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

December 2011 Issue 9 Volume 3 Number 4 Pages 1-9

EVALUATING THE EFFECT OF LOAD GROWTH ON ANNUAL NETWORK LOSSES IN TNEP CONSIDERING BUNDLE LINES USING DCGA

M. Mahdavi [1] **E. Mahdavi** [2]

1. School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran, me.mahdavi@ut.ac.ir
2. Electrical and Computer Engineering Faculty, Semnan University, Semnan, Iran

Abstract- The main task of transmission network expansion planning (TNEP) is minimization of the network expansion and operational costs, and providing required adequacy of lines along the planning horizon while meeting imposed technical and economic constraints. Until now, much research has been presented on the field of static transmission network expansion planning (STNEP). However, in all of them, the effect of load growth on annual network losses in transmission expansion planning has not been investigated. Therefore, in this paper, the STNEP problem is being studied considering the load growth effect on annual network losses by decimal codification genetic algorithm (DCGA). Finally, the proposed idea is tested on an actual transmission network of the Azerbaijan regional electric company, Iran. The results reveal that load growth has important effect on amount of annual network losses and subsequent network configuration. In addition, considering effect of this parameter on the network losses in TNEP is caused the total expansion cost of network (expansion cost of lines and substations) is calculated more exactly.

Keywords: TNEP, Load Growth, Annual Network Losses, DCGA.

I. INTRODUCTION

Transmission network expansion planning (TNEP) is an important component of power system planning. It determines the characteristic and performance of the future electric power network and influences the operation of power system directly. TNEP should be satisfied required adequacy of the lines for delivering safe and reliable electric power to load centers along the planning horizon [1-3]. Calculation of investment cost for network expansion is difficult because it is dependent on the various reliability criteria [4]. Thus, the long-term TNEP is a hard, large-scale combinatorial optimization problem that, generally, can be classified as static or dynamic. Static expansion determines where and how many new transmission lines should be added to the network up to the planning horizon. If in the static expansion the planning horizon is categorized in several stages we will have dynamic planning [5, 6].

In the majority of power systems, generating plants are located far from the load centers. In addition, the planned new projects are still far from completion. Due to these factors, investment cost for transmission network is huge. Thus, the STNEP problem acquires a principal role in power system planning and should be evaluated carefully because any effort to reduce transmission system expansion cost significantly improves cost saving. After Garver's paper that was published in 1970 [7], much research has been done on the field of TNEP problem. Some of them such as [1-3], [6], [8-25] is related to problem solution method. Some others, they proposed different approaches for solution of this problem considering various parameters such as uncertainty [5, 26], reliability criteria [4, 27, 28], and economic factors [29]. Also, some of them investigated this problem and generation expansion planning together [30, 31]. Recently, different methods such as GRASP [3], Bender decomposition [6], HIPER [17], branch and bound algorithm [32], sensitivity analysis [15], genetic algorithm [1, 11, 20], PSO [24], simulated annealing [16, 25] and Tabu search [12] have been proposed for the solution of STNEP problem. In all of them, the problem has been solved regardless to effect of load growth on network losses.

In Ref. [8], authors proposed a neural network based method for solution of the TNEP problem with considering both the network loss and construction cost of the lines. But the role of load growth on annual network losses has not been investigated in this study. In Ref. [10], the network expansion costs and transmitted power through the lines have been included in objective function and the goal is optimization of both expansion costs and loading of lines. In addition, the objective function is different from those which are represented in [6, 11, 12], [15-17], [20, 32], but the effect of load growth on annual network losses has not been investigated. In Ref. [33], the voltage level of transmission lines has been considered as a subsidiary factor but its objective function only includes expansion and generation costs and one of the reliability criteria i.e.: power not supplied

(PNS). Moreover, expansion planning has been studied as dynamic type and the effect of load growth on network losses has not been considered. In [34, 35], the expansion cost of substations with the network losses have been considered for the solution of STNEP problem.

The results evaluation in [34] was shown that the network with considering higher voltage level save capital investment in the long-term and become overload later. In [35], it was shown that the total expansion cost of the network was calculated more exactly considering effect of the inflation rate and therefore the network satisfies the requirements of delivering electric power more safely and reliably to load centers. However, load growth effect on the network losses has not been investigated in these papers. Ref. [36] studied the effect of losses coefficient on STNEP using the DCGA algorithm. It was showed that this coefficient has not any role in determining of network configuration and arrangement. However, considering its effect in expansion planning of transmission networks with various voltage levels is caused the total cost of the network is reduced considerably and therefore the problem is solved more exactly and correctly.

Finally, in Ref. [37] the effect of bundle lines on static expansion planning of a multiple voltage level transmission network was investigated by DCGA. It was concluded that considering the effect of bundle lines on static transmission expansion planning caused that the total expansion cost of network (expansion and operational costs) is considerably decreased and therefore the capital investment significantly saved. Moreover, it was shown that construction of bundle lines in transmission network with different voltage levels is caused that the network lines is overloaded later and the network would have higher adequacy. But, role of load growth in annual losses has not been evaluated.

