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IMPACT OF WIND ENERGY PENETRATION TO CONNECT THE LARGE SCALE DISTANT WIND FARM INTO THE GRID IN PROBABILISTIC MULTI OBJECTIVE TRANSMISSION EXPANSION PLANNING

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Abstract- As the share of wind energy in power system increases, consideration of these resources in power system planning, particularly in Transmission Expansion Planning (TEP) is becoming more and more important. In this paper, a Probabilistic Multi-Objective Transmission Expansion Planning (PMO-TEP) is presented to find the optimal node for connecting the large scale distant wind farm to the network from viewpoint of market competition. Furthermore, to investigate the uncertainty associated with wind speed variation and load prediction, a probabilistic analysis tool namely Two-Point Estimate Method (2PEM) is applied. The investment cost of new lines and congestion cost for enhancement of market competition are considered as multifarious objectives in PMO-TEP. Moreover, a reliability index is evaluated to ensure that all optimal plans are satisfying the security constraint (n–2 and n–1 criterion). Here, a Non-Dominated Sorting Genetic Algorithm II (NSGA-II) is utilized to handle the multi-objective optimization. Finally, a fuzzy decision-making analysis is used to obtain the optimal node for connecting the wind farm to the network among all optimal Pareto solutions. Different scenarios are demonstrated on the modified IEEE-RTS to trace the capability of proposed model.

Keywords: Transmission Expansion Planning, Wind Farm, 2PEM, Wind Penetration.

I. INTRODUCTION

As augmenting concerns pertinent to global warming, climate alterations, fuel price fluctuations and energy security, increase in share of renewable energy sources in electricity production has turned to be a controversial issue in power system study [1]. Among various renewable energy resources, wind energy is most promising source [2]. rapid development of wind energy and its penetration in electricity generation in the future of power network has large impacts on professionals in electric utilities who really need to know elaboration that positive and negative impacts of wind energy can have on power system [2].

Currently, five countries as Germany, USA, Denmark, India, and Spain have made a rapid progress in developing this type of energy [2]. Furthermore, an incentive policy such as renewable portfolio standard is developed in the countries, which have a low penetration of wind energy in electrical industry. High investment cost and changeability of wind power production and also being far from load center are some of barriers that prevent the efficient use of wind power generation.

Therefore, in this paper a multi objective framework for Transmission Expansion Planning (TEP) based on probabilistic analysis is utilized to propose an efficient topology for transmission network in the presence of wind energy. Traditionally, Transmission Expansion Planning (TEP) addresses an optimal topology of future network with minimum investment cost while satisfying security constraints [3]. In deregulated electricity markets, the transmission network is the interface where customers and sellers interact with each other [4].

Any form of transmission constraint or bottlenecks in transmission network will prevent perfect competition between market participants [4]. It is eligible that the generation should be close to the demand center but In practical, demand center is located physically in urban area that is difficult to expand generation especially for large scale wind farms that require a lot of land space to be constructed [5]. Suboptimal placement of generation causes congestion on transmission line and loads monetary with high price fluctuations.

Congestion on transmission confined power flow from low cost nodes to high value nodes making supply demand price imbalances [5]. Furthermore the attendance of congestion on one circuit makes price vitality not only through this specific line, but also across many other non-congested lines [4]. In short, congestion means that the specific line cannot support the particular trading scheme [4]. With regard to impact of large scale distant wind farm on congestion rent, the necessity of considering network congestion in Transmission Expansion Planning (TEP) problem is most felt.

In addition, new uncertainties including wind power production [6], load variation [7, 8] and generator's bids [9] are introduced with presence of deregulation in power system. Thus, a new approach is needed to deal with these uncertainties because traditional method for TEP is inefficient. A probabilistic method is employed in [5] to investigate the impact of wind energy on TEP problem. This paper studies congestion driven in Probabilistic Multi Objective Transmission Expansion Planning (PMO-TEO) incorporating large scale distant wind farm in detail.

Some candidate buses are selected in order to connect the specified wind farm to the network from concept of congestion driven and minimizing the total investment of new lines. A multi-objective framework is used to obtain a set of optimal solution and *n*–2 and *n*–1 contingency analysis is employed to determine the Expected Energy Not Served (EENS) in transmission level as constraint to ensure that all optimal plans have satisfied the security constraints. The Non-Dominated Sorting Genetic Algorithm II (NSGA-II) is used to handle the non-convex and mixed integer nature of problem.

