)
50	670
65	750
80	830

Table 11. Effect of changes in the marginal cost variation of new units

Marginal cost changing (%)	Investment capacity (MW)
80	590
100	670
120	710

investments have been made in buses 1, 2 and 3. But by limiting the transmission of power to the buses from buses 4 and 6, as well as with the growth of network load, ISO will have to invest in mentioned buses to meet demand.

5. CONCLUSION

In this paper, a new framework for solving the problem of generation expansion planning in the presence of investment incentives is presented.

The guaranteed purchase contract and the level of participation in the contractual market are known to affect the behavior of wind unit investors. Guaranteed contract will increase the willingness to invest in wind units as well as increase profits. And the strategic offering by the generation unit (which is determined during the market clearing operation), will increase the investment, as well as the wind unit profit.

Full participation in the electricity market will reduce the profitability of the investor. On the other hand, the full sale of capacity as a contractor affects the market price and increases the payments of the consumer and the operator.

An increase in the rate of growth will increase the capacity of the generation units. And increasing the marginal cost (offer) of other units reduces their participation and increases the number of wind units. Also restrictions on the transmission lines will make investments in place of load points.

Table 12. Effect of limiting the capacity of the transmission lines

Limiting of capacity L2-4 & L3-4	Buses 1, 2 & 3	Buses 4, 5 & 6
No limit	0(1)	390(4)
	0(2)	110(50)
	0(3)	120(6)
300 (MW)	0(1)	390(4)
	0(2)	90(5)
	50(3)	90(6)
100 (MW)	20(1)	340(4)
	50(2)	90(50)
	80(3)	40(6)

REFERENCES

1. L. Stankeviciute, P. Criqui, “Energy and climate policies to 2020: the impacts of the European ”20/20/20” approach,” International journal of energy sector management, vol. 2, no. 2, pp. 252-273, 2008.
2. S. Jin, A. Botterud and S. M. Ryan, “Temporal versus stochastic granularity in thermal generation capacity planning with wind power,” IEEE transactions on power systems, vol. 29, no. 5, pp. 2033-2041, 2014.
3. K. Rajesh, S. Kannan and C. Thangaraj, “Least cost generation expansion planning with wind power plant incorporating emission using Differential Evolution algorithm,” Electrical power and energy systems, vol. 80, pp. 275-286, 2016.
4. K. Rajesh, A. Bhuvanesh, S. Kannan and C. Thangaraj, “Least cost generation expansion planning with solar power plant using Differential Evolution algorithm,” Renewable energy, Vol. 85, pp. 677-686, 2016.
5. E. Hajipour, M. Bozorg and M. Fotuhi-Firuzabad, “Stochastic Capacity Expansion Planning of Remote Microgrids With Wind Farms and Energy Storage,” IEEE transactions on sustainable energy, vol. 6, no.2, pp. 491-498, 2015.
6. J. Salehi, S. Esmaeilpour, F. Samadi Gazijahani, A. Safari, “Risk Based Battery Energy Storage and Wind Turbine Allocation in Distribution Networks Using Fuzzy Modeling,” Journal of Energy Management and Technology, Vol. 2, no. 2, pp. 53-65, 2018.
7. J. Salehi, S. Esmaeilpour, A. Safari, F. Samadi, “Investment Deferral of Sub-Transmission Substation Using Optimal Planning of Wind Generators and Storage Systems,” Journal of Energy Management and Technology, Vol. 1, no. 1, pp. 18-29, 2017.
8. E. Hajipour, M. Bozorg, M. Fotuhi-Firuzabad, “Stochastic capacity expansion planning of remote microgrids with wind farms and energy storage,” IEEE transactions on sustainable energy, Vol. 6, no. 2, 2015.
9. R. Hemmati, R.-A. Hooshmand and A. Khodabakhshian, “Coordinated generation and transmission expansion planning in deregulated electricity market considering wind farms,” Renewable energy, vol. 85, pp. 620-630, 2016.
10. S. Kamalinia and M. Shahidehpour, “Generation expansion planning in wind-thermal power systems,” IET generation, transmission & distribution, vol. 4, no. 8, pp. 940-951, 2010.
11. N. Neshat and A. Naseri, “Cleaner power generation through market-driven generation expansion planning: an agent-based hybrid framework of game theory and Particle Swarm Optimization,” Journal of cleaner production, vol. 105, pp. 206-217, 2015.
12. D. Pozo, E. Sauma and J. Contreras, "A Three-Level Static MILP Model for Generation and Transmission Expansion Planning," IEEE transaction on power system, vol. 28, no. 1, pp. 202-210, 2013.