In this paper, the effect of load growth on the network losses in static expansion planning of a transmission network with various voltage levels is investigated. For this reason, the losses cost and also the expansion costs of related substations from the voltage level point of view are included in the objective function. The studied voltage levels are 230 and 400 kV. These voltages are extendable to another voltage levels, too. The proposed method is tested on a real transmission network of the Azerbaijan regional electric company. This network has been located in northwest of Iran. The results evaluation reveals that considering the load growth has important effect on annual network losses and therefore network arrangement. Also, considering its effect for solving the STNEP problem is caused that the network losses cost (operation costs) and subsequent total expansion cost of network is calculated more exactly.

Moreover, by considering the load growth effect in calculating the cost of annual network losses investment return is taking placed earlier. This paper is organized as follows: the STNEP problem formulation is given in Section 2. Section 3 describes completely the proposed GA based method, chromosome structure and the method of choosing selection, crossover and mutation operators for solution of the STNEP problem. The characteristics of case study system and applying of the proposed method are given in Section 4. Finally, in Section 5 conclusion is represented.

II. THE STNEP PROBLEM FORMULATION

The STNEP problem is a mixed-integer nonlinear optimization problem. Due to studying effect of the load growth on network losses in transmission networks with various voltage levels and subsequent adding expansion cost of substations to expansion costs, the proposed objective function is defined as follows:

$$C_T = \sum_{i,j \in \Omega} CL_{ij} n_{ij} + \sum_{k \in \Psi} CS_k + \sum_{i=1}^{NY} C_{loss_i} \tag{1}$$

$$C_{loss} = loss \times C_{MWh} \times k_{loss} \times 8760 \tag{2}$$

$$loss = \sum_{i,j \in \Omega} R_{ij} I_{ij}^2 \tag{3}$$

where,

C_T: Total expansion cost of network;

CL_{ij}: Construction cost of each line in branch *i-j*; (It is different for 230 and 400 KV lines);

CS_k: Expansion cost of *k*th substation;

C_{loss}: Annual loss cost of network;

loss: Total loss of network;

C_{MWh}: Cost of one MWh ($US/MWh);

k_{loss}: Loss coefficient;

n_{ij}: Number of all new circuits in corridor *i-j*;

R_{ij}: Resistance of branch *i-j*;

I_{ij} : Flow of branch *i-j*;

Ω: Set of all corridors;

Ψ: Set of all substations;

NY: Expanded network adequacy (year).

The Calculation method of CS_k is given in [34]. Several restrictions have to be modeled in a mathematical representation to ensure that the mathematical solutions are in line with the planning requirements. These constraints are as follows [5, 34].

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

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

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

$$0 \le n_{ij} \le \overline{n}_{ij} \tag{7}$$

$$Line\_Loading \le LL_{max} \tag{8}$$

where, $(i, j) \in \Omega$ and

S: Branch-node incidence matrix;

f: Active power matrix in each corridor;

g: Generation vector;

d: Demand vector;

θ: Phase angle of each bus;

γ_{ij}: Total susceptance of circuits in corridor *i-j*;

n_{ij}^0 : Number of initial circuits in corridor *i-j*;

$\overline{n}_{ij}$: Maximum number of constructible circuits in corridor *i-j*;

$\overline{g}$: Generated power limit in generator buses;

$\overline{f}_{ij}$: Maximum of transmissible active power through corridor *i-j* which will have two different rates according to voltage level of candidate line;

Line_Loading: Loading of lines at planning horizon year and start of operation time;
LL_{max}: Maximum loading of lines at planning horizon year.

In this study, the objective function is different from those which are mentioned in [1-20], [23-29], [31, 32] and in part of the problem constraints, $\overline{f}_{ij}$ and *Line_Loading* have been considered as two new additional constraints. It should be noted that LL_{max} is an experimental parameter that is determined according to load growth coefficient [35].

III. PROPOSED SOLUTION ALGORITHM

The goal of the STNEP 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 of the problem are discrete time type and consequently the optimization problem is an integer programming problem. For the solution of this problem, there are various methods such as classic mathematical and heuristic methods [5-21]. In this study, the decimal codification genetic algorithm is used to solve the STNEP problem due to flexibility, simple implementation and the advantages which were mentioned in [34]. In the proposed method, expansion and completion of objective function (for example, adding the network losses to objective function, extending the studied voltage levels to another levels and etc) would be practicable.

A. DCGA and Chromosome Structure of the STNEP Problem

Standard genetic algorithm is a random search method that can be used to solve non-linear system of equations and optimize complex problems. The base of this algorithm is the selection of individuals. It doesn’t need a good initial estimation for sake of problem solution, In other words, the solution of a complex problem can be started with weak initial estimations and then be corrected in evolutionary process of fitness. The standard genetic algorithm manipulates the binary strings which may be the solutions of the problem. This algorithm can be used to solve many practical problems such as transmission network expansion planning [34, 35].