A fuzzy decision method is implemented to achieve the best solution with regard to the satisfactory level of decision maker. Finally, sensitive analysis based on satisfactory levels is performed to obtain the best node in the network to connect the wind farm in each scenario. The rest of the paper is organized as follows: Section II provides the problem description, section III demonstrates the objective functions and constraints of PMO-TEP, the results of proposed method are derived in section IV, and the conclusion is drawn in section V.

II. PROBLEM DESCRIPTION

In this section, proposed probabilistic multi-objective algorithm accommodating uncertainties related to wind turbine generation and predicted load, the objective of proposed multi objective TEP, final decision making and the main characteristic of probabilistic analysis method (point estimate method) is demonstrated carefully.

A. Load and Wind Model

In this study, the uncertainty and random behavior of load is applied as normal Probability Distribution Function (PDF) as:

$$f(x) = \frac{1}{\sigma_{est}\sqrt{2\pi}} e^{\frac{-(x-\mu_{est})}{2\sigma_{est}^2}} \tag{1}$$

where, μ_{est} is the mean of predicted load and σ_{est} represents the standard deviation of predicted demand from the average value of load. The value of σ_{est} is obtained from the prediction error. The prediction error in this study is equal to 10%. The wind turbine generation P is function of wind speed (V) as shown in the following:

$$P = \begin{cases} 0 & 0 \le V \le V_{ci} \\ (A + BV + CV^2)P_r & V_{ci} \le V \le V_r \\ P_r & V_r \le V \le V_{co} \\ 0 & V \ge V_{co} \end{cases} \tag{2}$$

where, P_r is rated power of wind turbine, V_{ci} is cut in speed of wind turbine, V_r is rated speed of wind turbine, V_{co} is cut-out speed of wind turbine.

The value of *A*, *B* and *C* could be borrowed from [10]. From Equation (2), the production of a single wind turbine is calculated by predicted wind speed model. Therefore, the generation of wind farm is sum of all wind turbines in the site [5]. The Weibull distribution is used to model the uncertainty of wind speed in the power system studies in the literature [11]. The Weibull distribution parameters can be obtained from historical data.

In this context, the wind farm is assumed to be located in a site near the north part of Iran (Manjil). The historical data of this site (from January 1, 2005 to December 31, 2009) is presented in [12]. The sequential Monte Carlo Simulation is employed to simulate the wind speed change applying the Weibull distribution function of each hour in each mount.

B. Objective of PMO-TEP

The investment cost of new circuits is considered as traditional objective function of TEP problem. In order to improve the competition between market participants, the congestion cost is considered in the proposed method. The probabilistic analysis method (2PEM) is used to evaluate the uncertainties associated with the random behavior of the wind speed and demand.

In order to ensure that the all optimal solutions have satisfied the security constraint, the *n*–1 contingency analysis is performed by means of overload index in [6]. A final decision-making based on fuzzy satisfying approach, designated as the distance metric is applied. To manage nonlinearity and mixed integer nature of the optimization problem the genetic algorithm based NSGA II method is used in this context.

C. Probabilistic Optimal Power Flow

To deal with stochastic nature of wind farm generation and load in planning horizon, a probabilistic optimal power flow by means of two point estimate method is used in [5]. The point estimate method concentrates the statistical information provided by the first few central moments of a problem input random variable on *K* points for each variable, named 'concentration' [13]. The overall process of probabilistic optimal power flow by means of PEM is depicted in Figure 1. The mathematical procedure of two-point estimate method is formulated as following [5]:

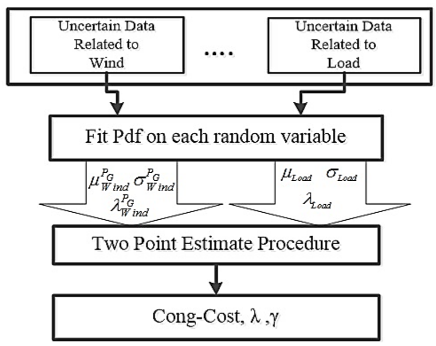

Figure 1. Overall process of probabilistic optimal power flow

Step 1- In the first step the initial value of expected outputs are assigned. The following steps are performed respectively:

