TRANSMISSION EXPANSION PLANNING CONSIDERING VOLTAGE LEVEL AND NETWORK LOSS USING GENETIC ALGORITHM

Saeed Jalilzadeh[1] Aahad Kazemi[2] Meisam Mahdavi[1] Hosein Haddadian[1]
e-mail: sa_jalilzadeh@yahoo.com e-mail: kazemi@iust.ac.ir e-mail: meysam@mail.znu.ac.ir e-mail: haddadian@mail.znu.ac.ir
1- Zanjan University, Faculty of Engineering, Department of Electrical Engineering, Iran
2- Iran University Science and Technology, Faculty of Engineering, Department of Electrical Engineering, Iran

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ABSTRACT

Up to now, various methods have been presented for solution of the static transmission network expansion planning (STNEP) problem. However, in all of these methods, STNEP problem has been solved regardless to voltage level of transmission lines and role of voltage level in reducing annual loss of the network. In this paper, STNEP has been studied considering voltage level and network loss using decimal codification based genetic algorithm (DCGA).The proposed method is tested on Garvers 6-bus network and an actual transmission network of the Azerbaijan regional electric company, Iran. The results show that considering the network loss in a power system with different voltage levels, decreases the operational costs considerably and the network satisfies the requirement of delivering electric power more safely and reliably to load centers.

I. INTRODUCTION

Transmission network expansion planning (TNEP) is a basic part of power system planning that determines where, when and how many new transmission lines should be installed. Its goal is to minimize the network construction and operational cost, while meeting imposed technical, economic and reliability constraints [1- 3].

Generally, transmission network expansion planning can be classified as static or dynamic. Static expansion determines where and how many new transmission lines should be installed up to the planning horizon. If in the static expansion the planning horizon is separated in several stages we have dynamic planning [4, 5]. One of the first approaches for solving the STNEP problem was proposed by Garver in 1970 [6]. Later, the different methods such as GRASP [3], Bender decomposition [4], HIPER [5], genetic algorithm [1, 6, 7], simulated annealing [8] and Tabu search [9] were proposed to solve the problem. In all of these methods, STNEP problem has been solved regardless to voltage level of transmission lines. In [10], both of network expansion costs and transmitted power through the lines have been included in objective function. The objective function is different from those which are explained in [5 - 10], but the voltage level of transmission lines and also the network loss has not been investigated. In [11], the voltage level of transmission lines has been considered as a subsidiary factor. Its objective function includes expansion and generation costs and also one of the reliability criteria, i.e., Power Not Supplied (PNS) has been considered in objective function, but the network loss has not been considered. In this paper, due to different voltage levels in transmission network which causes different annual loss, STNEP has been studied considering voltage level of transmission lines and the network loss using genetic algorithm. Thus, the loss cost and also the expansion cost of related substations from the voltage level point of view have been included in the objective function. The mathematical model of the STNEP problem is represented in section 2. In section 3, decimal codification genetic algorithm and also chromosome structure has been completely described. In section 4, the proposed idea has been applied to Garver's 6-bus network and real transmission network of the Azerbaijan regional electric company.

II. MATHEMATICAL MODEL OF THE PROBLEM

With respect to voltage level of transmission lines and subsequent expansion cost of substations, objective function is:

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

and:

$$CL_{ij} = CL_{1ij} + CL_{2ij} \tag{2}$$

$$C_{loss} = loss * C_{loss_u} * k_{loss} * 8760 \tag{3}$$

where C_T is total expansion cost of network, CL_{1ij} is construction cost of 230 kV line in corridor i-j, CL_{2ij} is construction cost of 400 kV line in corridor i-j, CS_k is expansion cost of kth substation, C_{loss} is annual loss cost of network, *loss* is total loss of network, C_{loss_u} is loss cost per generation ($\$/Mwh$), k_{loss} is loss coefficient, Ω is set of all corridors, Ψ is set of all substations, n_{ij} is number of all new circuits in corridor i-j. The calculation method of k_{loss} and CS_k has been presented in Appendices A and B, respectively. The problem constraints are:

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

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

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

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

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

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

where S, f, g, d, N, $\theta, \gamma_{ij}, n_{ij}^0, \overline{n_{ij}}, \overline{g}, \overline{f_{ij}}$, *Line_Loading* and LL_{max} are branch-node incidence matrix, active power matrix in each corridor, generation vector, demand vector, number of network buses, phase angle of each bus, total susceptance in corridor i-j, number of initial circuits in corridor i-j, maximum number of constructible circuits in corridor i-j, maximum generated power in generator buses, maximum active power in corridor i-j, Loading of lines at planning horizon year, maximum loading of lines at planning horizon year respectively. Here, the objective function is different from [4 - 9] and in the problem constraints, the change of $\overline{f_{ij}}$ according to different voltage levels and *Line_Loading* have been considered as two addition constraint. In our research, to solve this problem, the decimal codification genetic algorithm (DCGA) has been used due to flexibility, simple implementation and the advantages which were mentioned in [7].

