International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization on TPE (IOTPE)

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2011 | Issue 7 | Volume 3 | Number 2 | Pages 1-9

EVALUATING THE EFFECTS OF UNCERTAINTY IN FUEL PRICE ON TRANSMISSION NETWORK EXPANSION PLANNING USING IADPSO APPROACH

S. Jalilzadeh [1] A. Kimiyaghalam [2] A. Ashouri [3]

1. Electrical Engineering Department, University of Zanjan, Zanjan, Iran, sa_jalilzadeh@yahoo.com
2. Islamic Azad University, Zanjan Branch, Young Researchers Club, Zanjan, Iran, a.kimiyaghalam@gmail.com
3. Department of Electrical Engineering, Khodabandeh Branch, Islamic Azad University, Khodabandeh, Iran, a_ashouri2007@yahoo.com

Abstract- Transmission network expansion planning (TNEP) is a basic part of power system planning that determines where, when and how many new transmission lines should be added to the network so that the load is adequately supplied. There are several factors affecting TNEP, which sometimes make the problem results inaccurate and impractical because of their complicacy. Therefore, it should be tried to possibly introduce them in TNEP problem by using appropriate scientific tools. One of these parameters which is significantly effective in TNEP result, is the uncertainty of different parameters such as load growth, location of power plants in horizon year, and especially fuel price which indirectly affects the transmission lines loading and consequently the optimality of transmission plans via changing of loss and unsupplied load which are dependent on the power generation of power plants. Thus, in this paper, by considering the uncertainty of fuel price, in different scenarios, its determining role in TNEP result has been evaluated using IADPSO algorithm. To study the proposed approach, the 17-bus real network of Azerbaijan Regional Electrical Company is considered.

Keywords: Transmission Network Expansion Planning, Uncertainty, Fuel Price, IADPSO Approach.

I. INTRODUCTION

A major part of power system planning is Transmission Network Expansion Planning (TNEP). In TNEP, it is aimed to determine the location, time and number of new transmission lines, with the minimum construction and operation costs considering the condition of generation system and load. This planning is performed to supply loads adequately, considering a set of technical, economical and reliability constraints [1-3]. TNEP problem is generally divided into two types: static and dynamic expansion planning. The first one implements all of the planning targets, while in the second type, for simplification, the time variable is disregarded among the unknowns, and the planning is implemented for a load horizon year.

Along with electric consumption growth in today's world, there is more need to proper management and optimal planning of transmission network. Since, evaluating the role of effective parameters in TNEP has been obviously more and more important than ago. Uncertainty is one of the effective parameters in TNEP which was regarded by the planners about when Garver proposed his popular heuristic idea in 1970 [4] (which was the basis of modern transmission planning), and in the time that world experienced oil crisis [5]. Unprecedented increases of oil prices in recent years have highlighted the essentiality of this issue. Among the uncertainties in TNEP, we can count the demand (electric load of transmission substations), fuel price, existence of a power plant in horizon year and the preparation of approved transmission plans until the horizon year [6-7]. Also, the share of rivals in competitive market is one of the new uncertainties in TNEP scope [8], which has been arisen following the introduction of market concepts into power system.

The recent researches reveal the increasing of uncertainties in power system [9]. If the uncertainties are not regarded in TNEP, the outputs of TNEP will be conducted toward the undesirable points, and this will make the planning results infeasible and impractical. With regards to this fact, the uncertainties in different parts of network, has had different reflections among the researches. For example in [10], the uncertainty in load; in [5], the uncertainty in load and generation, in [11]; the uncertainty in load and lines capacity, in [12], uncertainty in the generators' preparation cost; and in [13], the uncertainty in load growth and inflation rate have been evaluated. In [14], the study has exposed the budget of lines' construction to uncertainty by using of fuzzy modeling. Also, Ref. [15] by regarding the uncertainty of load based on scenario technique [16], has evaluated the impact of loss on the static TNEP (STNEP).

As noted, the fuel price is one of the important factors that there is a severe uncertainty in its prediction. This parameter, by changing the optimal power generation of power plants, indirectly changes the lines loading and subsequently the constructed lines' arrangement. Hence, in this paper, by considering the uncertainty of fuel price in different scenarios, its significant effects on TNEP results are investigated by employing Improved Advance Discrete Particle Swarm Optimization (IADPSO) algorithm. It is worth mentioning that the considered uncertainty for the fuel price is based on the change of its average inflation rate during a ten-year time interval. To study the proposed approach, it is applied to the 17-bus real network of Azerbaijan Regional Electrical Company. Subsequently, first, the formulation of STNEP in the presence of uncertainty is presented and then the proposed solution algorithm is introduced and finally the simulation results are evaluated.

II. FORMULATION OF TNEP PROBLEM IN THE PRESENCE OF UNCERTAINTY

The objective function of STNEP problem, with regards to the scenarios for considering the uncertainty of fuel price is proposed by the following equation:

$$OF_k = EC_k + LC_k + \alpha \cdot \sum_{i=1}^{NB} r_i^k \tag{1}$$

$$EC_k = \sum_{i,j\in\Omega} CL_{ij} \cdot n_{ij} + \sum_{i=1}^{NB}\sum_{c=1}^{ST} m_i^k \cdot SC_c \tag{2}$$

$$LC_k = \left(\sum_{t=1}^{NY}\sum_{i=1}^{NC} R_i^k \cdot I_{i,t}^{k\,2}\right) \cdot K_{loss} \cdot 8760 \cdot C_{loss} \tag{3}$$

where

OF_k: Objective function in scenario k

EC_k: Network expansion cost in scenario k

LC_k: Network resistive loss cost in scenario k

r_i^k : Unsupplied load at bus i in scenario k

α: Economic worth of 1 MWh of unsupplied load

PR_k: Likelihood of occurring of scenario k

CL_{ij}: Construction cost of line at corridor ij

n_{ij}^k : Number of line circuits at corridor ij in scenario k

SC_c: Cost of transformer with the type of c given in [17]

m_i^k : Number of transformers predicted to be installed on ith bus in scenario k

