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Losses Analysis in TEP Considering Uncertainity in Demand by DPSO

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***Abstract*—**This paper presents a mathematical model and a methodology to analyze the losses in transmission expansion planning (TEP) under uncertainty in demand. The methodology is based on discrete particle swarm optimization (DPSO). DPSO is a useful and powerful stochastic evolutionary algorithm to solve the large-scale, discrete and nonlinear optimization problems like TEP. The effectiveness of the proposed idea is tested on an actual transmission network of the Azerbaijan regional electric company, Iran. The simulation results show that considering the losses even for transmission expansion planning of a network with low load growth is caused that operational costs decreases considerably and the network satisfies the requirement of delivering electric power more reliable to load centers.

***Keywords*—**DPSO,TEP,Uncertainty

I. Introduction

TRANSMISSION expansion planning (TEP) is an important component of power system planning that should answer the following questions [1, 2]:

1) Where to build a new transmission line?
2) When to build it?
3) What type of transmission line to build?

Taking into account the planning period, the planning roblem can be considered like a one-stage problem, when it s called static planning, or the planning horizon can be eparated in several stages, and in this case we have a ultistage transmission expansion planning problem [3]. In is study, we analysis only the static planning problem but the ethodology can be extended to the multistage planning.

Static TEP (STNEP) is a large-scale, discrete, non-linear ombinatorial optimization problem that different methods uch as GRASP [4], Bender decomposition [5], HIPER [6] nd sensitivity analysis [7] have been proposed for its solution. But in all of them, the problem has been solved regardless to ffect of network losses on transmission expansion planning in nvironments with uncertainty. The most researched planning s called basic and centralized planning in which the ncertainness in demand is not considered. In other words, in is planning, the optimal expansion plan is determined for nly one amount of demand.

Recently, global optimization techniques like genetic algorithm [1, 8, 9], simulated annealing [10, 11], Tabu search [12] and decimal coded genetic algorithm (DCGA) [13, 14] have been proposed for the solution of STNEP problem. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators.

Although, these methods seem to be good methods for the solution of TEP problem, However, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded efficiency to obtain global optimum solution and also simulation process use a lot of computing time. Moreover, in all of them, the role of losses in transmission expansion planning considering uncertainty in demand has not been studied. In order to overcome these drawbacks and regarding the fact that the literature about this issue is inexistent, in this paper, expansion planning is investigated considering network losses and uncertainty in demand using discrete particle swarm optimization (DPSO). Particle swarm optimization method (PSO) is a novel population based metaheuristic, which utilize the swarm intelligence generated by the cooperation and competition between the particle in a swarm and has emerged as a useful tool for engineering optimization [15, 16]. Unlike the other heuristic techniques, it has a flexible and well-balanced mechanism to enhance the global and local exploration abilities. Also, it suffices to specify the fitness function and to place finite bounds on the optimized parameters.

In this study, network losses cost, uncertainty in demand and also the expansion cost of related substations from the voltage level point of view are included in the proposed objective function. The studied voltage levels, in this study are 230 and 400 kV. The results evaluation reveals that considering the role of network losses for solution of the STNEP problem under environments with uncertainty in demand is caused that even for low load growth coefficients, configurations which have higher voltage levels be more economic for network expansion and therefore the total expansion cost of network (expansion and operational costs) decreases considerably.

II. The Problem Formlation under Uncertainity

Due to evaluating effect of the network losses on STEP problem in a multi voltage level transmission network under uncertainty in demand and subsequent adding expansion cost of substations to expansion costs, the proposed 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 STNEP.
EC_k: Expansion cost of network in scenario k.
LC_k: Annual losses cost of network in scenario k.
r_i^k : Loss of load for i-th bus in scenario k.