$$E(Y)^{(1)} = 0\ ;\ E(Y^2)^{(1)} = 0 \tag{3}$$

Step 2-

$$\begin{cases} \xi_{k,1} = \dfrac{\lambda_{k,3}}{2} + \sqrt{n + \left(\dfrac{\lambda_{k,3}}{2}\right)^2} & k = 1,\ ...,\ n \\ \xi_{k,2} = \dfrac{\lambda_{k,3}}{2} - \sqrt{n + \left(\dfrac{\lambda_{k,3}}{2}\right)^2} & k = 1,\ ...,n \\ P_{k,1} = \dfrac{-\xi_{k,2}}{2n\sqrt{n + \left(\dfrac{\lambda_{k,3}}{2}\right)^2}} & k = 1,\ ...,n \\ P_{k,2} = \dfrac{\xi_{k,1}}{2n\sqrt{n + \left(\dfrac{\lambda_{k,3}}{2}\right)^2}} & k = 1,\ ...,n \end{cases} \tag{4}$$

$\lambda_{k,3}$, n are skewness and number of random variables, respectively.

Step 3- The concentrations $x_{k,1}$, $x_{k,2}$ can be calculated as following:

$$\begin{cases} x_{k,1} = \mu_{X,k} + \xi_{k,1}.\ \sigma_{X,k} \\ x_{k,2} = \mu_{X,k} + \xi_{k,2}.\ \sigma_{X,k} \end{cases} \tag{5}$$

where, $\mu_{X,k}$, $\sigma_{X,k}$, are mean and variance of random variables X respectively.

Step 4- Run the deterministic optimal power flow with regard to vector X that can be considered as follow and h is the OPF function:

$$\begin{cases} X = [\ \mu_{k,1}, \mu_{k,2}, ..., x_{k,i}, ..., \mu_{k,n}] & i = 1, 2 \\ Y = h(X) \end{cases} \tag{6}$$

Step 4- Update the following equations:

$$\begin{cases} E(Y)^{K+1} \cong E(Y)^K + \sum_{i=1}^{2} P_{k,i} h(X) \\ E(Y^2)^{K+1} \cong E(Y^2)^K + \sum_{i=1}^{2} P_{k,i} h^2(X) \end{cases} \tag{7}$$

Step 5- The expected value and standard deviation of Y can be determined as following:

$$\begin{cases} \mu_Y = E(Y) \\ \sigma_Y = \sqrt{E(Y^2) - \mu_Y^2} \end{cases} \tag{8}$$

D. Final Decision Making

Solving the multi-objective transmission expansion planning problem results in a set of pareto-optimal solutions, on the other hand, due to imprecise nature of decision-making, a mathematical tool needs to applying human judgment. A fuzzy approach has been used in [5, 14] to represent the human thought. In this context a fuzzy satisfying method based on distance metric, is applied. With considering some desirable level for each objective, the final solution will be obtained from all of pareto-optimal solution. The procedure of final decision-making is as following:

First, the Membership Function (MSF), is assigned to each objective, which indicates the grade credence of decision maker to each objective. Figure 2 shows the graph of this membership function.

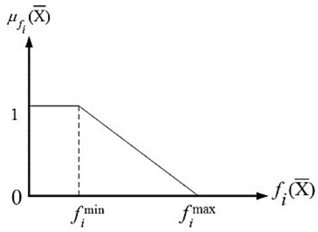

Figure 2. Linear type of membership function

The membership function is formulated as:

$$\mu_{f_i} = \begin{cases} 0 & f_i(X) > f_i^{\max} \\ \dfrac{f_i^{\max} - f_i(X)}{f_i^{\max} - f_i^{\min}} & f_i^{\min} \le f_i(X) \le f_i^{\max} \\ 1 & f_i(X) < f_i^{\min} \end{cases} \tag{9}$$

After defining membership function for each objective, the desired level of achievement of each objective will be fed to decision maker. The desirable levels of achievement are defined as μ_{ri}. Thus, the final optimal solution with regard to desired level (μ_{ri}) can be obtained as following optimization:

$$\min \sum_{\overline{X} \in \Phi} \left|\mu_{r_i} - \mu_{f_i}\right|^p, \quad P \in [1, \infty) \tag{10}$$

The Equation (10) will be less sensitive to desired level for larger P [5].

