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APPLICATION OF IADPSO APPROACH FOR TNEP PROBLEM CONSIDERING OF LOSS AND UNCERTAINTY IN LOAD GROWTH

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Abstract- The main goal of Transmission Network Expansion Planning (TNEP) is determination of the number, time and location of new lines to be added to transmission network. Up to now, different methods have been used to solve the static TNEP (STNEP). In most of them, this problem is implemented regardless of power loss and the uncertainty in the load demand. With respect to the importance of these two parameters (loss and uncertainty) and their key role in an effective and precise planning, the evaluation and solution of STNEP using more efficient methods can be very useful. Hence, in this paper, a new method named Improved Advance Discrete Particle Swarm Optimization (IADPSO) is employed for the solution of STNEP problem considering simultaneously the loss and uncertainty in load demand. Finally, the proposed approach is applied to the real transmission network of Azarbaijan Regional Electrical Company located in northwest of Iran. Comparison of the results obtained from the proposed method with those of Discrete Particle Swarm Optimization (DPSO) approach verifies the effectiveness and accuracy of the method in STNEP problem.

Keywords: IADPSO Approach, STNEP, Loss, Uncertainty.

I. INTRODUCTION

Transmission network expansion planning is one of the most important parts of power system expansion planning. Its aim is to determine the location, time and number of new transmission lines, with minimum construction and operation costs, to supply the loads adequately considering a set of technical, economical and reliability constraints [1, 2].

Generally, TNEP problem is divided into two types: static and dynamic expansion planning. The former, fulfils all of the planning targets, while in the later, for simplification, the time variable is omitted among the unknowns and the planning is implemented for a load horizon year [3].

Nowadays, with electric consumption growth, there is more need to proper management and optimal planning of transmission network. Therefore, evaluating the role of effective parameters in TNEP has been obviously more and more important than ago. One of these essential parameters is the power loss of transmission network which the networks owners have always tried to reduce it. The other effective parameter in TNEP is the uncertainty that was regarded by planners about when Garver proposed his popular heuristic idea [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 mention to 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. With regards to the events in Iran network in recent years, which the load demand has been different from the predicted values, hence in this paper, the uncertainty in the load demand is considered.

The STNEP problem is a non-linear and high-dimension optimization problem which different methods was proposed to solve it, such as: GRASP [6], Benders decomposition [3], HIPER [7], branch and bound algorithm [8], sensitivity analysis [9].

Recently, stochastic search methods like genetic algorithm [10, 11], simulated annealing [12], tabu search [13], and decimal codification genetic algorithm [14-16] have been employed to solve the STNEP. These evolutionary algorithms are heuristic search methods that are based on population and their performance is dependent on a series of random operations. Although the aforementioned algorithms seem to be good methods for solving the STNEP problem, however, when the number of problem parameters becomes more, they lose their accuracy and speed in finding the optimal solution. Thus, in this paper, IADPSO approach is used to settle this defect in STNEP. Particle swarm optimization is a meta-heuristic method that has become a powerful tool to solve the engineering problems using an intelligent competition between the particles of a population [17, 18]. Unlike the other heuristic methods, PSO, by using an elegant and flexible mechanism, is stronger in searching for optimal solutions.

The aim in this paper is to implement the STNEP problem in the presence of transmission power loss and the uncertainty in the load demand using IADPSO approach. Therefore, the cost of loss and uncertainty in load, and also the cost of substations expansion (from viewpoint of voltage level) are considered in the transmission expansion costs (objective function). It is worth mentioning that in this researc h the uncertainty in the load demand has been regarded based on scenario technique. Subsequently, after introducing the mathematical model of STNEP problem and the solution method, by application of the proposed approach to the real transmission network of Azarbaijan Regional Electrical Company, the obtained results are be evaluated.