C_{loss}: Per-unit loss cost in $/MWh

R_i^k : Resistance of line at corridor in scenario k

$I_{i,t}$: The current flowing through the ith corridor in year t and in scenario k, which varies with the annual load growth (after planning) and hence, is dependent on the time

K_{loss}: Loss coefficient that models the load's daily variation from its peak value

Ω : Set of all the network buses

NY: Number of years after horizon year which is used to calculate the loss values of expansion plans and is supposed a constant value (10-15 years)

NC: Number of expandable corridors of network

NB: Number of networks' buses (substations)

ST: Different types of installed transformers

NS: Number of considered scenarios

As it can be seen from Equations (1)-(3), all the costs included in the objective function have the index k and are dependent on the characteristics of the related scenario. The reason that the lines' construction cost is not dependent on scenario stems from the strategy of problem solution by the proposed algorithm (IDPSO); so that after a proposal for lines expansion in each stage of optimization, the other components of objective function are calculated according to this proposal and the related parameters of scenario. Therefore, the lines construction cost does not depend on the considered scenario; but, for example, for calculating the substations' expansion cost, their loading values are required which in turn we need to determine the power passing through the lines and hence, the active powers injected to the lines by the generating units.

The recent subject is completely related to the generation cost or fuel price, which is considered as one of the uncertainty sources. With regards to the energy consumption optimization and reduction of generation units' fuel cost, each scenario which is defined based on fuel price, affects the power generation of power plants, and disarranges the powers flowing through the lines to reach this goal. In this manner, the substations' expansion cost, or totally, each component of objective function which is dependent on lines loading (such as loss and unsupplied load) is affected by the considered scenario.

It should be mentioned that the transmission substations are only investigated or if necessary expanded from the voltage level point of view, and the related cost is included in the objective function.

The second component of objective function is the loss which has a significant weight compared to the other components; and its presence highlights and intensifies the competition between the cost and quality. That is to say by eliminating of loss from the objective function, the solving algorithm is conducted towards the low-cost solutions; namely, adding of cheap lines which have relatively high loss (such as low voltage lines) are proposed; whereas, in the presence of loss in the objective function, high-cost lines, which produce less loss, can participate in the competition, and a comprehensive objective function is composed.

About the unsupplied load, it should be mentioned that this component is equal to the overload value of the lines of expanded network which is not delivered to the load centers that because of lines' capacity limitation. As noted previously, this component, like the loss, is indirectly related to the fuel price of generating units. Valuing the worth of unsupplied load is very difficult, and several factors influence it. In this paper, a typical value has been considered for α . TNEP is exposed to the following constraints:

$$Sf^k + g^k - \delta^k d = 0 \tag{4}$$

$$f_{ij}^k - \gamma_{ij}^k (n_{ij}^0 + n_{ij}^k)(\theta_i^k - \theta_j^k) = 0 \tag{5}$$

$$\left|f_{ij}\right|^k \le (n_{ij}^0 + n_{ij}^k)\overline{f_{ij}} \tag{6}$$

$$0 \le g^k \le g_{\max} \tag{7}$$

$$0 \le n_{ij} \le \overline{n_{ij}} \tag{8}$$

$$0 \le \delta^k \le 1 \tag{9}$$

where
S : Network structure matrix
f^k : The matrix of flowing powers at each corridor composed of elements f_{ij}^k in kth scenario
g^k : Generation vector in scenario k composed of elements g_i^k
d^k : Demand vector composed of elements d_i
δ^k : Load supplying coefficient matrix at buses in scenario k composed of elements δ_i^k which are between 0 and 1. The nearer this coefficient is 1, the lower unsupplied load, and vice versa.
θ_i^k : Voltage angle of bus i in scenario k
γ_{ij} : Inverse of the reactance of all the circuits at corridor *i-j*
n_{ij} : Number of line circuits at corridor *i-j*
$\overline{g}$: Vector of maximum generable power
$\overline{n_{ij}}$: Maximum number of constructible line circuits at corridor *i-j*
$\overline{f_{ij}}$: Maximum transmission capacity of corridor *i-j*

In above equations, (4) and (5) are the relations of DC load flow (DCLF). It should be noticed that the DCLF has been used to increase the algorithm's speed, and also to prevent the divergence of load flow (due to the unbalance between active and reactive powers). But, of course, we desperately, must accept the approximation error. The constraints (6) and (7) respectively express the lines capacity limit and generation limit. The constraint (8) shows the maximum constructible lines at each corridor. Finally, (9) indicates the load supplying limit at each bus that is restricted between 0 and 100%.

Based on the reasons which was due to the independency of some parameters of problem from the defined scenario, parameters such as n_{ij}, γ_{ij} and S, after determining a new configuration for network expansion, are known, and they do not need to index k; because they are decision variables which are directly extracted from the network structure. Parameters such as $\overline{g}$, $\overline{n_{ij}}$ and $\overline{f_{ij}}$ are the input data of problem. It should be mentioned that the applied uncertainty on the fuel price in this research, the load demand (d) has not been considered as the uncertainty source, and due to this, is not affected by the defined scenario. However, this parameter can be exposed to uncertainty, as done in [15].

III. OPTIMIZATION OF GENERATION COST USING QUADRATIC PROGRAMMING

Generation vector is one of the unknowns which has been used in most of the TNEP studies at the stage after determining of the added lines to the network proposed by the solution algorithm. This vector along with the unsupplied load has been obtained using the linear programming (LP). Reference [17], had a new approach in optimal using of generation part; so that, by considering a quadratic function for generation cost, has converted the linear programming to quadratic one, and by combination with the cost of unsupplied load, has obtained the optimal value of the mentioned variable. In this way, the sum of generation cost and cost of unsupplied load is become minimum.

