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Evaluating the Effects of Uncertainty in Fuel Price on Transmission Network Expansion Planning using DABC Approach

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Abstract

Transmission Network Expansion Planning (TNEP) is one of the important parts of power system planning which determines the number, time and location of new lines for adding to transmission 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 DABC 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, DABC.

1. Introduction
One of the most important parts 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 the 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.

In today's world, along with electric consumption growth, there is more need to proper management and optimal planning of transmission network. Because of this, 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 Discrete Artificial Bee Colony (DABC) 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.

2. 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:

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

In which:

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

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

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 i^{th} 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 i^{th} 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 Eqs. (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 (DABC); 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:

$$Sf^k + g^k - \delta^k d = 0 \qquad (4)$$

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

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

$$0 \le g^k \le g_{\max} \qquad (7)$$

$$0 \le n_{ij} \le \overline{n_{ij}} \qquad (8)$$

$$0 \le \delta^k \le 1 \qquad (9)$$

Where:

S : Network structure matrix

f^k : The matrix of flowing powers at each corridor composed of elements f_{ij}^k in k^{th} 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 to 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].

3. Optimization of Generation Cost Using Quadratic Programming

Generation vector is one of the unknowns which have 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). Ref. [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:

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

$$GC_i^k = a_i^k * {g_i^k}^2 + b_i^k * g_i^k + c_i^k \tag{11}$$

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 Eq. (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.

4. DABC Algorithm and Its Application for the Problem Solution

In the ABC algorithm proposed by Karaboga, the position of a food source represents a possible solution to the optimization problem, and the nectar amount of a food source corresponds to the profitability (fitness) of the associated solution. Each food source is exploited by only one employed bee. In other words, the number of employed bees is equal to the number of food sources existing around the hive (number of solutions in the population). The employed bee whose food source has been abandoned becomes a scout. Using the analogy between emergent intelligence in foraging of bees and the ABC algorithm, the units of the basic ABC algorithm can be explained as follows:

4-1 Producing initial food source sites

If the search space is considered to be the environment of the hive that contains the food source sites, the algorithm starts with randomly producing food source sites that correspond to the solutions in the search space. Initial food sources are produced randomly within the range of the boundaries of the parameters.

$$x_{ij} = x_j^{\min} + rand(0,1)(x_j^{\max} - x_j^{\min}) \qquad (12)$$

Where i = 1. . .SN, j = 1. . .D. SN is the number of food sources and D is the number of optimization parameters. In addition, counters which store the numbers of trials of solutions are reset to 0 in this phase. After initialization, the population of the food sources (solutions) is subjected to repeat cycles of the search processes of the employed bees, the onlooker bees and the scout bees. Termination criteria for the ABC algorithm might be reaching a maximum cycle number (MCN) or meeting an error tolerance (_).

4-2 Sending employed bees to the food source sites

As mentioned earlier, each employed bee is associated with only one food source site. Hence, the number of food source sites is equal to the number of employed bees. An employed bee produces a modification on the position of the food source (solution) in her memory depending on local information (visual information) and finds a neighboring food source, and then evaluates its quality. In ABC, finding a neighboring food source is defined by (13)

$$v_{ij} = x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}) \qquad (13)$$

Within the neighborhood of every food source site represented by xi, a food source ti is determined by changing one parameter of xi. In Eq. (13), j is a random integer in the range [1, D] and k 2 {1, 2 . . . SN} is a randomly chosen index that has to be different from i./ij is a uniformly distributed real random number in the range [_1, 1]. As can be seen from Eq. (13), as the difference between the parameters of the xi,j and xk,j decreases, the perturbation on the position xi,j decreases. Thus, as the search approaches to the optimal solution in the search space, the step length is adaptively reduced.

If a parameter value produced by this operation exceeds its predetermined boundaries, the parameter can be set to an acceptable value. In this work, the value of the parameter exceeding its boundary is set to its boundaries. If xi > xmax i then xi ¼ xmax i; If xi <xmin i then xi ¼ xmin i .