III. PROBLEM FORMULATION

A. Objective Formulation

The first objective of PMO-TEP can be formulated as following:

$$\min\ f_1 = \sum_{k \in \Omega} c_k n_k \tag{11}$$

where, C_k is the investment cost of k_{th} line and n_k is the number of new line added in corridor k_{th}. With regard to LMP based market, the congestion cost in each alternative can be calculated deterministically as following:

$$cong\ \_cost = \sum_{(i,j) \in \Omega} f_{ij}(LMP_j - LMP_i) \tag{12}$$

$$LMP_i = LMP^{energy} + LMP_i^{cong} + LMP_i^{Loss} \tag{13}$$

where, LMPs are the Lagrange multipliers or shadow prices of power flow constraint that can be computed through an optimization with following objective function:

$$\min \quad (\sum_{i=1}^{ng} p_i(a_i p_i + b_i) - C_D^T P_D) \tag{14}$$

where, a, b and C_D^T are the bid parameters of generator and dispatch able load respectively. On the other hand, in one side market, Equation (14) can be represented as following:

$$\min\left(\sum_{i=1}^{ng} p_{g_i}(a_i p_{g_i}+b)\right)$$

$$\text{subject to}:\begin{cases} s^T f+g+r=d \\ f_{ij}-\gamma_{ij}(n_{ij}^0+n_{ij})(\theta_i-\theta_j)=0 \\ \left|f_{ij}\right|\le(n_{ij}^0+n_{ij})\overline{f_{ij}} \\ 0\le g\le\overline{g},\ 0\le r\le d \\ 0\le n_{ij}\le\overline{n_{ij}} \quad \forall(i,j)\in\Omega \end{cases} \quad (15)$$

where, f, g, r and d are power flow, generation, curtailed load and demand vectors, respectively. The following results are obtained by considering DCOPF model in power system study:

$$\begin{aligned} &LMP_i^{Loss}=0 \\ &LMP^{energy}=\lambda \\ &LMP_i^{cong}=\sum_{ij\in\Omega}\gamma_{ij}(\theta_i-\theta_j)\times\varsigma_{ij} \end{aligned} \quad (16)$$

where, λ and ς are the shadow price of quality and inequality constraints, respectively. The second objective will be obtained as following:

$$\min \quad f_2=\mu_{\text{cong\_cost}} \quad (17)$$

where, μ is the mean of congestion cost for two point of each wind farm generation.

B. Constraints

Here, a constraint has been developed to ensure that all the optimal solutions that found by NSGA-II have been satisfied the reliability criterion as [5]:

$$\begin{cases} \overline{EENS}_{TR}\le EENS_R \\ \overline{EENS}_{TR}=\overline{EENS}_{HLII}-\overline{EENS}_{HLI} \end{cases} \quad (18)$$

where, $EENS_{TR}$ is expected energy not served in transmission grid and $EENS_R$ is desired level for expected energy not served. n–2 and n–1 criterion are applied to determine the $EENS$ in HLII and HLI, respectively. More information that is detailed is derived in [4].

IV. OPTMIZATION ALGORITHM

Due to advantage of multi-objective optimization such as handling non-convex problem against mathematical method, the "Elitist Non-dominated Sorting Genetic Algorithm" [15]designated based on crowding distance method is used here. The basic idea of NSGA II Algorithm is to classify a population of solutions into the number of non-dominated front [14]. Figure 3 shows that the entire population has been classified in k level and Figure 4 illustrates the iteration of NSGA II.

V. CASE STUDY

The multi-objective transmission expansion planning algorithm was applied on the IEEE 24-bus test system as shown in Figure 5. The required data can be found in [16]. It is assumed that the network should be expanded in the next ten years with generation and load levels increases to 2.2 times of their original values (i.e., load and generation are 6270 MW and 7490 MW, respectively). The value of bid parameters, a and b, can be found in [16].

To investigate the impact of wind farm generation on congestion cost of power system, different wind energy scenarios were considered on the IEEE 24-bus as following:

Case 1- The modified IEEE-RTS without wind energy.

Case 2- The modified IEEE-RTS network in the presence of 2% wind energy penetration.

Case 3- The modified IEEE-RTS network in the presence of 5% wind energy penetration.

The new candidate line investment cost for connecting the wind farm to the network can be found in Table 5. The physical parameters of the new lines are the same as existing ones and the upper bound of the line in each corridor is set to be three. Other data of new lines are presented in [17]. The investment cost of installing new transmission line is considered to be 350 $/MW-mile. The wind farm is assumed to be located in a site near the north part of Iran (Manjil).