With regards to the importance of uncertainty sources especially fuel price in the recent years, the present research, by a view to deepen and complete the approach of Ref. [17], exposures the generation cost to the uncertainty; such that by defining different scenarios for the fuel price, the three coefficients of generation cost are changed and consequently, the result of *QP* for the generation vector changes in line with generation cost optimization. The change of generation vector, based on the load flow laws, directly affects the power flow in the lines, the lines loss, and the value of overload.

So, in this paper, the effect of uncertainty in fuel cost has directly been evaluated on TNEP result. This is essential to say that the linking loop between the fuel cost and TNEP is creation of appropriate background for optimization of generation cost; this matter is fulfilled using *QP*. It is obvious that if the generation vector is calculated without optimization and by using traditional methods (linear programming) with considering constraint (7), under this condition the fuel cost will not affect the TNEP results.

According to these comments, the fitness function of *QP*, like [17], is the sum of generation cost in the peak load of horizon year and the cost of unsupplied load. The only difference is that for applying the uncertainty of fuel cost and defining of different scenarios, the index k is added to the generation cost and unsupplied load. Hence, we have:

$$QPOF^k = \sum_{i=1}^{NB} \left[GC_i^k + \alpha * (1-\delta_i^k) * d_i \right] \tag{10}$$

$$GC_i^k = a_i^k g_i^{k2} + b_i^k g_i^k + c_i^k \tag{11}$$

where
$QPOF^k$: objective function of *QP* in scenario k
GC_i^k : Generation cost of power plant located at bus i in scenario k
a_i^k, b_i^k, c_i^k : Coefficients of generation cost of power plant located at bus i in scenario k

The constraints of *QP* except Equation (8) are the same of TNEP ones expressed in (3). Actually, regarding that execution of *QP* is one of the inner calculations of TNEP; the considered constraints in *QP* along with (8) are the final constraints of TNEP. Therefore, by performing *QP*, some important unknowns such as optimal generation, the power passing through the lines, and finally the total unsupplied load are determined.

IV. IADPSO ALGORITHM AND ITS APPLICATION FOR THE PROBLEM SOLUTION

Particle swarm optimization (PSO) algorithm is one of the stochastic-based searching methods which was inspired from the nature and is based on the social behavior of birds. The primary ideas of this algorithm were proposed by Kennedy and Eberhart in 1995 [19]. This concept has had proper performance in different kinds of optimization problems. In this algorithm, an L-number population composed of X vectors is considered. X is an n-member vector, that each of its elements (in this paper) is one of the parameters of STNEP. At first, the populations of particles are initialized randomly, and in the process of algorithm implementation, the particles are conducted towards objective that is finding optimal point.

The position of each particle is, in fact, its related X vector, and its worth is the value of fitness function at the related position. In the algorithm procedure, we can store the best experience of each particle and its related position. The best experience of ith particle and its related position are respectively named $pbest_i$ and $\vec{x}_{pbest_i}$. Like this, the best experience among the whole particle and the related position are respectively called $gbest_i$ and $\vec{x}_{gbest_i}$. In movement towards the minimum point, the velocity of each particle and its new position are specified as relations (12) and (13) [20]:

$$\vec{v}_i(t+1) = \omega \times \vec{v}_i(t) + c_1 r_1(\vec{x}_{pbest_i} - \vec{x}_i(t)) + \\ + c_2 r_2(\vec{x}_{gbest_i} - \vec{x}_i(t)) \tag{12}$$

$$\vec{x}_i(t+1) = \vec{x}_i(t) + \vec{v}_i(t+1) \tag{13}$$

In [12], ω is the inertia coefficient, and c_1 and c_2 are the acceleration rates. To randomize the nature of velocity, the coefficients c_1 and c_2 are multiplied by random numbers r_1 and r_2. Conventionally, in the execution of algorithm, the low values of ω lead to fast convergence at a local optimum point. Whereas, it's high values might obstacle the convergence. Normally, in the run of PSO, the value of ω is regulated during iterations and is linearly decreased from 1 near to zero [21].

It should be mentioned that PSO uses real numbers, whereas the parameters of TNEP are discrete-type numbers. Hence, this algorithm cannot be directly applied to solve TNEP. There are two ways for solving of TNEP using PSO algorithm:
1) Binary codification PSO algorithm (BPSO)
2) Discrete PSO (DPSO)

Here, due to the following reasons, the second method, i.e. DPSO method has been employed for the solution of STNEP:
1) To prevent from difficulties that arises while coding and decoding of problem parameters
2) To increase the convergence speed
3) Simplicity of accomplishment

In this method, the position vector of each particle is expressed by three arrays: the ID of start bus, the ID of end bus, and the number of lines circuits (both existing and new ones). At each iteration of DPSO algorithm, only the numbers of lines circuits are altered and the two other arrays namely the ID of start bus and the ID of end bus have constant values. As a result, in representing the position vector of each particle, these two arrays can be omitted and the position vector can be expressed by only one array. In Figure 1, the position vector of a typical particle with 12 corridors has been illustrated.

$$X_{typical} = (1, 2, 3, 1, 0, 2, 1, 0, 0, 1, 1, 2)$$

Figure 1. Position vector of a typical particle

There are 1 circuit at first corridor, 2 circuits at second corridor, 3 circuits at third corridor and finally, 2 circuits at the twelfth corridor. Also, the change of each corridor's circuit describes the velocity vector of that particle. The inertia weight (ω) is set during the learning according to (14):

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter \tag{14}$$

In above equation, $iter_{\max}$ is the maximum number of iterations, $iter$ is the present iteration number, $\omega_{\max}$ and $\omega_{\min}$ are the maximum and minimum values of the inertia weight respectively.