After producing ti within the boundaries, a fitness value for aminimization problem can be assigned to the solution ti by (14).

$$fitness_i = \begin{cases} 1/(1+f_i) & if \quad f_i \geq 0 \\ 1+abs(f_i) & if \quad f_i \prec 0 \end{cases} \qquad (14)$$

Where f_i fi is the cost value of the solution v_i . For maximization problems, the cost function can be directly used as a fitness function. A greedy selection is applied between xi and v_i ; then the better one is selected depending on fitness values representing the nectar amount of the food sources at xi and v_i . If the source at v_i is superior to that of xi in terms of profitability, the employed bee memorizes the new position and forgets the old one. Otherwise the previous position is kept in memory. If xi cannot be improved, its counter holding the number of trials is incremented by 1, otherwise, the counter is reset to 0.

4-3 Calculating probability values involved in probabilistic selection

After all employed bees complete their searches, they share their information related to the nectar amounts and the positions of their sources with the onlooker bees on the dance area. This is the multiple interaction features of the artificial bees of ABC. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source site with a probability related to its nectar amount. This probabilistic selection depends on the fitness values of the solutions in the population. A fitness-based selection scheme might be a roulette wheel, ranking based, stochastic universal sampling, tournament selection or another selection scheme. In basic ABC, roulette wheel selection scheme in which each slice is proportional in size to the fitness value is employed (15):

$$p_i = \frac{fitness_i}{\sum_{i=1}^{SN} fitness_i} \qquad (15)$$

In this probabilistic selection scheme, as the nectar amount of food sources (the fitness of solutions) increases, the number of onlookers visiting them increases, too. This is the positive feedback feature of ABC.