The historical data of this site from January 1, 2005 to December 31, 2009 are presented in [12]. The sequential Monte Carlo Simulation is employed to simulate the wind speed change applying the Weibull distribution function of each hour in each mount. Therefore, the Figure 6 depicts the simulated and real wind speed in a specific day for Manjil site.

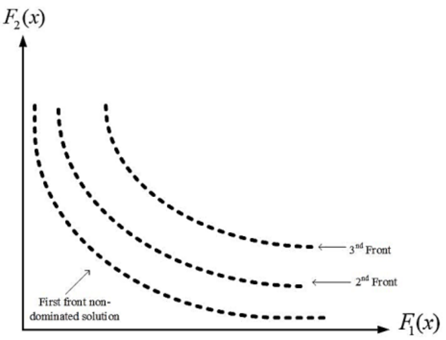

Figure 3. Classification of population

A. Implementation of Purposed Method for Case 1

The initial population for NSGA-II is equal to 100 individuals. After 200 iterations, 100 non-dominated solutions are achieved. With regard to the Figure 7, the minimum investment cost to remove the congestion is about 73.5 M$. Table 1 shows the final optimal plan for case1 with different desirable level and sensitivity of decision maker procedure.

B. Implementation of proposed method for Case2

The Penetration of wind generation in this case is considered to be 2%. The capacity of wind farm is equal to 150 MW. The initial population for NSGA-II in this case is considered to be 200 individuals. After 250 iterations, 200 non-dominated solutions are achieved. These solutions are illustrated in Figure 8. The optimal solution of TEP problem in this case, considering different desired levels is shown in Table 2. The minimum investment cost to remove congestion in this case is about 111.3 M$. The selected lines for connecting the wind farm to the network are shown in Table 4.

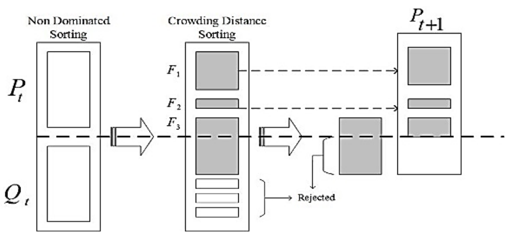

Figure 4. NSGA-II procedure

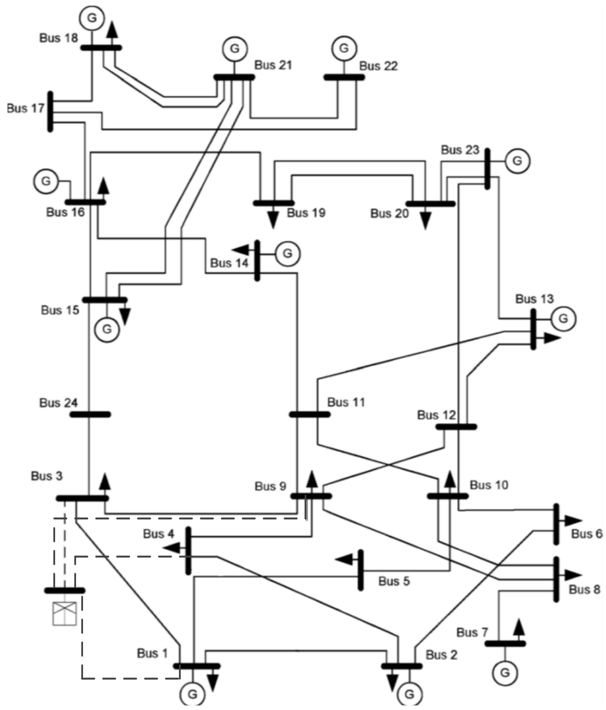

Figure 5. Modified IEEE-RTS with the candidate lines for wind farm connection

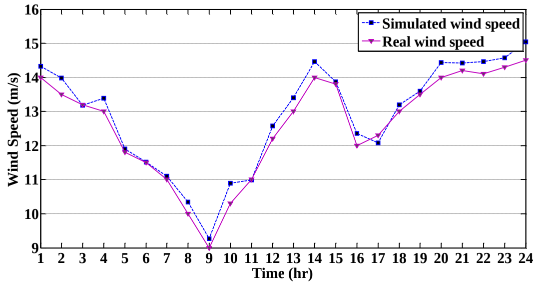

Figure 6. Real and simulated wind speed in a specific day

Table 1. Optimal plans for case 1

Satisfactory Level		Case 1		
μ_{d1}	μ_{d2}	*IC*	*CC*	*NL*
0.8	0.8	42.24	3.7768	10
0.8	0.6	42.24	3.7768	10
0.6	0.8	64.43	1.2539	13