Finally, the new velocity and position of each particle are obtained by (15) and (16):

$$\vec{v}_i(t+1) = Fix[\omega \times \vec{v}_i(t) + c_1 r_1(\vec{x}_{pbest_i} - \vec{x}_i(t)) + \\ + c_2 r_2(\vec{x}_{gbest_i} - \vec{x}_i(t))] \tag{15}$$

$$\vec{x}_i(t+1) = \vec{x}_i(t) + c\vec{v}_i(t+1) \tag{16}$$

where t is the iteration number, $v_{\min} \le v_i \le v_{\max}$, and $Fix(.)$ is used to get the integer part

When the obtained value of v_i is higher than $v_{\max}$, then v_i is set to $v_{\max}$. Similarly, when v_i is lower than $v_{\min}$, then v_i is set to $v_{\min}$. By the way, when the value of x_i is more than the maximum constructible circuits at the corresponding corridor, then x_i is set to its maximum value. And when x_i is negative, it is set to zero. The other variables are calculated using (12) and (13).

From (15) it can be observed that the best position of particles concurrently occurs with $pbest_i$. In this condition, the particles are maintained in a point of inertia weight (ω). If the velocities of particles are very near to zero, they are not able to move toward $gbest_i$. This means that the particles have been converged to the best experience of particles and are far from the group. In this situation, the convergence speed will be decreased [22].

In this paper, to settle this defect, the improved ADPSO (IADPSO) algorithm has been used. The proposed algorithm is similar to DPSO, but it has been merged with mutation operator which is one of the operators of genetic algorithm [15, 16]. This operator prompts that the particles skip from the local optima and search in other areas to find the global optima. This operator causes the increase of convergence speed and the accuracy of algorithm. In this study, for the sake of fast convergence of algorithm and also obtaining the accurate results, High searching speed is essential in determining the proper parameters when much iteration is involved. Therefore, several methods have been proposed to improve the PSO algorithm speed and convergence toward the global minimum until now. One method to use is the advanced PSO algorithm. This technique can improve PSO performance by putting the adaptively changing terms. These changing terms are caused that the parameters of the original PSO algorithm can change according to the convergence rate which is presented by the fitness. Thus, the original PSO is changed like this:

$$r_1 = 1 - \frac{p_{best_i}}{P_i} + \text{rand}$$
$$r_2 = 1 - \frac{p_{gbest_i}}{P_i} + \text{rand} \tag{17}$$

where rand is a random value between 0 and 1. r_1 can influence the movement of the second term (individual term) as a weight factor. In early searching stage, the difference between pbest and gbest are the fitness values at the best position of between pbest and P_i is relatively bigger than that in the last stage.

Accordingly, the value of $(1 - \frac{p_{pbest_i}}{p_i})$, is also bigger than that in the last stage. As an individual particle approaches near the individual best position, the movement of individual particle becomes gradually slow. So we can expect faster convergence than the original. r_2 has an effect on the movement of the third term (group). Likewise, it is interpreted as follows:

$$p_{gbest_i} < p_{pbest_i} < p_i \tag{18}$$

$$0 \le 1 - \frac{g_{best_{id}}}{g_{id}} \le 1 - \frac{g_{best_{gd}}}{g_{id}} \le 1 \tag{19}$$

Because gbest is supposed as optimal and lowest value in entire particles' fitness values, Equation (12) can be derived. Equation (13) can be easily derived from Equation (12). If the particles converge to the optimal value, *pbest* and P_i will have the same value, *gbest*. Therefore, the replaced $(1 - \frac{p_{pbest_i}}{p_i})$ and $(1 - \frac{p_{gbest_i}}{p_i})$ will become zero, so that the second and third terms will move slowly. It can derive the fast searching.

$$\text{if} \quad \lim_{t \to t_{\max}} g_{best_{id}} = \lim_{t \to t_{\max}} g_{id} = g_{best_g}$$
$$\lim_{t \to t_{\max}} (1 - \frac{g_{best_{id}}}{g_{id}}) = \lim_{t \to t_{\max}} (1 - \frac{g_{best_{id}}}{g_{id}}) = 0 \tag{20}$$

where $t_{\max}$ is the iteration of convergence.

In this study, for the sake of fast convergence of algorithm and also obtaining the accurate results, the parameters are valued as Table 1. It is worth mentioning that the algorithms have been run several times and then the best results are selected. The flowchart of the proposed method is illustrated in Figure 2.

Table 1. Values of IADPSO parameters

Parameter name	Value
Problem dimension	153
Number of particles	10
$iter_{\max}$	500
c_1	0.2
c_2	0.3
C	0.5
Mutation rate	0.01
$\omega_{\min}$	0.4
$\omega_{\max}$	0.9
$v_{\max}$	4
$v_{\min}$	-4