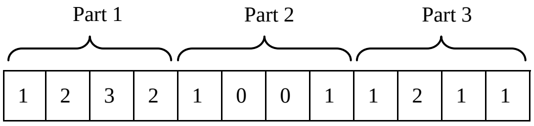
The genetic algorithm generally includes the three fundamental genetic operators of reproduction, crossover and mutation. These operators conduct the chromosomes toward better fitness. There are three methods for coding the transmission lines based on the genetic algorithm method.

1) Binary codification for each corridor.
2) Binary codification with independent bits for each line.
3) Decimal codification for each corridor.

Although binary codification is conventional in genetic algorithm but in here, the third method has been used due to due to following reasons [35]: 1) Avoiding difficulties which are happened at coding and decoding problem. 2) Preventing the production of completely different offspring from their parents and subsequent occurrence of divergence in mentioned algorithm.

In this method, crossover can take place only at the boundary of two integer numbers. Mutation operator selects one of existed integer numbers in chromosome and then changes its value randomly. Reproduction operator, similar to standard form, reproduces each chromosome proportional to value of its objective function. Therefore, the chromosomes which have better objective functions will be selected more probable than other chromosomes for the next population (i.e., Elitism strategy). Consequently, the selected chromosome considering voltage level and bundle of lines and also simplicity in programming was divided into the following parts as shown in Figure 1. In part 1, each gene includes number of existed circuits (both of constructed and new circuits) in each corridor. Genes of part 2 and part 3 describe voltage levels and number of corresponding bundle lines of existed genes in part 1.

It should be noted that the binary digits of 0 and 1 have been used for representing voltage levels of 230 and 400 kV, respectively. If other voltage levels exist in the network, the numbers 2, 3 and etc., can be used for representing them in the genes of part 2. Therefore, the proposed coding structure would be extendable to other voltage levels. A typical chromosome for a network with 4 corridors is shown in Figure 1. In the first corridor, one 400 kV transmission circuit with one bundle conductor, in the second corridor, two 230 kV transmission circuits with two bundle conductors, in the third corridor, three 230 kV transmission circuits with one bundle conductor and finally in the forth corridor, two 400 kV transmission circuits with one bundle conductor have been predicted. Also, the flowchart of the proposed method is shown in Figure 2.



Part 1				Part 2				Part 3			
1	2	3	2	1	0	0	1	1	2	1	1

Figure 1. Typical chromosome structure

B. Selection, Crossover and Mutation Process

Selection operator selects the chromosome in the population for reproduction. The more fit the chromosome, the higher its probability of being selected for reproduction. Thus, selection is based on the survival-of-the-fittest strategy, but the key idea is to select the better individuals of the population, as in tournament selection, where the participants compete with each other to remain in the population. The most commonly used strategy to select pairs of individuals that has applied in this paper is the method of roulette-wheel selection, in which every string is assigned a slot in a simulated wheel sized in proportion to the string’s relative fitness. This ensures that highly fit strings have a greater probability to be selected to form the next generation through crossover and mutation. After selection of the pairs of parent strings, the crossover operator is applied to each of these pairs.

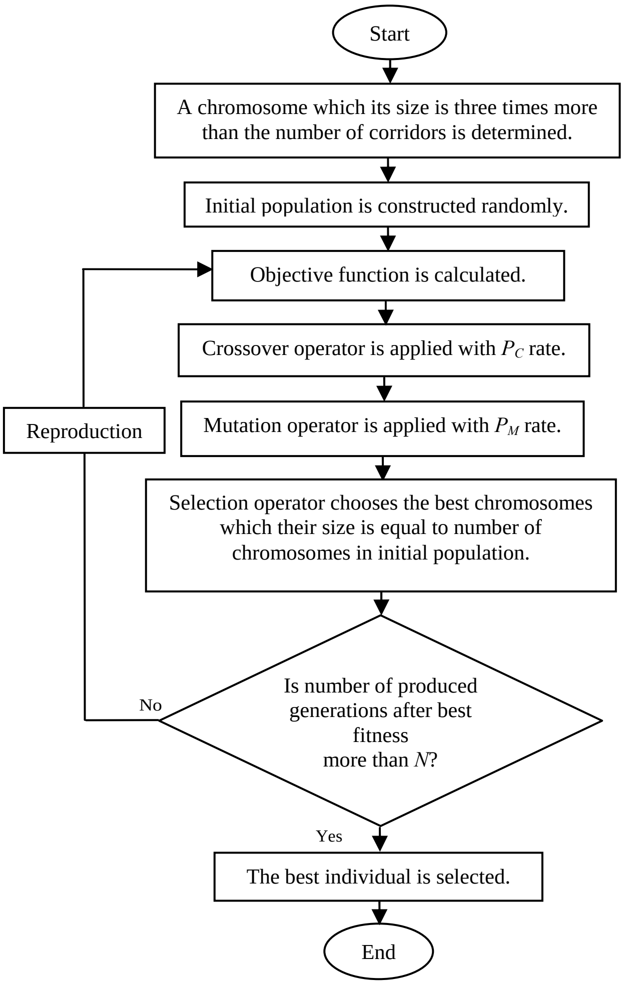


Figure 2. Flowchart of the proposed method

The crossover operator involves the swapping of genetic material (bit-values) between the two parent strings. Based on predefined probability, known as crossover probability, an even number of chromosomes are chosen randomly. A random position is then chosen for each pair of the chosen chromosomes. The two chromosomes of each pair swap their genes after that random position. Crossover may be applied at a single position or at multiple positions. In this work, because of choosing smaller population multiple position crossovers are used with probability of 0.1.