Table 2. Optimal plans for case 2

Satisfactory Level		Case 2		
μ_{d1}	μ_{d2}	*IC*	*CC*	*NL*
0.8	0.8	102.19	0.74	18
0.8	0.6	104.84	1.419	20
0.6	0.8	117.09	1.034	23

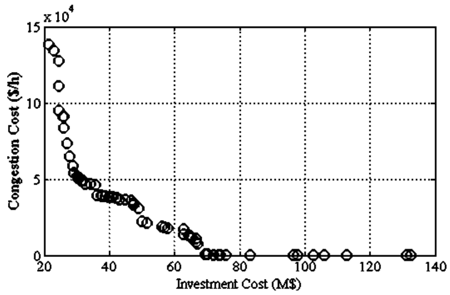

Figure 7. The trade-off between investment cost and congestion cost in case 1

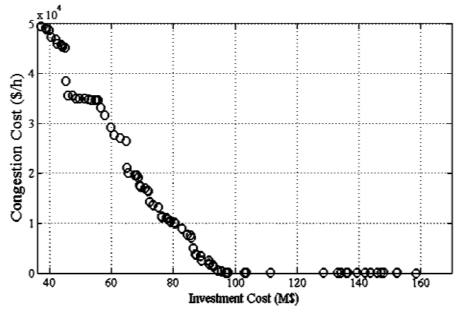

Figure 8. The trade-off between investment cost and congestion cost in case 2

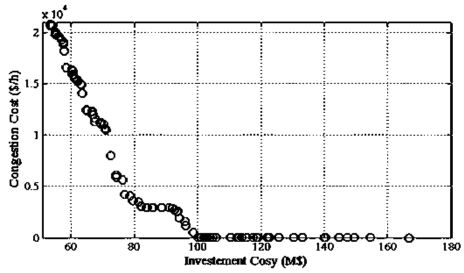

Figure 9. The trade-off between investment cost and congestion cost in case 3

Table 3. Optimal plans for case 3

Satisfactory Level		Case 3		
μ_{d1}	μ_{d1}	*IC*	*CC*	*NL*
0.8	0.8	106.57	0.5825	20
0.8	0.6	106.57	0.5825	20
0.6	0.8	118.11	0.2921	21

where, *IC* = Investment Cost (M$)
CC = Congestion Cost (×10^4 $/h)
NL = Number of new added lines
B_i = Index of candidate nodes (i) to connecting the wind farm

Table 4. Optimal node for connecting the wind farm in to the network

Satisfactory Level		Case 2				Case 3			
μ_{d1}	μ_{d2}	*B*1	*B*9	*B*3	*B*4	*B*1	*B*9	*B*3	*B*4
0.8	0.8	0	0	1	1	2	0	0	0
0.8	0.6	1	0	0	0	2	0	0	0
0.6	0.8	1	0	0	0	1	0	1	0

Table 4 shows the optimal node for connecting the wind farm into the network for two scenarios with different satisfactory level. The results show that the optimal node for connecting the wind farm is different for different wind energy penetration.

Table 5. Investment cost of candidate lines

From	To	Investment cost
25	1	20 M$
25	3	18.65 M$
25	4	18.65 M$
25	9	25.6 M$

VI. CONCLUSIONS

In this paper, the TEP is considered as probabilistic multi objective optimization problem. The investment cost and congestion cost are considered as multifarious objective of proposed PMO-TEP. Furthermore, EENS of transmission level is considered as constraint to ensure that all optimal plans have satisfied the security constraint. The two point estimation method is utilized to apply the uncertainty of load and wind generation in planning horizon. Different scenarios (0%, 2%, and 5% penetration of wind) are implemented in this study to trace the capability of proposed framework.

By applying suggested method to these scenarios, the non-dominated solution is obtained by NSGA-II algorithm. In each scenario, the optimal line for connecting the wind farm in to the network for minimizing the total cost and the congestion cost is achieved. Finally, a sensitivity analysis based on fuzzy decision-making method is applied to each scenario to obtain the optimal solution of PMO-TEP. The results show that the planners must consider the impact wind energy penetration for connecting the large scale distant wind farm into network.