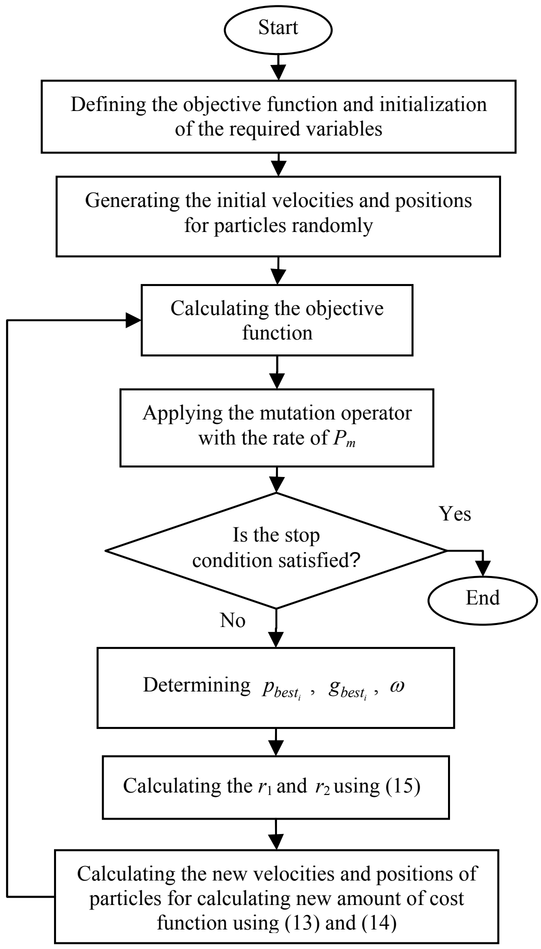

Figure 2. Flowchart of the IADPSO approach

V. NUMERICAL STUDY

The proposed idea is set up in MATLAB 7.0 environment and is applied on the Iran Azarbaijan Regional Electrical Company, [17] (as an actual network) shown in Figure 3.

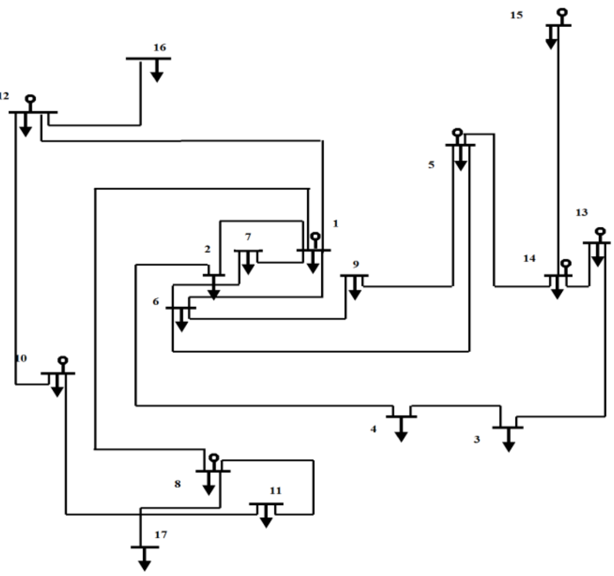

Figure 3. Transmission network of Iran Azarbaijan Regional Electrical Company

With regards to the aim of paper, some changes have been made in the test network (such as omitting a substation and adding of two lines). Also, the capacity of power plants in the horizon year (10 years ahead) have been changed according to Table 2, which in order to more flexibility and proper evaluating of the role of fuel cost, it has been 288 MW more than the load of horizon year (4062). Also, for better comparison, the coefficients of generation costs (a in terms of Rial/MW^2 and b in terms of 10^3 Rials/MW) have been presented in this Table. As seen (regarding that the weight of b in the cost is more), the generation cost of high-capacity power plants is low.

Table 2. Capacity of power plants in horizon year (MW)

Power plant	1	5	8	10	13	15
Capacity	1250	1100	750	290	720	240
a	4.8	4.5	4	6	4.3	3
b	160	170	190	270	180	200

After classifying the power plants based on their capacity, it is supposed that the fuel of plants 1 and 5 is from type 1 (like gas), that of plants 1 and 5 is from type 2 (like gas oil), and for plants 10 and 15 is from type 3 (like fuel oil). Subsequently, at first, TNEP by considering a fixed inflation rate for fuel price is accomplished and the results are evaluated from different points of view. Then the inflation rates of different fuels are changed and their effects on the TNEP results are investigated. The annual load growth factor for this network is 7% and the base inflation rate of fuel price is considered 10%. Also, the coefficients α and C_{loss} are supposed 34x10^6 Rials/MW and 330000 Rials/MW, respectively.

A. First Scenario: Performing TNEP Considering the Base Value for Inflation Rate of Different Fuels

In this part, TNEP considering a fixed value (10%) for inflation rate is performed; the best expansion plan obtained from IADPSO approach and the related costs are represented in Tables 3 and 4. Also, the optimal generation of different power plants is depicted in Figure 1. This optimal power generation is yield in the time of peak load at the horizon year.

Table 3. The best plan with inflation rate of 10% for different fuels price

Corridor	Number of circuits	Voltage level (kv)
1-7	1	230
1-9	2	400
1-11	2	400
2-5	2	400
2-7	1	230
3-13	1	230
4-5	2	400
4-9	1	230
5-7	2	230
5-9	1	400
5-12	2	400
6-15	2	230
8-10	2	400
8-17	2	400
11-13	2	400
11-17	1	230
13-16	2	230

Table 4. The related costs of Table 3

Parameter	Cost (10^9 Rials)
Lines construction	1858.5
Substations' expansion	742
Loss	2038.3
Unsupplied load	0
Total	4638.9

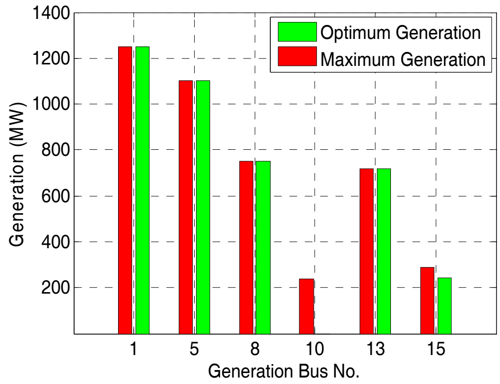

Figure 4. Maximum and optimal generation of power plants in the peak time of planning horizon

It is observed that the optimal generation of power plants which use of the first type of fuel (1250 MW and 1100MW power plants) and the second type (750 MW and 720 MW power plants) are equal to their maximum capacity; therefore, the decrease of inflation rate of fuel price of these generating units below the base value (10%), which causes that they become more and more cheaper, has no effect on the increase of their optimal generation, and the lowest-cost configuration of the optimal generation of power plants (regarding the constraints of transmission network considered in QP) will be the configuration shown in Figure 4.