Each individuals (children) resulting from each crossover operation will now be subjected to the mutation operator in the final step to forming the new generation. The mutation operator enhances the ability of the GA to find a near optimal solution for a given problem by maintaining a sufficient level of genetic variety in the population, which is needed to make sure that the entire solution space is used in the search for the best solution. In a sense, it serves as an insurance policy; it helps prevent the losses of genetic material. This operator randomly flips or alters one or more bit values usually with very small probability known as a mutation probability (typically between 0.001 and 0.01). In a binary coded GA, it is simply done by changing the gene from 1 to 0 or vice versa. In DCGA, as in this study, the gene value is randomly increased or decreased by 1 providing not to cross its limits. Practical experience has shown that in the transmission expansion planning application the rate of mutation has to be larger than ones reported in the literature for other application of the GA. Here, mutation is used with probability of 0.01 per bit.

After mutation, the production of new generation is completed and it is ready to start the process all over again with fitness evaluation of each chromosome. The process continues and it is terminated by either setting a target value for the fitness function to be achieved, or by setting a definite number of generations to be produced. Due to the stochastic nature of the GA, there is no guarantee that different executions of the program converge to the same solution.

Thus, in this study, the program has been executed for four times as continual i.e. after running of the genetic program, obtained results are inserted in initial population of next run and this process is iterated for three times. In addition to this continual run, a more suitable criteria termination has accomplished that is production of predefined generations after obtaining the best fitness and finding no better solution. In this work a maximum number of 1500 generations has been chosen.

IV. RESULTS AND DISCUSSIONS

The transmission network of the Azarbaijan Regional Electric System (Iran) is used to test and evaluation of the proposed method. This actual network has been located in northwest of Iran and is shown in Figure 3. The system data and construction costs of 400 and 230 kV lines are listed in Tables 1-7.

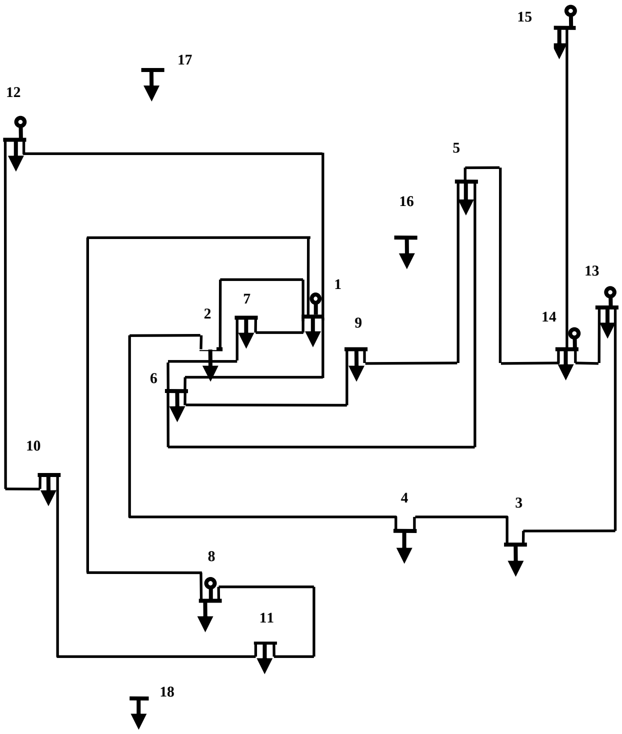


Figure 3. Transmission network of the Azarbaijan Regional Electric Company (Iran)

Table 1. Arrangement of lines

Corridor	Length of Corridor (km)	Voltage Level (kV)	Number of Circuit	Number of Bundle
6-1	55	230	1	1
2-1	14	230	2	1
9-6	18	230	1	1
4-2	83	230	1	1
14-5	110	230	1	1
11-8	65	230	2	1
11-10	125	230	2	1
15-14	139	230	1	1
12-1	122	400	1	2
9-5	100	230	1	1
6-5	103	230	2	1
13-3	105	400	1	2
4-3	81	230	1	1
14-13	44	230	2	1
12-10	134	230	2	1
8-1	75	230	2	1
7-6	33	230	1	1
7-1	22	230	1	1

Table 2. Arrangement of substations

Substation	Voltage Level (kV)	Substation	Voltage Level (kV)
1	400/230	10	230/132
2	230/132	11	230/132
3	400/230	12	230/132
4	230/63	13	230/63
5	230/132	14	400/230
6	230/132	15	230/63
7	230/132	16	230/20
8	230/132	17	230/132
9	230/132	18	230/132