II. MATHEMATICAL MODEL OF STNEP IN THE PRESENCE OF UNCERTAINTY

Considering the loss and uncertainty of load demand in static expansion planning of a transmission network with different voltage levels and consequently inclusion of substations expansion cost in transmission expansion costs, the objective function is defined as follows:

$$OF=\sum_{k=1}^{NS}\left(EC_k+LC_k+\alpha\times\sum_{i=1}^{NB} r_i^k\right)\times PR_k \tag{1}$$

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

$$LC_k=\left(\sum_{t=1}^{NY}\sum_{i=1}^{NC} R_{ij}^k I_{ij,t}^{k\;2}\right)\times K_{loss}\times 8760\times C_{MWh} \tag{3}$$

where:

OF: Objective function of the proposed STNEP problem

EC_k: Transmission lines expansion cost in kth scenario

LC_k: The cost of transmission network resistive loss

r_i^k : Unsupplied load of ith substation in kth scenario

α: A Coefficient to convert the unsupplied load to cost

PR_k: The likelihood of kth scenario's occurrence

CL_{ij}: Construction cost of line at corridor i-j

n_{ij}^k : Number of constructed circuits at corridor i-j in kth scenario

SC_c: The cost of transformer with type c (the related costs are given in appendix)

m_i^k : Number of transformers installed on ith substation in kth scenario

C_{MWh}: Per-unit cost of power generation ($/MWh)

R_{ij}^k : The resistance of corridor i-j in kth scenario

$I_{ij,t}^k$: The current passing through the corridor i-j in tth time and kth scenario which varies following the load growth (after expansion) and therefore depends on the time

K_{loss}: Loss coefficient

Ω: The set of all the network's substations

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 years)

NC: Number of expandable corridors of network

NB: Number of network's buses (substations)

ST: Different types of installed transformers

NS: Number of considered scenarios

As it can be seen from (1)-(3), all the costs included in the objective function have the index k and are dependent on the characteristics of the related scenario. It should be mentioned that the unsupplied load (r_i^k) is the overload value of expanded lines of network which is not delivered to the load centers due to the transmission capacity limitation of the lines. Determining the worth of unsupplied load is a burdensome subject, but in this paper, an approximate value has been considered for α .

The problem constraints are as follows:

$$S^k f^k+g^k-d^k=0 \tag{4}$$

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

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

$$0\le n_{ij}^k\le\overline{n_{ij}} \tag{7}$$

where:

$(i,j)\in\Omega$

S^k : Network structure matrix in kth scenario

f^k : Matrix of power flow at the corridors in kth scenario

g^k : Generation vector in kth scenario

d^k : Demand vector in kth scenario

θ_i^k : Voltage angle of ith substation in kth scenario

γ_{ij}^k : Inverse of the reactance of all circuits at corridor i-j in kth scenario

n_{ij}^k : Number of circuits at corridor i-j in kth scenario

$\overline{n_{ij}}$: Maximum number of constructible circuits at corridor i-j

$\overline{f_{ij}}$: Maximum transmission capacity of corridor i-j

β: Reliability margin coefficient of lines loading to keep the lines adequacy after expansion

Regarding that in this study it is aimed to determine the number and voltage level of lines for adding to the network to reach the required adequacy in a horizon year, so the problem variables are discrete type. Thus, the above optimization problem is an integer programming problem which different methods such as mathematical and non-mathematical classic methods and heuristic methods can be used to solve it. In this research, the IADPSO method, because of its flexibility and simplicity, is selected for solution of the problem. In this way, there is capability of expanding and completing the objective function (e.g. considering the network loss or extension of voltage levels).

III. SOLVING THE STNEP PROBLEM USING IADPSO APPROACH

Particle swarm optimization (PSO) is one of the stochastic searching algorithms which has been inspired from the nature and is based on the social behaviors of birds. The primary idea of this algorithm was proposed by Kenedy and Eberhart in 1995 [19]. This method has had appropriate performance in solving the optimization problems. In this algorithm an L-number population of X vectors is considered. X is a vector that has n dimension and each dimension is a parameter of STNEP problem. At first random values is dedicated to the particles, and in the process of algorithm, the particles are conducted to the goal which is finding the optimal solution. Position of each particle is in fact its related X vector, and its fitness is the objective function in that position. In the process of algorithm, the best experience if each particle and the related position can be saved. The best experience of ith particle is named $pbest_i$ and the corresponding position is named $\vec{x}pbest_i$. Similarly, the best experience among the whole particles and its related position are called $gbest_i$ and $\vec{x}gbest_i$ respectively. In moving toward the optimal point, the velocity and new position of each particle are determined using (8) and (9) [20]:

$$\vec{v}_i(t+1) = \omega\times\vec{v}_i(t) + c_1 r_1(\vec{x}_{pbest_i} - \vec{x}_i(t)) + c_2 r_2(\vec{x}_{gbest_i} - \vec{x}_i(t)) \tag{8}$$

$$\vec{x}_i(t+1) = \vec{x}_i(t) + \vec{v}_i(t+1) \tag{9}$$

In (8), ω is the particle's inertia weight and c_1 and c_2 are acceleration coefficients. For randomization of the velocity, the coefficient c_1 and c_2 have been multiplied by random numbers: r_1 and r_2. Usually, the lower values of ω result in the premature convergence to local optima, whereas its high values may obstruct the convergence. Commonly, in PSO algorithm, the value of ω is regulated during the learning and is reduced linearly from 1 to near zero [21].