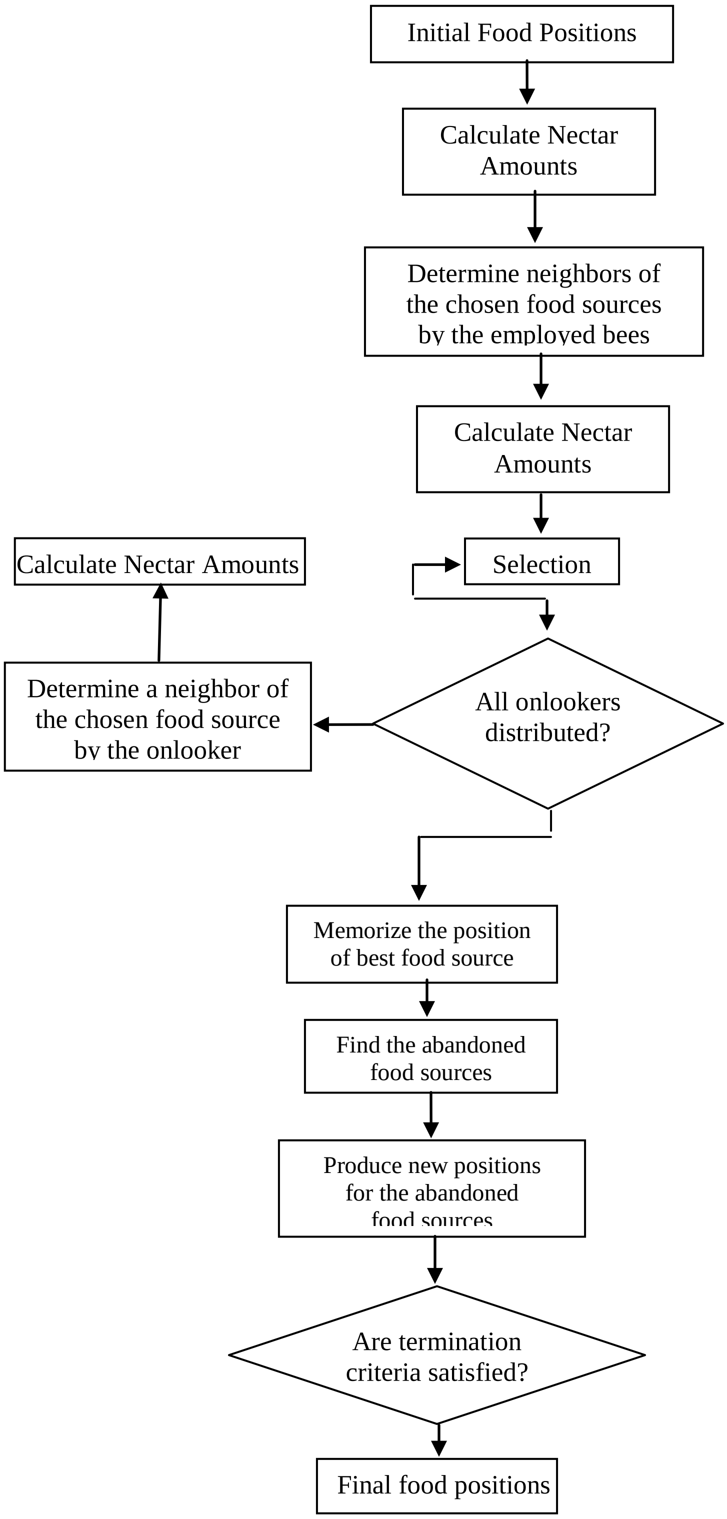

Figure 1: Flowchart of the Artificial Bee Colony algorithm.

4-4 Food source site selection by onlookers based on the information provided by employed bees

In the ABC algorithm, a random real number within the range [0,1] is generated for each source. If the probability value (pi in Eq. (15)) associated with that source is greater than this random number then the onlooker bee produces a modification on

The position of this food source site by using Eq. (13) as in the case of the employed bee. After the source is evaluated, greedy selection is applied and the onlooker bee either memorizes the new position by forgetting the old one or keeps the old one. If solution xi cannot be improved, its counter holding trials is incremented by 1; otherwise, the counter is reset to 0. This process is repeated until all onlookers are distributed onto food source sites.

4-5 Abandonment criteria: Limit and scout production

In a cycle, after all employed bees and onlooker bees complete their searches, the algorithm checks to see if there is any exhausted source to be abandoned. In order to decide if a source is to be abandoned, the counters which have been updated during search are used. If the value of the counter is greater than the control parameter of the ABC algorithm, known as the ‘‘limit”, then the source associated with this counter is assumed to be exhausted and is abandoned. The food source abandoned by its bee is replaced with a new food source discovered by the scout, which represents the negative feedback mechanism and fluctuation property in the self-organization of ABC. This is simulated by producing a site position randomly and replacing it with the abandoned one. Assume that the abandoned source is xi, and then the scout randomly discovers a new food source to be replaced with xi. This operation can be defined as in (1). In basic ABC, it is assumed that only one source can be exhausted in each cycle, and only one employed bee can be a scout. If more than one counter exceeds the ‘‘limit” value, one of the maximum ones might be chosen programmatically. [19]
All these units and interactions between them are shown as a flowchart on Fig. 1.
It should be mentioned that ABC 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 ABC algorithm:

1) Binary codification ABC algorithm (BABC)
2) Discrete ABC (DABC)

Here, due to the following reasons, the second method, i.e. DABC 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 bee colony 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 DABC 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 Fig. 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 2. 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 bee colony.

Table 1. Values of DABC parameters

Parameter name	Value
Problem	153
Number of bees	10
$iter_{\max}$	500

5. **Numerical Study**

The proposed idea is set up in MATLAB7.0 environment and is applied on the Azerbaijan Regional Electrical Company, [17] (as an actual network) shown in Fig. 3. 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 II, which in order to more fexibility and proper evaluating of the role of fuel cost, it has been 288MW 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. 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 34 10^6Rials/MW and 330000Rials/MW, respectively.