Table 3. Generation and load arrangements

Bus	Load (MW)	Generation (MW)	Bus	Load (MW)	Generation (MW)
1	378	715	10	134	0
2	202	0	11	125	0
3	42	0	12	256	288
4	53	0	13	78	101
5	45	0	14	46	60
6	64	0	15	45	101
7	88	0	16	11	0
8	49	514	17	14	0
9	70	0	18	79	0

Table 4. Characteristics of 400 kV lines

Number of Line Bundles	Maximum Loading (MVA)	Reactance (p.u./Km)	Resistance (p.u./Km)
1	750	1.24e-4	3.5e-5
2	1321	9.7e-5	7e-5
3	1982	8.6e-5	1.05e-4

Table 5. Characteristics of 230 kV lines

Number of Line Bundles	Maximum Loading (MVA)	Reactance (p.u./Km)	Resistance (p.u./Km)
1	397	3.85e-4	1.22e-4
2	794	2.84e-4	2.44e-4

Table 6. Construction cost of 400 kV

Number of Line Circuits	Fix Cost of Line Construction ($\times 10^3$ dollars)	Variable Cost of Line Construction ($\times 10^3$ dollars)
1	1748.6	92.9
2	1748.6	120.2

Table 7. Construction cost of 230 kV

Number of Line Circuits	Fix Cost of Line Construction ($\times 10^3$ dollars)	Variable Cost of Line Construction ($\times 10^3$ dollars)
1	546.5	45.9
2	546.5	63.4

In order to evaluate the influence of load growth on the network losses and subsequent transmission expansion planning, the proposed idea is tested on the above mentioned system, considering and neglecting the network loss for two cases. In case 1, annual network losses is calculated regardless to load growth for years after expansion time, while in case 2, the load growth has been considered for calculation of network losses at years after planning horizon. Also, the planning horizon year and maximum loading of lines and substations are 10 (year 2021) and 50% for both cases, respectively.

A. Case 1

In this case, for ignoring the load growth effect on calculation of annual network losses, the network losses is increased with specific rate for each year after expansion. This specific rate is named inflation coefficient for losses that has been considered 1.15. The proposed method is applied to the case study system and the results (lines which must be added to the network up to planning horizon year) are listed in Tables 8-11. The first and second configurations are obtained neglecting and considering the network losses, respectively.

Table 8. First configuration: neglecting the network losses

Corridor	Voltage Level (kV)	Number of Circuits	Number of Bundle
8-9	230	2	2
8-2	230	1	2

Table 9. Second configuration: considering the network losses

Corridor	Voltage Level (kV)	Number of Circuits	Number of Bundle
8-9	230	2	2
8-2	230	2	2
1-7	230	1	2

Table 10. Expansion cost of network with the first configuration

Expansion Cost of Substations	0 million $US
Expansion Cost of Lines	9.665 million $US
Total Expansion Cost of Network	9.665 million $US

Table 11. Expansion cost of network with the second configuration

Expansion Cost of Substations	0 million $US
Expansion Cost of Lines	21.733 million $US
Total Expansion Cost of Network	21.733 million $US

Total expansion cost (sum of expansion costs and losses cost) of expanded network with the two obtained configurations has been shown in Figure 4. It can be seen that the total expansion cost of network with the second configuration is more than that of the first one until about 7 years after planning horizon (2028), but afterward the total expansion cost of network with first configuration becomes more than another one. The reason is that the network losses cost of second configuration becomes less than that of first one about 7 years after planning horizon. Process of investment return for this configuration in comparison with the first one is shown in Figure 5. In fact, this curve is equal to subtraction of cost curves of two mentioned configurations in Figure 4.

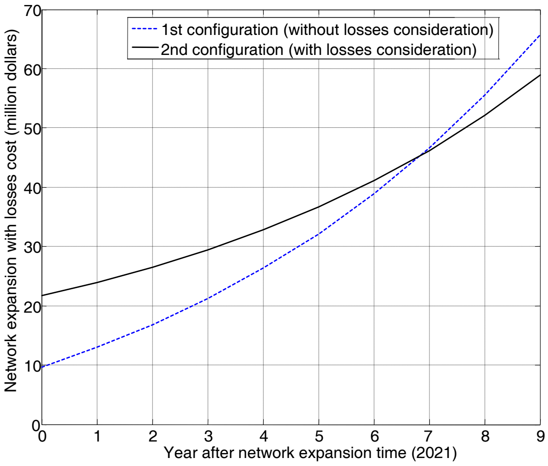


Figure 4. Sum of expansion costs and annual loss cost of the network with the two proposed configurations in case 1

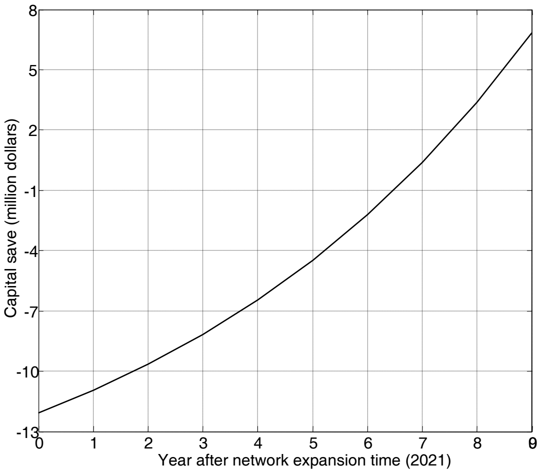


Figure 5. Investment return curve by choosing of the second configuration in comparison with the first one in case 1