It should be mentioned that PSO deals with real numbers, whereas the parameters of TNEP problem are discrete type numbers. Therefore, this algorithm cannot be directly applied to this problem. There are two ways for the solution of TNEP using PSO approach:

1) Binary codification PSO algorithm (BPSO)
2) Discrete PSO algorithm (DPSO)

Here, because of the following reasons, DPSO algorithm has been used for STNEP problem:

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). In 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 (10):

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter \tag{10}$$

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 (11) and (12):

$$\vec{v}_i(t+1) = Fix[\omega\times\vec{v}_i(t) + c_1 r_1(\vec{x}_{pbest_i} - \vec{x}_i(t)) + c_2 r_2(\vec{x}_{gbest_i} - \vec{x}_i(t))] \tag{11}$$

$$\vec{x}_i(t+1) = \vec{x}_i(t) + c\vec{v}_i(t+1) \tag{12}$$

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. When x_i is negative, it is set to zero. The other variables are calculated using (8) and (9).

From (11) 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 DPSO (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. The flowchart of the proposed approach is depicted in Figure 2. 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:

$$r_1 = 1 - \frac{p_{best_i}}{P_i} + rand$$
$$r_2 = 1 - \frac{p_{gbest_i}}{P_i} + rand \tag{13}$$

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:

$$p_{gbest_i} < p_{pbest_i} < p_i \tag{14}$$

$$0 \le 1-\frac{g_{best_{id}}}{g_{id}} \le 1-\frac{g_{best_{gd}}}{g_{id}} \le 1 \tag{15}$$

Because gbest is supposed as optimal and lowest value in entire particles’ fitness values, Equation (8) can be derived. Equation 9 can be easily derived from Equation (8). 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.

$$\text{if} \quad \lim_{t\to t_{\max}} g_{best_{id}} = \lim_{t\to t_{\max}} g_{id} = g_{best_g}$$

$$\lim_{t\to t_{\max}} (1-\frac{g_{best_{id}}}{g_{id}}) = \lim_{t\to t_{\max}} (1-\frac{g_{best_{id}}}{g_{id}}) = 0 \tag{16}$$

where $t_{\max}$ is the iteration of convergence. Figure 2 shows the flowchart of the IADPSO algorithm. In this study, in order to acquire better performance and fast convergence of the PSO algorithms, parameters which are used in these algorithms have been initialized according to Tables 1-3. The mentioned algorithms are run several times and then optimal results are selected. The parameters are valued as Table 1.

IV. SIMULATION RESULTS

The test network in this paper is the transmission network of Azarbaijan Regional Electrical Company located in northwest of Iran which is shown in Figure 3 and its details have been given in [16].

In this work, for considering the uncertainty in the load demand, three different scenarios with equal occurrence probabilities is regarded for the load growth which are presented in Table 2. Besides, the planning horizon is 2019 (9 years ahead) and the loss of network is calculated after the planning horizon (namely the operation time after expansion) until 10 years after that (2029). Hence, to compare the scenarios from the viewpoint of the impact on consumption load of the network, in Table II, the load of network in the horizon year with the corresponding load growth factors are given. The coefficient α, β and C_{MWh} are respectively considered 10M$/MW, 40% and 33$/MW.

The IDPSO approach, with considering the loss component in the objective function, was applied to the case study and the results were gained according to Table 3. Table 3 represents the lines which must be added to the network until the planning horizon.