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α: A coefficient for converting loss of load to cost ($US/MW).
PR_k: Occurrence probability of scenario k.
CL_{ij}: Construction cost of transmission line in corridor i-j.
n_{ij}^{k} : Number of new circuits of corridor i-j in scenario k.
SC_c: Cost of c-th type transformer (related costs are given in Appendix A).
m_i^k : Number of transformers that have been predicted for constructing in i-th bus under scenario k.
C_{MWh}: Cost of one MWh ($US/MWh).
R_{ij}^k : Resistance of branch i-j in scenario k.
$I_{ij,t}^k$: Flow of branch i-j in t-th year under scenario k. This current is varied with respect to annual load growth and therefore depends on the time.
K_{loss}: Losses coefficient.
Ω : Set of all network busses.
NY: Number of years after expansion to calculate the network losses. Its rate in all scenarios has been considered 10 years.
NC: Number of expandable corridors of network.
NB: Number of network busses.
ST: Number of types for constructed transformers.
NS: Number of scenario.
The calculation method of K_{loss} has been given in [13].
According to [13, 14] the problem constraints are:

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

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

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

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

Where, $(i,j)\in\Omega$ and:
S^k: Branch-node incidence matrix in scenario k.
f^k: Active power matrix for each corridor in scenario k.
g^k: Generation vector in scenario k.
d^k: Demand vector in scenario k.
θ_i^k : Phase angle of each bus in scenario k.
γ_{ij}^k :Total susceptance of circuits for corridor i-j in scenario k.
n_{ij}^k : Number of constructible circuits for corridor i-j in scenario k.
$\overline{n_{ij}}$: Maximum number of constructible circuits in corridor i-j.
$\overline{f_{ij}}$: Maximum of transmissible active power through corridor i-j which will have two different rates according to voltage level of candidate line.
β: A coefficient for providing security margin from loading of lines view point. This coefficient guaranties required adequacy of lines to satisfy the all of network loads at years after expansion.

The goal of the STEP problem is to obtain number of lines and their voltage level to expand the transmission network in order to ensure required adequacy of the network along the specific planning horizon. Thus, problem parameters are discrete time type and consequently the optimization problem is an integer programming problem. For solution of this problem, there are various methods such as classic mathematical and heuristic methods. In this study, the discrete particle swarm optimization is used to solve the STEP problem due to flexibility and simple implementation.

III. Disceret Particle Swarm Optimizaion

The PSO algorithm was introduced by Eberhart and Kennedy in 1995 [17]. Original PSO was inspired by the behavior of a flock of birds or a school of fish during their food-searching activities. The PSO believed to be effective in multi dimensional, linear and nonlinear problems. The form of PSO has the position vector and the velocity vector term, and it is represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ and $V_i = (v_{i1}, v_{i2} \ldots v_{id})$ for i-th particle in d-dimensional space. By the function, namely, the fitness function for optimization, the best positions of each particle and whole particle (group) are obtained at best fitness function. Each of them is represented as $Pbest_{id} = (pbest_{i1},\ldots,pbest_{id})$, $Pbest_g = (pbest_{g1},\ldots,pbest_{gd})$ [18]. The following equations are used to calculate new velocities and positions of the particles for calculating the next fitness function value [19]:

$$v_{id}(t+1) = \omega \times v_{id}(t) + c_1 r_1 (P_{best_{id}} - x_{id}(t)) + c_2 r_2 (P_{best_{gd}} - x_{id}(t)) \tag{8}$$

$$x_{id}(t+1) = x_{id}(t) + c v_{id}(t+1)\,,\quad i = 1,2\ldots,n \qquad d = 1,2\ldots,D \tag{9}$$