B. Case 2

In this case, in order to consider effect of load growth on annual network losses, DC load flow is rune for years after expansion and the network losses is calculated individually for each year after expansion time. Therefore, rate of annual network losses with respect to load growth is different for each year after planning horizon. The proposed idea, considering load growth effect in calculating the network losses, is tested on case study and the results (lines which must be added to the network up to planning horizon year) are given in Tables 12-15.

Table 12. First configuration: neglecting the network losses

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

Table 13. Second configuration: considering the network losses

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

Table 14. Expansion cost of network with the first configuration

Expansion Cost of Substations	0 million $US
Expansion Cost of Lines	36.751 million $US
Total Expansion Cost of Network	36.751 million $US

Table 15. Expansion cost of network with the second configuration

Expansion Cost of Substations	20.645 million $US
Expansion Cost of Lines	128.817 million $US
Total Expansion Cost of Network	149.462 million $US

Also, total expansion cost (sum of expansion and losses costs) of expanded network with the two proposed configurations has been shown in Figure 6. Process of investment return for this configuration in comparison with the first one is shown in Figure 7.

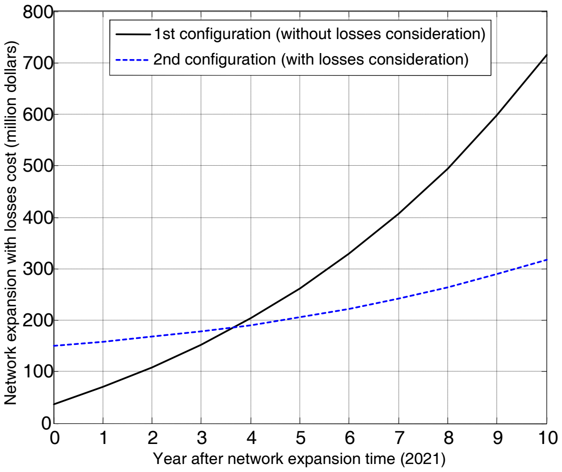


Figure 6. Sum of expansion costs and annual loss cost of the network with the two proposed configurations in case 2

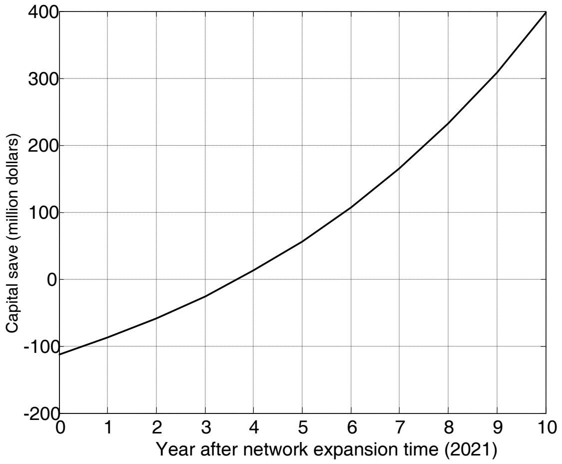


Figure 7. Investment return curve by choosing of the second configuration in comparison with the first one in case 2

From voltage level of added lines point of view, although power losses of 400 kV lines is less than lines with voltage level of 230 kV, but with respect to Table 9, even considering the network losses, the expansion of network by 400 kV lines is not economic and it is rejected by the proposed GA based method. The reason is that the construction of 400 kV lines in corridors which their sending and receiving substations have not voltage level of 400 kV, which would be caused substations are expanded and subsequent total expansion cost of the network is increased . In other words, in this case, network losses cost of the lines with upper voltage level (in here, 400 kV) cannot compete with expansion costs (expansion cost of lines and substations). But, according to Table 13, it can be seen that considering the network losses, 400 kV lines have been expanded in addition to 230 kV lines, too. Its reason is that considering the load growth effect on network losses is caused that total cost of annual network losses increases and therefore network losses cost of the lines with upper voltage level can compete with expansion costs. Thus, load growth has effective role in determining the network arrangement and configuration.

Also, by comparing between Figures 4 and 6, it can be concluded that considering effect of load growth in calculation of network losses is caused that the cost curve of second configuration cuts the first one nearly 3 years earlier. Thus, considering the effect of load growth on calculation of network losses is caused that process of investment return happens faster and subsequent the significant amount of capital is saved. Consequently, load growth has important effect on rate of network losses and subsequent transmission expansion planning and considering it is caused the total expansion cost (expansion and operation costs) is calculated more precisely and correctly.