But, with increasing the inflation rate of the price of the two types of fuel, and consequently with increasing the generation cost of plants 1 and 5, and also 8 and 13, it is expected that the optimal generation of these plants be reduced for decreasing the total generation cost. This issue will be investigated separately in scenarios 2 and 3. On the other side, the optimal generation of power plants which use of third-type fuel (240 and 290 MW power plants) is a fraction of their maximum generable power. Therefore, unlike the four previous plants, increasing the inflation rate of price of the fuel of these two power plants compared to the base value (10%) is ineffective, and with regards to operation of the other plants in their maximum capacity, the rest of load demand (242 MW out of 4062 MW) will be distributed between these two plants (regarding their cheapness), which it will again yield the configuration of Figure 4.

With regards to these explanations, the decrease of inflation rate of price of third-type fuel (by 5%) in the fourth scenario is analyzed and evaluated. It is mentioned that the results of all the changes which will be made in the next scenarios, will be compared with this scenario as the base scenario.

B. Second Scenario: Evaluating the Role of First Type Fuel Price in TNEP

Based on the discussions made in first scenario, in this scenario, by fixing the inflation rate of price of second and third type of fuel in 10%, the inflation rate of the first type of fuel is increased to 15%. The best result obtained from performing of IADPSO and the related costs have been reported in Tables 5 and 6. Also, the optimal generation of power plants in horizon year is given in Figure 5.

Table 5. The best obtained plan with inflation rate of 15% for the price of first type fuel

Corridor	Number of circuits	Voltage level (kv)
1-9	2	400
1-11	2	400
2-5	2	400
1-12	1	400
2-16	2	230
4-5	2	400
4-10	2	400
5-7	2	400
5-12	2	400
6-15	2	400
8-10	2	400
8-17	1	400
9-13	2	400

Table 6. The related costs of the plan of Table 5

Parameter	Cost (10^9 Rials)
Lines construction	1961.2
Substations' expansion	766
Loss	1971.4
Unsupplied load	0
Total	4698.6

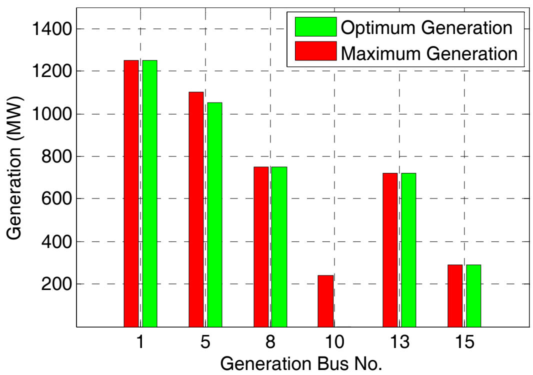

Figure 5. Maximum and optimal generation of power plants by considering the inflation rate of 15% for the first type fuel

According to Figure 5, as expected, the optimal generation of plant 5, due to the expensiveness of its fuel price has been decreased, and it has been increased for the plants which their generations (in the first scenario) were below their maximum capacity (plants 10 and 15). The interesting point is that the optimal generation of plant 1, because of the cheapness compared to plant 5, has not been changed. By analyzing Table 5 and comparing it with Table 2, it is discovered that the voltage level of some lines connected to generating substations: 5 and 15 (gray colored rows) have been changed proportional to the change of the generation of related plants; such that, the voltage level of connected lines to substation 5, regarding the decrease of the generation of plant 5, is from low capacity (230kv) type, but, those connected to substation 15 is from high capacity (400 kv) type. Whereas, the other connected lines to these substations have no reverse changes, or at least have been remained unchanged. Thus, it is observed that the change of the price of first type fuel indirectly has significant effects on the final result of TNEP. Comparison of Table 6 with Table 4 shows the increase of network expansion costs because of the decrease of generation of high-capacity inexpensive power plants.

C. Third Scenario: Increasing the Inflation Rate of the Price of Second Type Fuel

Like the second scenario, in this scenario, inflation rate of the price of second type fuel which supplies the 720 MW and 750 MW power plants, is increased to 15%, whereas, that of the first and third type fuels is 10%. Under this condition, the best obtained result for TNEP, by 10 times run of IADPSO, and the related costs have been presented in Tables 7 and 8. The optimal generation of power plants can be seen in Figure 6.

Table 7. The best obtained plan with inflation rate of 15% for the price of second type fuel

Corridor	Number of circuits	Voltage level (kv)
1-7	1	400
1-9	2	400
2-5	2	400
4-5	1	400
4-5	2	400
5-11	2	400
5-11	2	400
5-12	2	400
5-16	2	230
5-17	2	400
6-9	1	230
8-10	2	230
9-13	2	400
11-15	2	400

Table 8. The related costs of the plan of Table 7

Parameter	Cost (10^9 Rials)
Lines construction	1923
Substations' expansion	528
Loss	1801.4
Unsupplied load	0
Total	4252.4

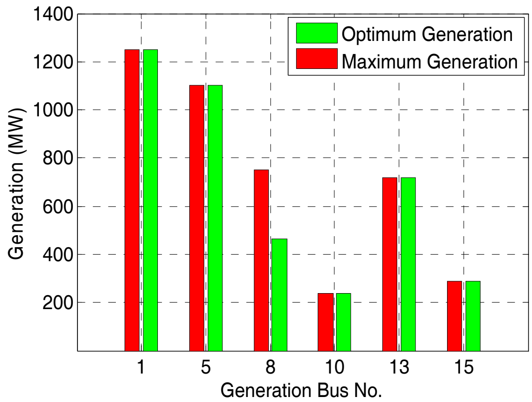

Figure 6. Maximum and optimal generation of power plants by considering the inflation rate of 15% for the second type fuel