Where n is the number of particle in a swarm, and D is the number of swarms, which is the dimension of the search space. t is the iteration number and c_1, c_2 are the acceleration constant. r_1, r_2 are the uniformly distributed random number between 0 and 1, and ω is the inertia weight factor. $v_{id}(t)$ is the current velocity, and $x_{id}(t)$ the current position of i-th particle in d-th swarm. $pbest_{id}$ is the best position of i-th particle, and $pbest_{gd}$ is the best position of the group. The first term of (8), $\omega v_{id}(t)$, provides particles' movements to roam in the search space. The second term, $c_1 r_1 \times (p_{best_{id}} - x_{id}(t))$, represents the individual movement. Third term, $c_2 r_2 \times (pbest_{gd} - x_{id}(t))$, represents the social behavior in finding the global best solution. $v_{id}(t)$ is limited by $-v_d^{\max} \le v_{id}^{\,t} \le v_d^{\max}$, and $v_d^{\max}$ is proportional to the velocity of the convergence into the best solution. Usually, $v_d^{\max}$ is fixed in the range of the movement from the past c_1 and c_2, the lower value takes the movement from the past target region, but the higher value takes the movement toward the past target region. The results of past experiments about PSO show that ω was not considered at an early stage of PSO algorithm. However, ω affects the iteration number to find an optimal solution. If the value of ω is low, the convergence will be fast, but the solution will fall into the local minimum. On the other hand, if the value will increase, the iteration number will also increase and therefore the convergence will be slow. Usually, for running the PSO algorithm, value of inertia weight is adjusted in training process. It was shown that in PSO algorithm, the value of ω should be high in the first stage so that ω decreases gradually [20].

Regarding the fact that parameters of the TEP problem are discrete time type and the performance of standard PSO is based on real numbers, this algorithm can not be used directly for solution of the TEP problem. There are two methods for solving the transmission expansion planning problem based on the PSO technique [21]:

1) Binary particle swarm optimization (BPSO).
2) Discrete particle swarm optimization (DPSO).

Here, the second method has been used due to avoid difficulties which are happened at coding and decoding problem, increasing convergence speed and simplification. In this approach, the each particle is represented by three arrays: start bus ID, end bus ID and number of transmission circuits (the both of constructed and new circuits) at each corridor. In the DPSO iteration procedure, only number of transmission circuits needs to be changed while start bus ID and end bus ID are unchanged in calculation, so the particle can omit the start and end bus ID. Thus, particle can be represented by one array. A typical particle with 12 corridors is shown in Fig. 1.

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

Fig. 1. A typical particle

In Fig. 1, in the first, second, third corridor and finally 12th orridor, one, two, three and two transmission circuits have een predicted, respectively. Also, the particle's velocity is epresented by circuit's change of each corridor. The value of) is considered high in the first stage and then with increasing ne iterations its value decreases gradually. Therefore, ω is used s the follows:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k \times iter_{\max}} \quad (10)$$

Where $\omega_{\max}$ is the current weight factor, $iter_{\max}$ is the naximum number of iteration, and k is a constant which is djusted around 1.

Finally, position and velocity of each particle is updated by ne following equations [17]:

$$v_{id}(t+1) = Fix[\omega \times v_{id}(t) + c_1 r_1 (P_{id} - x_{id}(t)) + c_2 r_2 (P_{gd} - x_{id}(t))] \quad (11)$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \quad (12)$$

Where, P_{id} and P_{gd} are $pbest_{id}$ and $gbest_{gd}$, and $fix(.)$ is etting the integer part of f. When v_{id} is bigger and smaller than v_d^{max} and $-v_d^{max}$, make $v_{id}=v_d^{max}$ and $v_{id}=-v_d^{max}$, respectively. Vhile, x_{id} is bigger than upper bound of circuit number allowed to be added to a candidate corridor for expansion, then make x_{id} equal the upper bound. While $x_{id}<0$, make $x_{id}=0$. The other variables are the same to (8) and (9).

The flowchart of the proposed DPSO algorithm is shown in Fig. 2.

In this study, in order to acquire better performance and fast convergence of the proposed algorithm, parameters which are used in discrete PSO algorithm have been initialized according to Table 1.