V. CONCLUSIONS

In this paper, the effect of load growth on the network losses in static transmission network expansion planning is studied using the decimal codification genetic algorithm. With respect to simulation results of two mentioned cases, it can be concluded that load growth plays important role in determining the rate of network losses and subsequent transmission expansion planning. Also, it can be said, considering this important parameter for solution of TNEP problem is caused the network losses cost (operational costs) is calculated more correctly and therefore total expansion cost of network is obtained more precisely. Moreover, considering effect of this parameter is caused that the curve of second configuration cuts the first one earlier and process of investment cost return take places faster. Also, from voltage level of added lines point of view, considering the effect of load growth on network losses is caused that the 400 kV lines is added to the network too, in addition to more expansion of 230 kV lines. In this study, a network loss has been calculated according to DC Load Flow (DCLF). The AC Load Flow (ACLF) using can improve the proposed method because the network losses can be calculated more accurately. Thus, using the ACLF for calculation of the network losses would be our future work in solution of the TNEP problem.

APPENDIX

GA and Required Data

Load growth coefficient = 1.08
Loss cost in now = 36.1 ($/MWh))
Number of initial population = 5
End condition: 1500 iteration after obtaining best fitness (*N*=1500)

REFERENCES

[1] A.R. Abdelaziz, “Genetic Algorithm-Based Power Transmission Expansion Planning”, The 7th IEEE International Conference on Electronics, Circuits and Systems, Vol. 12, pp. 642-645, Dec. 2000.

[2] V.A. Levi, M.S. Calovic, “Linear-Programming-Based Decomposition Method for Optimal Planning of Transmission Network Investments”, IEE Transactions on Generation, Transmission and Distribution, Vol. 140, No. 6, pp. 516-522, 1993.

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

[4] J. Choi, T. Mount, R. Thomas, "Transmission System Expansion Plans in View Point of Deterministic, Probabilistic and Security Reliability Criteria", The 39th Hawaii International Conference on System Sciences, Vol. 10, pp. 1-10, Jan. 2006.

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

[6] S. Binato, M.V.F. Periera, S. Granville, "A New Benders Decomposition Approach to Solve Power Transmission Network Design Problems", IEEE Transactions on Power Systems, Vol. 16, No. 2, pp. 235-240, 2001.

[7] L.L. Garver, "Transmission Net Estimation Using Linear Programming", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-89, No. 7, pp. 1688-1696, 1970.

[8] T. Al-Saba, I. El-Amin, "The Application of Artificial Intelligent Tools to the Transmission Expansion Problem", Electric Power Systems Research, Vol. 62, No. 2, pp. 117-126, 2002.

[9] R. Chaturvedi, K. Bhattacharya, J. Parikh, "Transmission Planning for Indian Power Grid: A Mixed Integer Programming Approach", International Transactions in Operational Research, Vol. 6, No. 5, pp. 465-482, 1999.

[10] J. Contreras, F.F. Wu, "A Kernel-Oriented Algorithm for Transmission Expansion Planning", IEEE Transactions on Power Systems, Vol. 15, No. 4, pp. 1434-1440, 2000.

[11] R.A. Gallego, A. Monticelli, R. Romero, "Transmission System Expansion Planning by an Extended Genetic Algorithm", IEE Transactions on Generation, Transmission and Distribution, Vol. 145, No. 3, pp. 329-335, 1998.

[12] R.A. Gallego, R. Romero, A.J. Monticelli, "Tabu Search Algorithm for Network Synthesis", IEEE Transactions on Power Systems, Vol. 15, No. 2, pp. 490-495, 2000.

[13] K.J. Kim, Y.M. Park, K.Y. Lee, "Optimal Long-Term Transmission Expansion Planning Based on Maximum Principle", IEEE Transactions on Power Systems, Vol. 3, No. 4, pp. 1494-1501, 1988.

[14] G. Liu, H. Sasaki, N. Yorino, "Application of Network Topology to Long Range Composite Expansion Planning of Generation and Transmission Lines", Electric Power Systems Research, Vol. 57, No. 3, pp. 157-162, 2001.

[15] M.V.F. Periera, L.M.V.G. Pinto, "Application of Sensitivity Analysis of Load Supplying Capacity to Interactive Transmission Expansion Planning", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-104, pp. 381-389, 1985.

[16] R. Romero, R.A. Gallego, A. Monticelli, "Transmission System Expansion Planning by Simulated Annealing", IEEE Transactions on Power Systems, Vol. 11, No. 1, pp. 364-369, 1996.

[17] R. Romero, A. Monticelli, "A Hierarchical Decomposition Approach for Transmission Network Expansion Planning", IEEE Transactions on Power Systems, Vol. 9, No. 1, pp. 373-380, 1994.

[18] R. Romero, A. Monticelli, "A Zero-One Implicit Enumeration Method for Optimizing Investments in Transmission Expansion Planning", IEEE Transactions on Power Systems, Vol. 9, No. 3, pp. 1385-1391, 1994.

[19] H. Samarakoon, R.M. Shrestha, O. Fujiwara, "A Mixed Integer Linear Programming Model for Transmission Expansion Planning with Generation Location Selection", Electric Power Systems Research, Vol. 23, No. 4, pp. 285-293, 2001.