From Figure 6, it can be seen that the expensiveness of second type power plants has resulted in that their optimal generation has been decreased, and like the previous scenario (regarding the impossibility of the change of the generation of first type power plants 1250 MW and 1100 MW) the generation of third type or low capacity power plants has been increased. By evaluating Table 6, the change of final result of TNEP compared to the first scenario (the base scenario) is obvious; such that, like the previous scenario, by changing the optimal generation of some power plants, the type and number of some lines connected to them have been changed in the desired direction and the others have been remained unchanged. For example, the number of lines connected to plant 8 (which its optimal generation has been reduced) has been reduced to one line, and its voltage level has been selected from low capacity (230 kv) type. In contrast, the voltage level of line connected to plant 15 (which its optimal generation has been increased), in the optimal plan of scenario one, has been upgraded from two-circuit 230 kv to high capacity 400 kv one.

It should be mentioned that the capacity of single circuit 400kv line, which here is of three-bundled type, is about 2000 MW. This is 600 MW greater than the capacity of double circuit two-bundled 230 kv line (1400 MW). The increase of number of 400kv lines in this plan compared to the plan of Table 2 is significant. It can be said that the mentioned lines, with high capacity, compensate the effect of decreasing the number of lines and increasing the lines’ average loading. Unlike Table 5, Table 7 shows that more using of low-capacity power plants (more appropriate sharing of load among the low-capacity and medium-capacity power plants) and also operating of high-capacity ones (first type) in their maximum capacity result in the reduction of overall costs.

D. Forth Scenario: Decreasing the Inflation Rate of the Price of Third Type Fuel

As final experiment, this scenario investigates the effect of reduction of the inflation rate of the price of third type fuel which supplies the low capacity 240 MW and 290 MW power plants. By considering the inflation rate of 5% for this fuel, and by fixing the inflation rates of other fuels in 10%, the best obtained result and its related costs are provided in Tables 8 and 9. Also the optimal arrangement of power plants is depicted in Figure 7.

As seen from Figure 7, the effect of the cheapness of the third type power plants is similar to the expensiveness of second type power plants, and here the optimal generations of aforesaid power plants have been equal to their maximum capacity. This change of generation arrangement, similar to the previous scenarios, has had similar effect on lines loading; such that in the final expansion plan given in Table 9, the voltage level of lines connected to substation 8, with regards to the reduction of generation of plant 8, is of low-capacity (230 kv) type; and the number of lines connected to plant 8 has been decreased, and the voltage level of line connected to plant 10 and 15 has been upgraded to high-capacity (400 kv) type, to transmit the increased power generation of this plant. The results given in Table 10 complete the explanations about the third scenario. This table represents the cheapest expansion plan in the case of occurring the conditions of this scenario. The significant number of 400 kv lines and following it the considerable decrease of network loss verifies this fact.

Table 9. The best obtained plan with inflation rate of 5% for the price of third type fuel

Corridor	Number of circuits	Voltage level (kv)
1-7	1	230
1-9	2	400
1-10	1	400
2-5	2	400
2-7	1	400
4-5	1	400
5-7	2	230
5-11	2	400
5-12	2	400
6-15	1	400
8-17	1	400
11-13	2	400

Table 10. The related costs of the plan of Table 9

Parameter	Cost (10^9 Rials)
Lines construction	1712
Substations’ expansion	578
Loss	1939
Unsupplied load	0
Total	4229

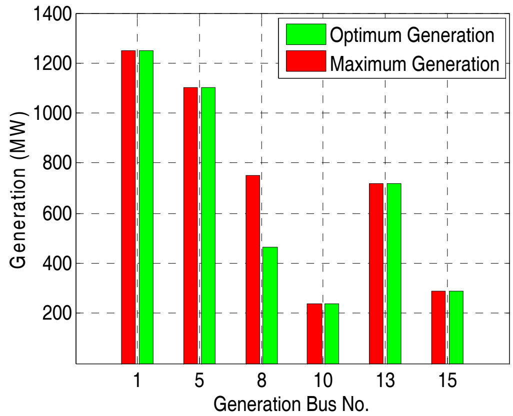

Figure 7. Maximum and optimal generation of power plants by considering the inflation rate of 5% for the third type fuel

VI. CONCLUSIONS

In this research, the role of uncertainty of fuel price in TNEP with regards to its effect on the optimal power generation of power plants and following it, on the lines loading was investigated. By performing TNEP in different scenarios for annual inflation rate of different fuel types, it was observed that the uncertainty of fuel price, by changing the optimal generation of power plants for reduction of overall generation costs, has considerable effect on the TNEP result. As an example, about the transmission network of Azerbaijan Regional Electrical Company, it is concluded that every uncertainty of fuel price that leads to reduction of optimal generation of high-capacity power plants, result in more expensive expansion plans and vice versa, every uncertainty of fuel price that lead to the increase of the generation of low-capacity plants and decrease of medium-capacity ones, brings about cheap expansion plan for the network.

REFERENCES

[1] A.R. Abdelaziz, "Genetic Algorithm based Power Transmission Expansion Planning", IEEE Int. Conf. on Electronics, Circuits & Syst., Vol. 2, pp. 642-645, 2000.

[2] V.A. Levi, M.S. Calovic, "A New Decomposition based Method for Optimal Expansion Planning of Large Transmission Networks", IEEE Trans. on Power Syst., Vol. 6, No. 3, pp. 937-943, 1991.

[3] S. Binato, G.C. De Oliveira, J.L. De Araujo, "A Greedy Randomized Adaptive Search Procedure for Transmission Expansion Planning", IEEE Trans. on Power Syst., Vol. 16, No. 2, pp. 247- 253, 2001.