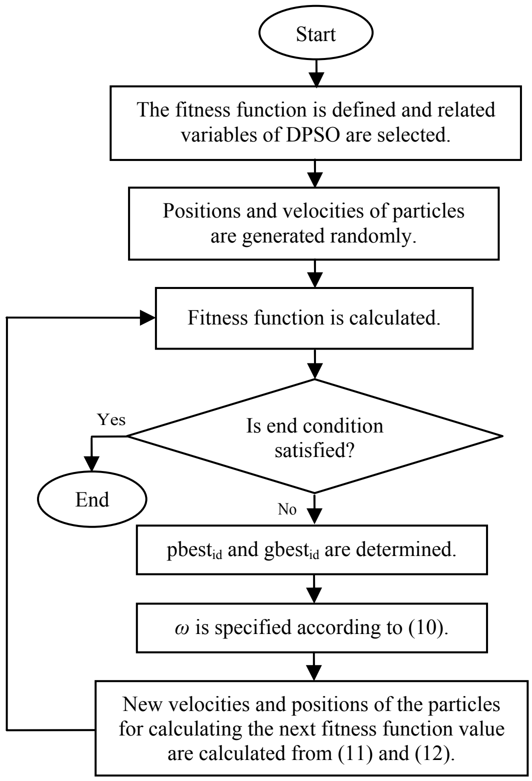

Fig. 2 Flowchart of the DPSO algorithm

TABLE I
VALUE OF PARAMETERS FOR DPSO

Parameter	Value
Problem dimension	153
Number of particles	5
$iter_{\max}$	500
C_1	1
C_2	1.5
$\omega_{\min}$	0.4
$\omega_{\max}$	0.9
v_d^{max}	2

IV. FITNESS FUNCTION CHOOSING

The fitness function is one of the key elements of discrete particle swarm optimization (DPSOs) as it determines whether a given potential solution will contribute its elements to future generation through the selection process or not. Since the objective of DPSOs is to maximize the fitness, while the objective of transmission planning model is to minimize the objective function (OF) presented by Eq. (1), therefore it is necessary to map the objective function into the fitness function. The fitness function (Fit) adopted in this work is:

$$Fitness = \frac{A}{OF} \quad (7)$$

Where, A is a system-dependent constant that in order to prevent the fitness from obtaining too small values, its value is considered big.

V. Results and Discussion

The transmission network of the Azerbaijan regional electric system is used to test and evaluation of the proposed method. This actual network has been located in northwest of Iran and is shown in Fig. 3. All details of this network are given in [22].

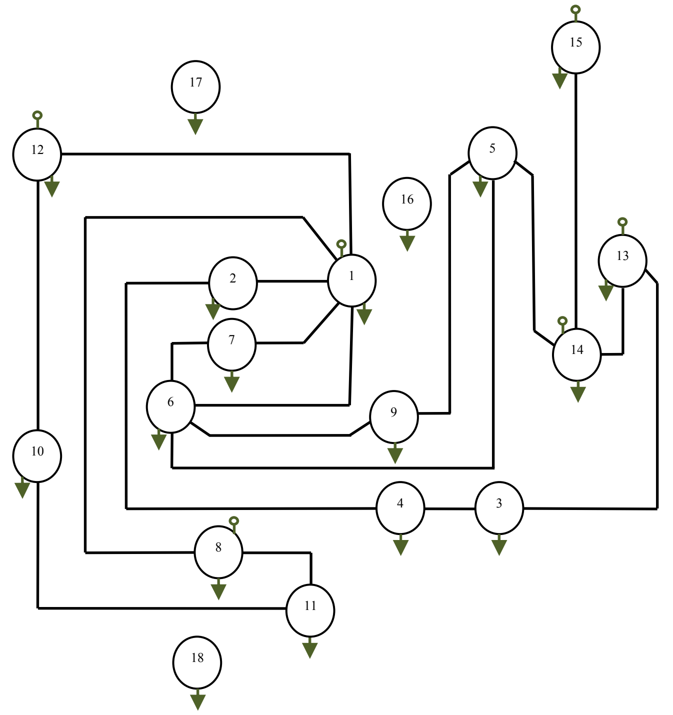

Fig. 3 Transmission network of the Azerbaijan regional electric company

For considering uncertainty in STEP problem, three different cenarios with equal occurrence probabilities have been redicted for load growth. Also planning horizon is year 2019 10 years ahead) and network losses is calculated by DC load low from planning horizon year to 10 years after it (year 029). Therefore, for feasibility of comparing the scenarios rom their effect rate on network load view point, rates of etwork load at planning horizon with related load growth oefficients for different scenarios are given in Table 2. Value f coefficients α and β, and also C_{MWh} are considered 0^7 \$US/MW), 40% and 33 (\$US/MWh) respectively. The roposed method is applied to the case study system and the esults (lines which must be added to the network during the lanning horizon year) are given in Tables 3 and 4.