[20] E.L. da Silva, H.A. Gil, J.M. Areiza, "Transmission Network Expansion Planning under an Improved Genetic Algorithm", IEEE Transactions on Power Systems, Vol. 15, No. 3, pp. 1168-1174, 2000.

[21] R.C.G. Teive, E.L. Silva, L.G.S. Fonseca, "A Cooperative Expert System for Transmission Expansion Planning of Electrical Power Systems", IEEE Transactions on Power Systems, Vol. 13, No. 2, pp. 636-642, 1998.

[22] J. Yen, Y. Yan, J. Contreras, P.C. Ma, F.F. Wu, "Multi-Agent Approach to the Planning of Power Transmission Expansion", Decision Support Systems, Vol. 28, No. 3, pp. 279-290, 2000.

[23] T. Sum-Im, G.A. Taylor, M.R. Irving, Y.H. Song, "Differential Evolution Algorithm for Static and Multistage Transmission Expansion Planning", IET Generation, Transmission and Distribution, Vol. 3, No. 4, pp. 365-384, 2009.

[24] H. Shayeghi, M. Mahdavi, A. Bagheri, "Discrete PSO Algorithm Based Optimization of Transmission Lines Loading in TNEP Problem", Energy Conversion and Management, Vol. 51, No. 1, pp. 112-121, 2010.

[25] R.A. Gallego, A.B. Alves, A. Monticelli, R. Romero, "Parallel Simulated Annealing Applied to Long Term Transmission Network Expansion Planning", IEEE Transactions on Power Systems, Vol. 12, No. 1, pp. 181-188, 1997.

[26] S. Jalilzadeh, A. Kimiyaghalam, A. Ashouri, "Evaluating the Effects of Uncertainty in Fuel Price on Transmission Network Expansion Planning Using IADPSO Approach", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 7, Vol. 3, No. 2, pp. 1-9, 2011.

[27] R.S. Chanda, P.K. Bhattacharjee, "A Reliability Approach to Transmission Expansion Planning Using Minimal Cut Theory", Electric Power Systems Research, Vol. 33, No. 2, pp. 111-117, 1995.

[28] A.M.L. Silva, L.S. Rezende, L.A.F. Manso, L.C. Resende, "Reliability Worth Applied to Transmission Expansion Planning Based on Ant Colony System," International Journal of Electrical Power and Energy Systems, Vol. 32, No. 13, pp. 1077-1084, 2010.

[29] N.H. Sohtaoglu, “The Effect of Economic Parameters on Power Transmission Planning”, IEEE Transactions on Power Systems, Vol. 13, pp. 941-945, 1998.

[30] B. Graeber, “Generation and Transmission Expansion Planning in Southern Africa”, IEEE Transactions on Power Systems, Vol. 14, pp. 983-988, 1999.

[31] M.S. Kandil, S.M. El-Debeiky, N.E. Hasanien, “Rule-Based System for Determining Unit Locations of a Developed Generation Expansion Plan for Transmission Planning”, IEE Transactions on Generation, Transmission and Distribution, Vol. 147, No. 1, pp. 62-68, 2000.

[32] S.T.Y. Lee, K.L. Hocks, H. Hnyilicza, “Transmission Expansion of Branch and Bound Integer Programming with Optimal Cost Capacity Curves”, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-93, pp. 1390-1400, 1970.

[33] A.S.D. Braga, J.T. Saraiva, “A Multiyear Dynamic Approach for Transmission Expansion Planning and Long-Term Marginal Costs Computation”, IEEE Transactions on Power Systems, Vol. 20, No. 3, pp. 1631-1639, 2005.

[34] S. Jalilzadeh, A. Kazemi, H. Shayeghi, M. Mahdavi, “Technical and Economic Evaluation of Voltage Level in Transmission Network Expansion Planning Using GA”, Energy Conversion and Management, Vol. 49, No. 5, pp. 1119-1125, 2008.

[35] 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, No. 11, pp. 3017-3024, 2008.

[36] H. Shayeghi, M. Mahdavi, “Studying the Effect of Losses Coefficient on Transmission Expansion Planning Using Decimal Codification Based GA”, International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 1, Vol. 1, No. 1, pp. 58-64, 2009.

[37] M. Mahdavi, H. Shayeghi, A. Kazemi, “DCGA Based Evaluating Role of Bundle Lines in TNEP Considering Expansion of Substations from Voltage Level Point of View”, Energy Conversion and Management, Vol. 50, No. 12, pp. 2067-2073, 2009.

BIOGRAPHIES

Meisam Mahdavi received the M.Sc. degree in Electrical Engineering from Zanjan University, Zanjan, Iran, in 2008. Currently, he is a Ph.D. student in Electrical Engineering at University of Tehran, Tehran, Iran. His research interests are in the area of Power System Planning and Operation, Reliability, Electricity Market, and Parameter Identification of Electrical Machines and Transformers.

Elham Mahdavi is a B.Sc. student of Electrical Engineering at Semnan University, Semnan, Iran. Her research interests are Power System Planning and Restructuring.