III. DECIMAL CODIFICATION GENETIC ALGORITHM AND CHROMOSOME STRUCTURE

Standard genetic algorithm is a random search method that can be used to solve non-linear system of equations and optimize complex problems. This algorithm can be used to solve many practical problems such as transmission network expansion planning. According to [7], there are three methods for coding the transmission lines in genetic algorithm: 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 this paper the third method has been used to prevent the production of completely different offspring from their parents and subsequent occurrence of divergence in mentioned algorithm [7]. 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. Accordingly, selected chromosome considering different voltage levels for transmission lines and also simplicity in programming is divided to following parts (as shown in Figure. 1):

In part I each gene includes number of transmission circuits (both of constructed and new circuits) in each corridor. Each gene in part II is related to the gene of voltage level that is given in part I. It should be mentioned that the binary digits of 0 and 1 have been used for representing voltage levels of 230 and 400 kV respectively. A typical chromosome for a network with 6 corridors has been shown in Figure 1. In the first corridor one 400 kV transmission circuit, in the second corridor two 230 kV transmission circuits, and finally in the sixth corridor two 230 kV transmission circuits have been predicted.

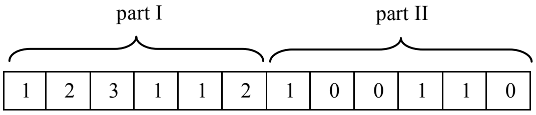

Figure 1. Typical chromosome.

IV. RESULTS AND DISCUSSION

The proposed idea is test on two networks. First case is Garvers 6-bus network and second case is transmission network of the Azerbaijan regional electric company. In continuation test results of proposed algorithm on two mentioned networks will be described.

A. Garver's 6-Bus Network

First network that is studied in this paper is Garver's network. This network is shown in Figure 2 and its details are described in [6]. The configuration of this network is considered according to table 1.

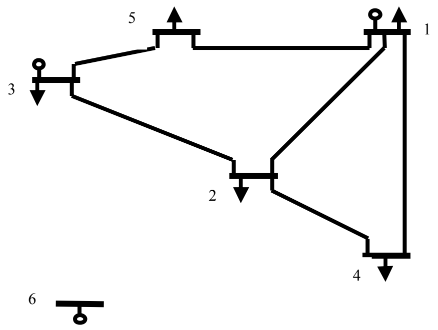

Figure 2. Garver's 6-bus network.

TABLE 1
CHARACTERISTICS OF THE LINES AND SUBSTATIONS

Corridor	Voltage Level (kV)	Substation	Voltage Level (kV)
1-2	230	1	230/63
1-4	230	2	400/230
1-5	230	3	400/63
2-3	400	4	230/63
2-4	230	5	400/230
3-5	400	6	400/230

The planning horizon year and the maximum loading are as: 1) Planning horizon year is 15 (year 2021). 2) Maximum loading of lines and substations is 50% at planning horizon year. After examination of proposed method on case study following results were obtained (lines which must be added to the network up to planning horizon year):

TABLE 2

FIRST CONFIGURATION: NEGLECTING THE LOSS

Corridor	Voltage Level (kV)	Number of Circuits
2-6	230	4
3-5	400	2
4-6	230	4
5-6	230	1

TABLE 3

EXPANSION COST OF NETWORK WITH THE FIRST CONFIGURATION

Expansion Cost of Substations	0 million dollars
Expansion Cost of Lines	96.175 million dollars
Total Expansion Cost of Network	96.175 million dollars

TABLE 4

SECOND CONFIGURATION: CONSIDERING THE LOSS

Corridor	Voltage Level (kV)	Number of Circuits
2-6	400	4
3-5	400	2
4-6	230	3

TABLE 5

EXPANSION COST OF NETWORK WITH THE SECOND CONFIGURATION

Expansion Cost of Substations	0 million dollars
Expansion Cost of Lines	108.415 million dollars
Total Expansion Cost of Network	108.415 million dollars