TABLE II
Proposed Scenarios for Considering Uncertainty in Demand

Scenario Number	Scenario 1	Scenario 2	Scenario 3
Load Growth (%)	5	7	9
Load (MW)	3427	4139	4981

The first and second configurations are obtained neglecting and considering the network losses, respectively. By comparing the Tables 3 and 4, ignoring the network losses, a configuration with lower voltage level lines is proposed for expansion of the network. But if the network losses are considered, a configuration with higher voltage level lines is proposed for expansion purpose. Also, for better analyzing of proposed configurations, their expansion costs for different scenarios form load growth point of view are given in Tables 5 and 6.

TABLE III
First Configuration for All Scenarios: Neglecting the Losses

Corridor	Voltage Level (kV)	Number of Circuits
2-5	230	2
3-7	230	2
4-6	230	2
4-8	230	2
5-11	230	1
5-15	230	1
8-17	230	1
8-18	230	1
9-13	230	1
9-16	230	1

TABLE IV
Second Configuration for All Scenarios: Considering the Losses

Corridor	Voltage Level (kV)	Number of Circuits
1-2	400	2
1-5	400	2
1-16	400	2
2-5	230	2
2-7	400	1
2-8	400	2
2-13	400	2
3-13	400	1
4-5	230	2
4-13	230	2
5-6	400	2
5-15	230	2
5-16	400	2
5-18	400	2
7-8	400	2
8-9	400	2
8-11	400	1
9-14	400	2
13-14	400	2
13-15	230	2
16-17	230	2

Comparison between Tables 5 and 6 shows that if network losses are neglected for solution of STEP problem, a configuration with lower expansion cost and higher network losses is obtained. But considering the network losses, a plan with respectively higher expansion cost and lower network losses is proposed for network expansion. Moreover, Tables 5 and 6 show that uncertainty in demand has no effect on expansion cost of lines while it effects on losses cost and expansion cost of substations. The reason is that expansion cost of substations from voltage level point of view and losses cost depend on loading of lines and substations. Thus, different load growths can be effect on these costs. Finally, it can be said that proposed configurations by discrete PSO for different scenarios are same and any loss of load is not exist. This fact reveals that proposed method has high efficiency for solution of STEP problem. Total expansion cost (sum of expansion and losses costs) of expanded network with the two proposed configurations for different scenarios is shown in Figs 4-6.

TABLE V
EXPANSION COSTS OF THE NETWORK FOR FIRST CONFIGURATION UNDER DIFFERENT SCENARIOS

Scenario Number	Scenario 1	Scenario 2	Scenario 3
Expansion Cost of Lines (million $US)	67.1	67.1	67.1
Expansion Cost of Substations (million $US)	0	0	0
Losses Cost (million $US)	594.7	1600.6	4303.8
Loss of Load Cost (million $US)	0	0	0
Total Expansion Cost of Network (million $US)	661.8	1667.7	4370.9

TABLE VI
EXPANSION COSTS OF THE NETWORK FOR SECOND CONFIGURATION UNDER DIFFERENT SCENARIOS

Scenario Number	Scenario 1	Scenario 2	Scenario 3
Expansion Cost of Lines (million $US)	240.1	240.1	240.1
Expansion Cost of Substations (million $US)	21	25.6	29.2
Losses Cost (million $US)	77.9	209.6	563.7
Loss of Load Cost (million $US)	0	0	0
Total Expansion Cost of Network (million $US)	339	475.3	833