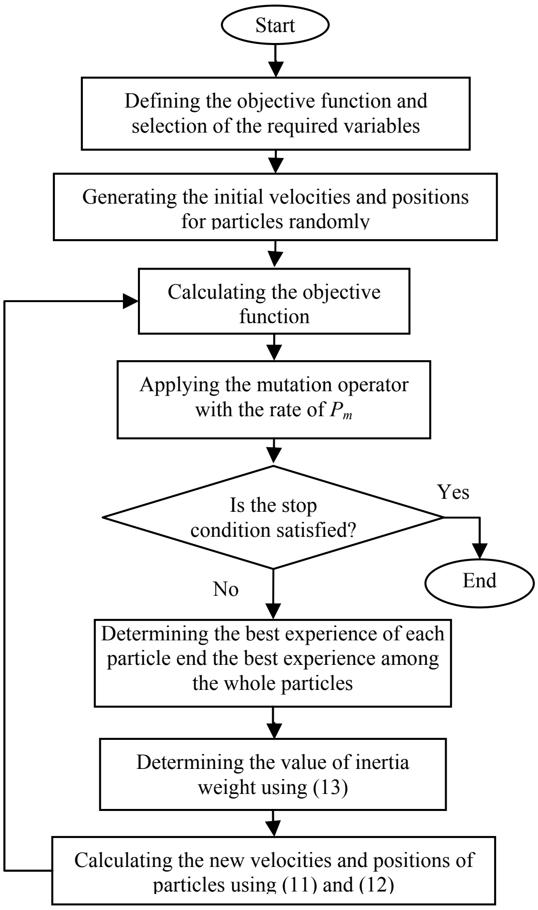

Figure 2. Flowchart of the IADPSO approach

Table 1. Values of IDPSO 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

For better analysis of the obtained plans and to verify the correctness and accuracy of the proposed method in comparison with other evolutionary algorithms, the DPSO method was also applied to the test network and the costs of proposed plans in different scenarios (in M$) were resulted according to Tables 4 and 5.

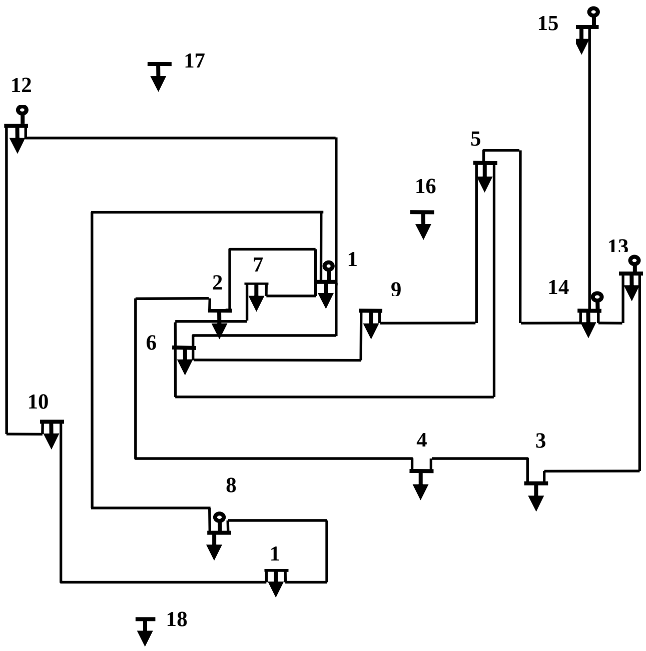

Figure 3. Transmission network of Azarbaijan Regional Electrical Company

Table 2. Regarded scenarios to consider the uncertainty in the demand

Scenario number	First	Second	Third
Load growth (%)	5	7	9
Load value(MW)	3427	4139	4981

Table 3. The best plan for STNEP proposed by IADPSO

Corridor	Number of circuits	Voltage level (kv)
1-5	2	400
1-8	2	400
2-5	2	400
2-7	1	230
3-13	1	400
5-6	1	400
5-7	2	400
5-9	2	400
7-8	2	400
8-11	2	400
8-18	2	400
9-14	2	400
10-11	2	230
11-13	2	400
12-17	2	230
13-14	2	400
13-15	2	400

Table 4. Expansion costs of the best plan proposed by DPSO in different scenarios

Scenario / Cost	First	Second	Third
Lines construction	240.1	240.1	240.1
Substations expansion from voltage level point of view	21	25.6	29.2
loss	77.9	209.6	563.7
Unsupplied load (MW)	0	0	0
Total cost	339	475.3	833

Table 5. Expansion costs of the best plan proposed by DPSO in different scenarios

Scenario / Cost	First	Second	Third
Lines construction	230.9	230.9	230.9
Substations expansion from voltage level point of view	22	21	20.6
loss	417.5	159.7	59.3
Unsupplied load (MW)	0	0	0
Total cost	670.4	411.6	310.8

According to Table 3, it can be observed that although the 400kv lines are more expensive than 230kv ones, but most of the added lines to the network are 400kv and only five 230kv lines have been proposed for the network expansion. It can be stemmed from the fact that the loss of 400kv lines is less than that of 230kv ones. For more comprehension of this matter, the total costs obtained by IADPSO method in different scenarios with and without considering the loss have been illustrated in Figures 4, 5 and 6. A notice to these curves reveals the economic merit of the plan in which the loss has been considered (the second plan) to the plan that the loss has not been considered; so that with the lowest load growth (5%), after 5 years from the planning horizon, the investment on the second plan has economic superiority to the first plan.