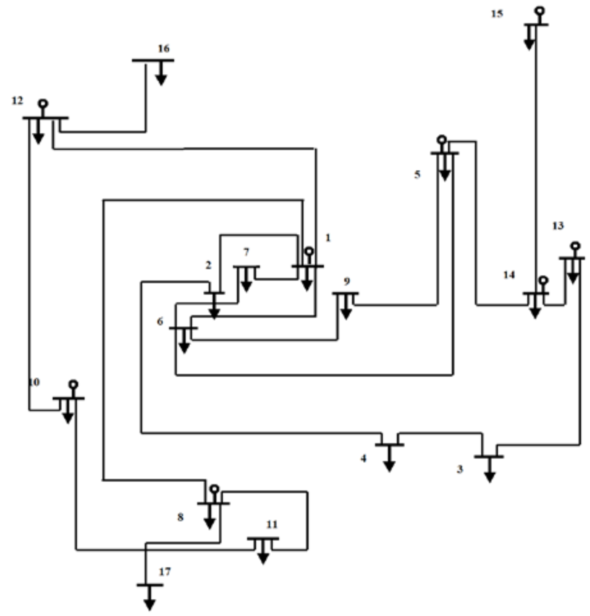

Figure 3. Transmission network of Azerbaijan Regional Electrical Company

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

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 DABC approach and the related costs are represented in Tables III and IV. Also, the optimal generation of different power plants is depicted in Fig. 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 price of different fuels

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

Table 4. The related costs of table 3

Parameter	Cost (10^9 Rials)
Lines construction	1841
Substations' expansion	652
Loss	2201.5
Unsupplied load	0
Total	4694.5

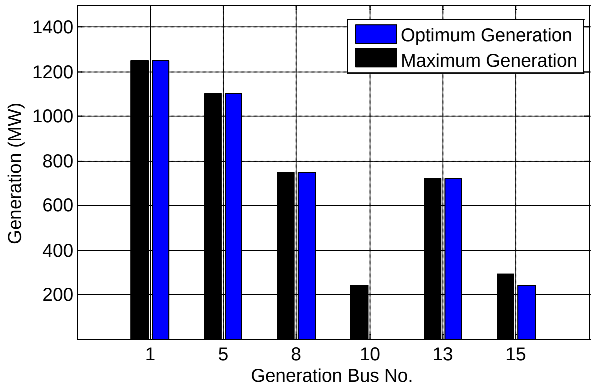

Figure 4: Maximum and optimal generation of power plants in the peak time of planning horizon

It is observed that the optimal generation of power plants which use of the first type of fuel (1250MW and 1100MW power plants) and the second type (750MW and 720MWower 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 Fig. 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 290MW 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 (242MW out of 4062MW) will be distributed between these two plants (regarding their cheapness), which it will again yield the configuration of Fig. 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.

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 ssecond 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 DABC 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 Fig. 5.

According to Fig. 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 (400kv) 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.

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

Corridor	Number of circuits	Voltage level (kv)
1-7	1	400
1-9	2	400
2-5	2	400
4-5	2	400
2-5	2	400
4-11	1	400
5-7	2	400
5-10	2	400
5-11	2	400
5-12	2	400
8-10	2	400
5-15	1	400
5-16	1	230
6-9	1	230
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 (10^9Rials)
Lines construction	2001
Substations' expansion	746
Loss	1992.6
Unsupplied load	0
Total	4839.6

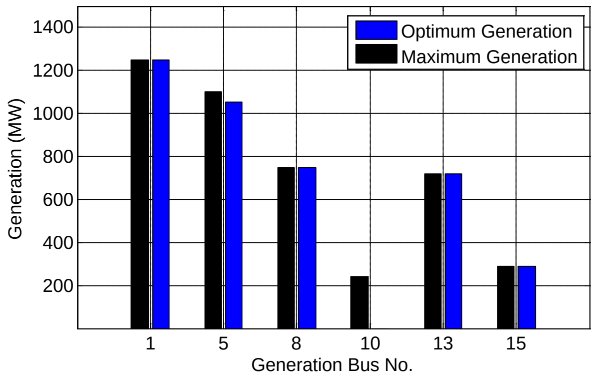

Figure 5: Maximum and optimal generation of power plants by considering the inflation rate of 15% for the first type fuel

Third scenario: increasing the inflation rate of the price of second type fuel

Like the second scenario, in this scenario, the inflation rate of the price of second type fuel which supplies the 720MW and 750MW 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 DABC, and the related costs have been presented in Tables 7 and 8. Also, the optimal generation of power plants can be seen in Fig. 6.