13. M. Asensio, P. Meneses de Quevedo, G. Muñoz-Delgado and J. Contreras, "Joint Distribution Network and Renewable Energy Expansion Planning considering Demand Response and Energy Storage Part I: Stochastic Programming Model," IEEE transaction on micro grid, vol. 9, no. 2, pp. 655 - 666, 2016.

14. S. Shenoy, D. Gorinevsky, "Data-driven stochastic pricing and application to electricity market," IEEE journal of selected topics in signal processing, Vol. 10, no. 6, pp. 1029-1039, 2016.

15. A. Galetovic, C. M. Muñoz, and F. A. Wolak, "Capacity payments in a cost-based wholesale electricity market: the case of Chile," The Electricity journal, vol. 28, no. 10, pp. 80-96, 2013.

16. P. M. Sotkiewicz, J. M. Vignolo, "Nodal pricing for distribution networks: efficient pricing for efficiency enhancing DG," IEEE transactions on power systems, vol. 21, no. 2, pp. 1013-1014, 2006.

17. K. Shaloudegi, N. Madinehi, S. H. Hosseinian, H. A. Abyaneh, "A novel policy for locational marginal price calculation in distribution systems based on loss reduction allocation using game theory," IEEE transactions on power systems, vol. 27, no. 2, pp. 811-820, 2012.

18. R. K. Singh, S. K. Goswami, "Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction, and voltage improvement including voltage rise issue," International journal of electrical power & energy systems, vol. 32, no. 6, pp. 637-644, 2010.

19. M. J. Rider, J. M. Lopez-Lezama, J. Contreras, A. Padilha-Feltrin, "Bilevel approach for optimal location and contract pricing of distributed generation in radial distribution systems using mixed-integer linear programming," IET generation, transmission and distribution, vol. 7, no. 7, pp. 724-734, 2013.

20. S. Shafiee, H. Zareipour, A. M. Knight, N. Amjady, B. Mohammadi-Ivatloo, "Risk-constrained bidding and offering strategy for a merchant compressed air energy storage plant," IEEE Transactions on Power Systems, Vol. 32, no. 2, 946-957, 2017.

21. H. Shayeghi, A. Ghasemi, "Day-Ahead electricity price forecasting using WT, ANN and Chaotic gravitational search model," Tabriz journal of electrical engineering, vol. 45, no. 4, pp. 105-115, 2015.

22. M. Vatanpour, A. Sadeghi Yazdankhah, "Application of Benders decomposition in stochastic scheduling of thermal units with coordination of wind farm and energy storage system considering security constraint," Journal of energy management and technology, vol. 2, no. 1, pp. 9-17, 2018.

23. J. M. Lopez-Lezama, A. Padilha-Feltrin, J. Contreras, J. I. Munoz, "Optimal contract pricing of distributed generation in distribution networks," IEEE transactions on power systems, vol. 26, no. 1, pp. 128-136, 2011.

24. S. J. Kazempour, A. J. Conejo, C. Ruiz, "Strategic generation investment using a complementarity approach," IEEE transactions on power systems, vol. 26, no. 2, pp. 940-948, 2011.

25. M. Ramezanian Langeroudi, S. M. Mirhosseini Moghaddam, B. Alizadeh, "Strategic bidding for GENCOs using reinforcement learning methodology based on LMP in electricity market," Tabriz journal of electrical engineering, vol. 47, no. 2, pp. 537-549, 2017.

26. A. Sadeghi Mobarakeh, A. Rajabi-Ghahnavieh, H. Haghighat, "A bi-level approach for optimal contract pricing of independent dispatchable DG units in distribution networks," International transaction on electrical energy systems, vol. 28, no. 8, pp. 1685-1704, 2016.

27. M. Nojavan Goltappeh, H. Seyedi, B. Mohammadi Ivatloo, "Assessment of preventive facilities against voltage instability considering power system losses, correlated wind turbine uncertainty and load variations," Tabriz journal of electrical engineering, vol. 47, no. 1, pp. 305-318, 2017.