According to tables 3 and 5 the expansion cost of substations is 0. The reason is that voltage level of proposed lines for expansion of the network has been existed in their both first and end substations therefore substations don’t require to expansion from the voltage level point of view. Sum of expansion costs and annual loss cost (total expansion cost) of expanded network with two proposed configurations have been shown in Figure 3. The total expansion cost of network with second configuration (most of its lines are 400 kV) is more than that of the first one until about 6 years after planning horizon, but afterward, the total expansion cost with first configuration (most of its lines are 230 kV) becomes more than another one. The reason is that the loss cost of second configuration (most of the lines are 400 kV) becomes less than that of the first one (most of the lines are 230 kV), about 6 years after planning horizon. If the network is studied neglecting the loss the first configuration is more economic, but if the network is studied after expansion time (the network loss is considered), the second configuration is more economic because it has a return of investment after the 6th year of expansion. Capital saving profile for this configuration in comparison with the first one is shown in Figure 4. The first configuration becomes overload 14 years after expansion time while second configuration is overloaded 16 years after expansion time. Therefore, from the transmitted power point of view through the lines, the second configuration is more suitable than the first one.

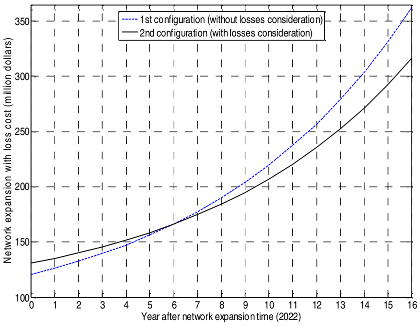

Figure 3. Sum of expansion costs and annual loss cost of the network with two proposed configurations.

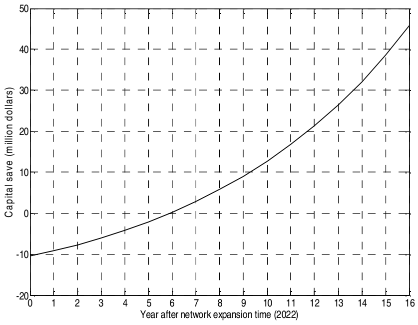

Figure 4. Capital saving profile of the second configuration in comparison with first one.

B. Transmission Network of the Azerbaijan Regional Electric Company

Second network that is studied in this paper is transmission network of the Azerbaijan regional electric company. This actual network has been located in northwest of Iran and is shown in Figure 5. The network characteristics are given in Appendix C. In here, the planning horizon year and the maximum loading have been considered as: 1) Planning horizon year is 15 (year 2020). 2) Maximum loading of lines and substations is 30% at planning horizon year.

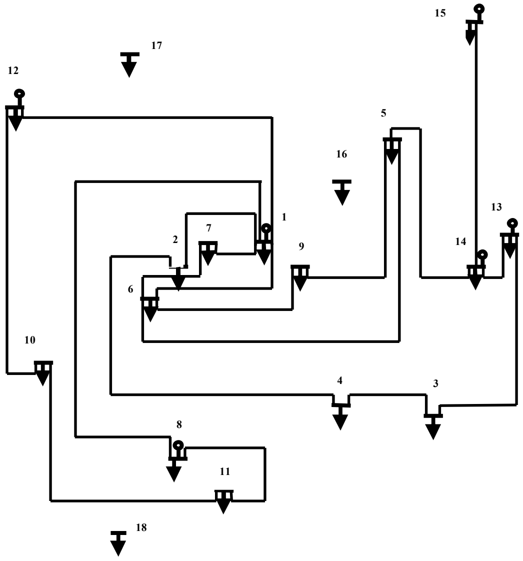

Figure 5. Transmission network of the Azerbaijan regional electric company

After examination of proposed method on this case study following results were obtained (lines which must be added to the network up to planning horizon year):

TABLE 6
FIRST CONFIGURATION: NEGLECTING THE LOSS

Corridor	Voltage Level (kV)	Number of Circuits
1-9	230	2
2-8	400	2
4-8	230	2
6-8	230	2
7-8	400	1
8-10	230	2
5-15	230	1
1-11	230	1
1-18	230	1
10-18	230	1
11-18	230	2

TABLE 7
EXPANSION COST OF NETWORK WITH THE FIRST CONFIGURATION

Expansion Cost of Substations	25.6 million dollars
Expansion Cost of Lines	72.019 million dollars
Total Expansion Cost of Network	96.619 million dollars

TABLE 8
SECOND CONFIGURATION: CONSIDERING THE LOSS

Corridor	Voltage Level (kV)	Number of Circuits
1-9	230	2
2-8	400	2
4-8	230	2
6-8	230	2
7-8	400	1
8-10	230	2
5-15	230	2
1-11	230	1
1-18	230	1
10-18	230	1
11-18	230	2

TABLE 9
EXPANSION COST OF NETWORK WITH THE SECOND CONFIGURATION

Expansion Cost of Substations	25.6 million dollars
Expansion Cost of Lines	73.679 million dollars
Total Expansion Cost of Network	99.279 million dollars