REFERENCES

[1] E. Alishahi, M.P. Moghaddam, M.K. Sheikh El Eslami, "An Investigation on the Impacts of Regulatory Interventions on Wind Power Expansion in Generation Planning", Energy Policy, Vol. 39, No. 8, pp. 4614-4623, Aug. 2011.
[2] G. Ahrabian, A. Roshan Milani, A. Lafzi, "Wind Farm Transient Behavior Optimizing by Capacitor Banks Switching", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 1, Vol. 1, No. 1, pp. 65-68, December 2009.
[3] S. Hosseini Naveh, R. Ghadiri Anari, M. Zeinaddini Meymand, "An Application of a Combinatorial Hybrid Heuristic Algorithm to Transmission Expansion Planning", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 16, Vol. 5, No. 3, pp. 58-63, September 2103.
[4] G.B. Shrestha, P.A.J. Fonseka, "Congestion Driven Transmission Expansion in Competitive Power Markets", IEEE Trans. Power Syst., Vol. 19, No. 3, pp. 1658-1665, 2004.
[5] M. Moeini Aghtaie, A. Abbaspour, M.F. Firuzabad, "Incorporating Large Scale Distant Wind Farms in Probabilistic Transmission Expansion Planning, Part I - Theory and Algorithm", IEEE Trans. Power Syst., Vol. 27, No. 3, pp. 1585-1593, 2012.
[6] H. Yu, C.Y. Chung, K.P. Wong, J.H. Zhang, "A Chance Constrained Transmission Network Expansion Planning Method with Consideration of Load and Wind Farm Uncertainties", IEEE Trans. Power Syst., Vol. 24, No. 3, pp. 1568-1576, 2009.
[7] T.D. Torre, J.W. Feltes, T.G.S. Roman, H.M. Merrill, "Deregulation, Privatization, and Competition - Transmission Planning under Uncertainty", IEEE Trans. Power Syst., Vol. 14, No. 2, pp. 460-465, 1999.
[8] G. Latorre, R.D. Cruz, J.M. Areiza, A. Villegas, "Classification of Publications and Models on Transmission Expansion Planning", IEEE Trans. Power Syst., Vol. 18, No. 2, pp. 938-946, 2003.
[9] Z. Xu, Z.Y. Dong, K.P. Wong, "Transmission Planning in a Deregulated Environment", Gener. Transm. Distrib. IEEE, Vol. 153, No. 3, pp. 326-334, 2006.
[10] R. Billinton, H. Chen, R. Ghajar, "A Sequential Simulation Technique for Adequacy Evaluation of Generating Systems Including Wind Energy", IEEE Trans. Energy Convers., Vol. 11, No. 4, pp. 728-734, 1996.
[11] J.V. Seguro, T.W. Lambert, "Modern Estimation of the Parameters of the Weibull Wind Speed Distribution for Wind Energy Analysis", J. Wind Eng. Ind. Aerodyn., Vol. 85, No. 1, pp. 75-84, Mar. 2000.
[12] www.suna.org.ir, www.google.com/search?q=%3Ahttp%3A%2F%2F+www.suna.org.ir/%2F.&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla: en-US:official&client=firefox-a&channel=fflb.
[13] J.M. Morales, J. Perez-Ruiz, "Point Estimate Schemes to Solve the Probabilistic Power Flow", IEEE Trans. Power Syst., Vol. 22, No. 4, pp. 1594-1601, 2007.
[14] P. Maghouli, S.H. Hosseini, M.O. Buygi, M. Shahidehpour, "A Multi-Objective Framework for Transmission Expansion Planning in Deregulated Environments", IEEE Trans. Power Syst., Vol. 24, No. 2, pp. 1051-1061, 2009.
[15] K. Deb, "Multi-Objective Optimization Using Evolutionary Algorithms, 1st Ed.", Wiley, 2009.
[16] C. Grigg, P. Wong, P. Albrecht, R. Allan, M. Bhavaraju, R. Billinton, Q. Chen, C. Fong, S. Haddad, S. Kuruganty, W. Li, R. Mukerji, D. Patton, N. Rau, D. Reppen, A. Schneider, M. Shahidehpour, C. Singh, "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., Vol. 14, No. 3, pp. 1010-1020, 1999.
[17] R. Fang, D.J. Hill, "A New Strategy for Transmission Expansion in Competitive Electricity Markets", IEEE Trans. Power Syst., Vol. 18, No. 1, pp. 374-380, 2003.

BIOGRAPHIES

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