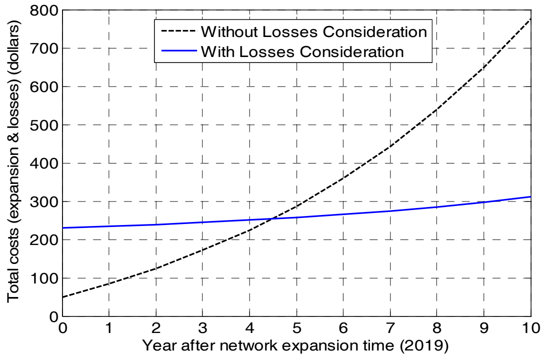

Figure 4. Total cost of network expansion with and without considering the loss in the first scenario

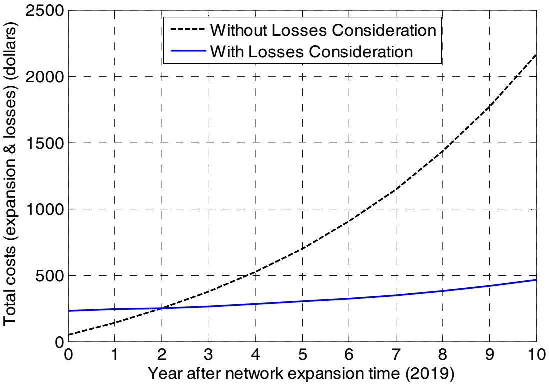

Figure 5. Total cost of network expansion with and without considering the loss in the second scenario

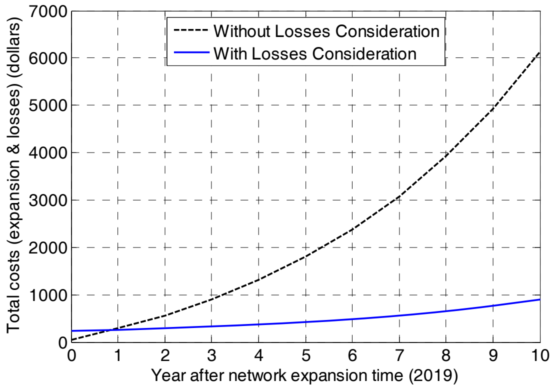

Figure 6. Total cost of network expansion with and without considering the loss in the third scenario

With increasing the load growth, this event takes place earlier; such that with the load growth of 7%, it happens after 2 years and with the load growth of 9%, it happens after 1 year from the horizon year (2021 and 2020 respectively).

Tables 4 and 5 indicate that in the implemented methods (DPSO and IADPSO) there is no unsupplied load and this shows the effectiveness of both methods in providing the energy of network reliably, but with comparison of total cost of plan, the preciseness of proposed approach (IADPSO) compared to DPSO method is discovered, because the use of this method leads to the decrease in total network expansion cost and more optimality of STNEP problem solution

IV. CONCLUSIONS

In this paper, transmission network expansion planning considering the network loss, in the presence of uncertainty in the demand (load growth) by using improved advance discrete particle swarm optimization (IADPSO) method was fulfilled. Beside verifying the strength and accuracy of IADPSO approach in obtaining better results compared to DPSO method, it was shown that considering the loss in expansion planning under different scenarios would be profitable for the network owners, and the high primary investment on expansion plan, even with low load growths, would be economical in the near future. It was also concluded that even with low load growths, the expansion of mentioned network using 400kv lines would be economical in short term not in long term.

APPENDIX

The costs of different 400/230kv transformers have been presented in Table 6. The costs of different transformers with different capacities

Table 6. Costs of different transformers with different capacities

Rated power (MVA)	125	160	200	315
Cost (M$)	18	22	26	22

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BIOGRAPHIES

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