[4] L.L. Garver, "Transmission Network Estimation using Linear Programming", IEEE Trans. on Power App. and Syst., Vol. PAS-89, No. 7, pp. 1688-1696, 1970.

[5] M.R. Hessamzadeh, H. Seifi, "Transmission Network Expansion Planning Considering Uncertainty", 13th Iranian Conference on Electrical Engineering, pp. 489-495, 2005.

[6] "Dealing with Uncertainty in System Planning - Has Flexibility Proved to be an Adequate Answer?", CIGRE, Electra, No. 151, Working Group 37.10, pp. 53-65, 1993.

[7] "Methods for Planning under Uncertainty", Electra, No. 161, 1995.

[8] H. Rudnick, R. Palma, E. Cura, C. Silva, "Economically Adapted Transmission Systems in Open Access Schemes-Application of Genetic Algorithms", IEEE Trans. on Power Systems, Vol. 11, No. 3, 1996.

[9] Tractebel, E. Van Geert, "Increased Uncertainty a New Challenge for Power System Planners", Special Report, CIGRE Work Group on Transmission Planning, pp.120-145.

[10] I.D.J. Silva, M.J. Rider, R. Romero, C.A. Murari, "Transmission Expansion Network Planning Considering Uncertainness in Demand", IEEE Power Eng. Soc. General Meeting, Vol. 2, pp. 1424-1429, 2005.

[11] J. Alvarez, J. Ponnambalam, K. Quintana, H. Victor, "Transmission Expansion under Risk using Stochastic Programming", Int. Conf. on Probabilistic Methods Applied to Power Syst., pp. 1-7, 2006.

[12] J. Choi, T. Mount, R. Thomas, "Transmission System Expansion Planning Considering Expected Stand-by Cost based on Probabilistic Approach", IEEE Power Syst. Conf. & Expos., pp. 1498-1506, 2006.

[13] H. Shayeghi, S. Jalilzadeh, M. Mahdavi, H. Haddadian, "Studying Influence of Two Effective Parameters on Network Losses in Transmission Expansion Planning using DCGA", Energy Conversion and Management, Vol. 49, pp. 3017-3024, 2008.

[14] G.C. Oliviera, S. Binato, L. Thome, M.V. Periera, "Security Constrained Transmission Planning: A Mixed Integer Disjunctive Approach", IEE Proc. Gener., Transm., Distrib., Vol. 152, pp. 828-836, 2005.

[15] A. Kimiyaghalam, S.H. Hosseini, H. Haddadian, "Evaluating the Effect of Loss on Transmission Network Expansion Planning in Uncertainty Environment using Improved Genetic Algorithm", 23th International Power System Conference, PSC, 2008.

[16] M.R. Hessamzadeh, H. Seifi, "Hybrid Algorithm in Transmission Network Expansion Planning in Uncertainty Environment", 20th International Power System Conference, PSC, pp. 1-8, 2005.

[17] H. Haddadian, "Dynamic Transmission Network Expansion Planning", M.Sc. Thesis, University of Zanjan, Iran, 2007.

[18] H. Shakuri Ganjuri, H. Ahmadi, M. Karimi Zandani, "Interruption Management in Iran by Electric Energy Planning and Considering the Regional Exchanges for Minimizing of Costs", 23th International Power System Conference, PSC, 2008.

[19] J. Kennedy, R. Eberhart, "Particle Swarm Optimization", IEEE Int. Conf. Neural Networks, Vol. 4, pp. 1942-1948, 1995.

[20] A. Jalilvand, A. Kimiyaghalam, A. Ashouri, A. Mahdavi, "Advanced Particle Swarm Optimization-based PID Controller Parameters Tuning", The 12th IEEE Int. Multitopic Conference, Pakistan, pp. 429-435, 2008.

[21] M. Clerc, J. Kennedy, "Particle Swarm-Explosion, Stability, and Convergence in a Multidimensional Complex Space", IEEE Trans. Evolutionary Computation, Vol. 6, No. 1, pp. 58-73, 2002.

[22] A.A.A. Esmin, G.L. Torres, A.C.Z. De Souza, "A Hybrid Particle Swarm Optimization Applied to Loss Power Minimization", IEEE Trans. Power Systems, Vol. 20, No. 2, pp. 859-866, 2005.

BIOGRAPHIES

Saied Jalilzadeh was born in Salmas, Iran, 1962. He received the B.Sc. and M.Sc. degrees from University of Tabriz (Tabriz, Iran) and the Ph.D. degree from Iran University of Science and Technology (Tehran, Iran), all in Power Electrical Engineering, in 1987, 1991, and 2001, respectively. Currently, he is a Professor of Power Electrical Engineering at University of Zanjan (Zanjan, Iran). He is also an academic member of Power Electrical Engineering at University of Zanjan and teaches Power System Analysis, Power System Operation, and Reactive Power Control. His research interests are in the area of Power Quality, Energy Management Systems, ICT in Power Engineering and Virtual E-learning Educational Systems. He is a member of the International Electrical and Electronic Engineers.

Ali Kimiyaghalam was born in Tehran, Iran, 1983. He received the B.Sc. and M.Sc. degrees from Islamic Azad University, Abhar and Zanjan Branches (Iran), all in Power Electrical Engineering in 2007 and 2010, respectively. His research interests are in the area of Renewable Energies, Power System Planning, Reliability and Power Quality.

Ahmad Ashouri was born in Khodabandeh, Iran, 1984. He received the B.Sc. degree from Islamic Azad University, Abhar Branch, Iran, and the M.Sc. degree from Zanjan University, Iran, all in Power Electrical Engineering, in 2007 and 2010, respectively. At present, he is a Ph.D. candidate at Islamic Azad University, Science and Research branch, Iran. His research interests are in the area of Petri Net, Power System Planning, Reliability and Power Quality.