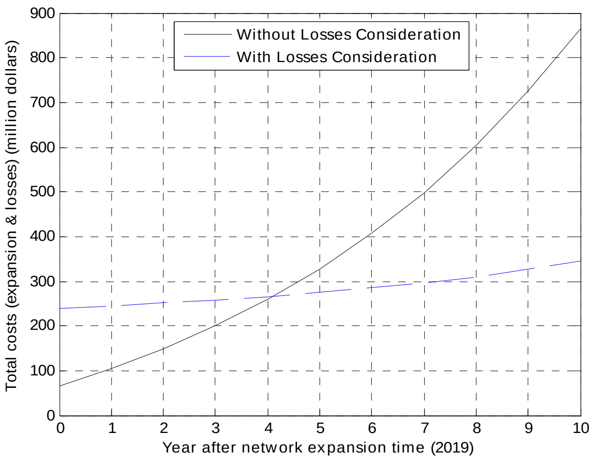

Fig. 4 Sum of expansion costs and annual losses cost of the network with the two proposed configurations for scenario 1

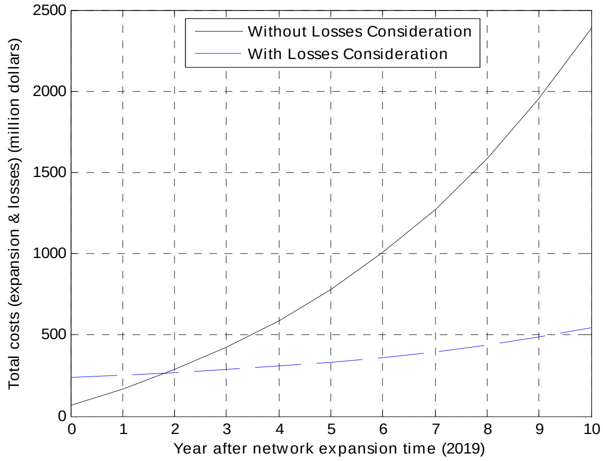

Fig. 5 Sum of expansion costs and annual losses cost of the network with the two proposed configurations for scenario 2

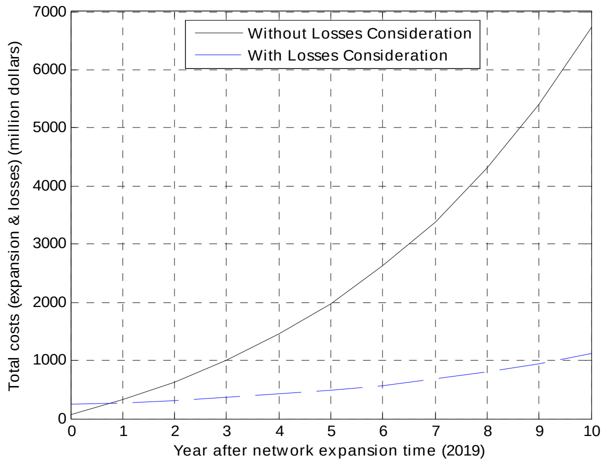

Fig. 6 Sum of expansion costs and annual losses cost of the network with the two proposed configurations for scenario 3

It can be seen that, for all scenarios, the total expansion cost of network with the second configuration is more than that of the first one until, about a few years after planning horizon, but afterward, the total expansion cost of network with first configuration becomes more than another one. For load growth of 5%, second one has investment return in comparison with first one about 4 years after expansion time. With rising load growth, investment return takes places earlier (for load growths of 7% and 9% this time is about 2 years and 1 year respectively). Accordingly, it can be concluded that the network losses has important role in transmission expansion planning even for low load growths.

VI. CONCLUSION

In this paper, the effect of network losses on STEP problem under environments with uncertainty in demand is studied using discrete particle swarm optimization. The results analysis reveals that considering the network losses in transmission expansion planning under different load growths is caused that total expansion costs and losses cost of network is decreased for long-term and mid-term. Also, it can be said that although cost of lines with higher voltage levels are more than other lines (lines with lower voltage levels), constructing this type of lines in transmission network is caused that investment cost is considerably saved and therefore the total expansion cost is calculated more exactly. Consequently, even in networks with low load growth, network losses plays important role in transmission expansion planning and subsequent determination of network arrangement and configuration. In addition, it can be concluded that the proposed algorithm is a respectively efficient method for solution of STEP problem.

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