From Fig. 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 1250MW and 1100MW) the generation of third type or low capacity power plants has been increased. By evaluating Table 7, 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 (230kv) 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 230kv to high capacity 400kv one. It should be mentioned that the capacity of single circuit 400kv line, which here is of three-bundled type, is about 2000MW. This is 600MW greater than the capacity of double circuit two-bundled 230kv line (1400MW). The increase of number of 400kv lines in this plan compared to the plan of Table II 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.

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)
1-6	1	230
1-7	1	230
1-9	2	400
2-15	2	400
2-5	2	400
4-11	2	400
2-7	1	230
3-13	1	230
4-5	1	400
5-7	2	230
5-11	2	400
5-12	2	400
5-16	2	230
6-13	2	230
8-17	1	400
8-10	2	230
11-13	2	400

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

Parameter	Cost (10^9Rials)
Lines construction	1995
Substations' expansion	520
Loss	1787
Unsupplied load	0
Total	4302

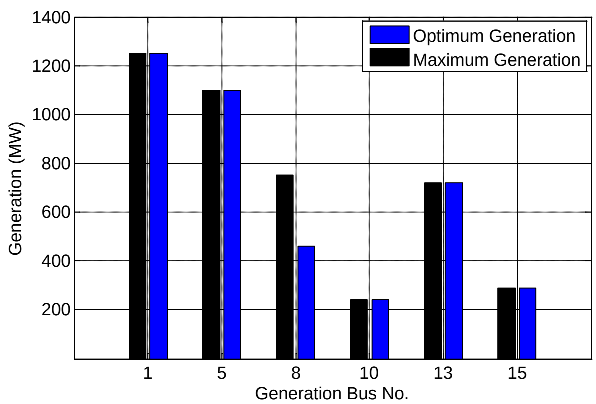

Figure 6: Maximum and optimal generation of power plants by considering the inflation rate of 15% for the second type fuel

Third 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 240MW and 290MW 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 Fig. 7. As seen from Fig. 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 4, the voltage level of lines connected to substation 8, with regards to the reduction of generation of plant 8, is of low-capacity (230kv) type; and the number of lines connected to plant 8 has been decreased, and the voltage level of line connected to plant 15 has been upgraded to high-capacity (400kv) type, to transmit the increased power generation of this plant. The results given in Table 4 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 400kv 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
2-5	2	400
2-7	1	230
4-5	1	400
5-7	2	230
5-11	2	400
5-12	2	400
5-16	1	230
7-15	2	400
8-10	2	230
11-13	2	400

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

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

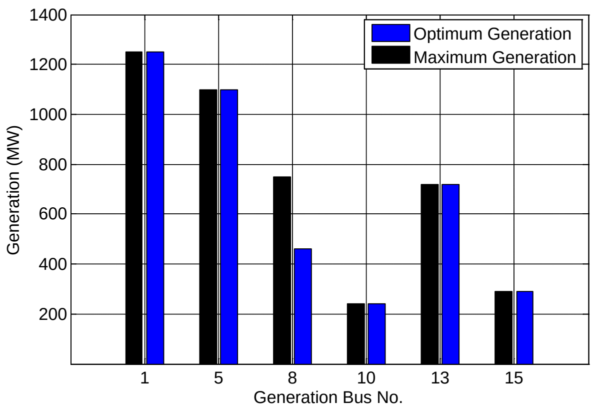

Figure 7: Maximum and optimal generation of power plants by considering the inflation rate of 5% for the third type fuel

6. Conclusion

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.

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