Total expansion cost of expanded network with the two proposed configurations has been shown in Figure 6. It seems that the first configuration is more economic but if the network is studied about 8 years after planning horizon time the second configuration is more economic. Thus, in the second configuration investment cost is returned after the 8th year of the expansion time. Capital saving profile for this configuration in comparison with the first one is shown in Figure 7. According to Figure 7, it should be noted that expanded transmission network with above-mentioned configuration will save capital about 33 million dollars 16 years after expansion time in comparison with the first configuration totally. This value is about 33% of total expansion cost of network that is considerably, while expansion cost of network with this configuration is different with the first configuration a little (less than 3 million dollars). Therefore it is realized that the network losse play important role in determining of network configuration and arrangement. From voltage level of added lines point of view, expansion of the 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.

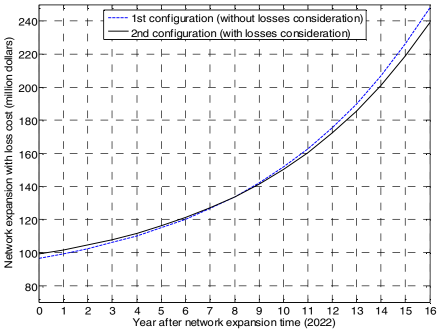

Figure 6. Sum of expansion costs and annual loss cost of the network with two proposed configurations.

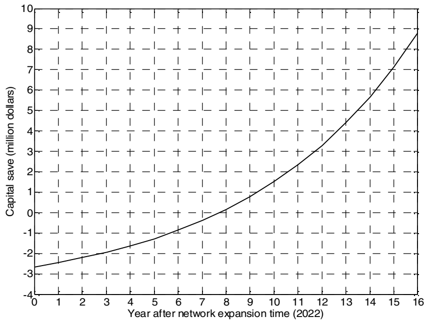

Figure 7. Capital saving profile of the second configuration in comparison with first one.

VI. CONCLUSION

According to simulation results, it is concluded that the network loss and voltage level of lines play important role in determining of network configuration and arrangement. Thus, considering voltage level of lines and subsequent the network loss in expansion planning of a network is caused more *230 kV* and *400 kV* lines are added to network. Although expansion cost of the network with considering voltage level and subsequent the network loss becomes more, but due to be less of the network loss, total expansion cost of network (the sum of expansion cost of lines and substations and network losses cost) is decreased in long-term planning. In addition, networks which are expanded by more *400 kV* lines are economic in long-term and from transmitted power through the lines point of view is overloaded later.

VII. APPENDIX

A. Calculation Method for Loss Coefficient (k_{loss})

This coefficient that simulates ratio of load changes to peak load is equal to area square of under the load duration curve (LDC). Load duration curve for a typical network is shown in Figure 8.

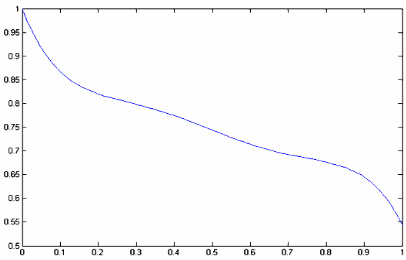

Figure 8. Load duration curve for a typical network.

B. Calculation Method for Expansion Cost of Substations (CS_k)

In the transmission network expansion planning it is assumed that power plants and substations have enough adequacy for providing required power of loads and only the lines should be expanded. Thus, in here, substations have been expanded only from voltage level point of view. For example, construction of a 400 kV line in corridor which it's first and end substations are 230/63 kV causes expansion of these substations to 400/230 kV. For calculation of this cost, DC Load Flow (DCLF) program is run with presence of candidate lines. Then according to transmitted power trough the lines and using KCL the power of transmission substations is calculated. In accordance with this obtained powers and the standard capacities of transformers, number of required transformers is determined. Therefore, total expansion cost of substations can be calculated.

C. Characteristics of Case Study System

TABLE 10
ARRANGEMENT OF LINES

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

TABLE 11
ARRANGEMENT OF SUBSTATIONS, GENERATION AND LOAD

Substation	Voltage Level (kV)	Load (MW)	Generation (MW)
1	400/230	378	715
2	230/132	202	0
3	400/230	42	0
4	230/63	53	0
5	230/132	45	0
6	230/132	64	0
7	230/132	88	0
8	230/132	49	514
9	230/132	70	0
10	230/132	134	0
11	230/132	125	0
12	230/132	256	288
13	230/63	78	101
14	400/230	46	60
15	230/63	45	101
16	230/20	11	0
17	230/132	14	0
18	230/132	79	0

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