TRANSMISSION NETWORK ADEQUACY OPTIMIZATION USING GENETIC ALGORITHM

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

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ABSTRACT

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 added to the network. Up to now, various methods have been presented to solve the static transmission network expansion planning (STNEP) problem. But in all of these methods, lines adequacy rate has not been represented at the end of planning horizon, i.e., expanded network misses adequacy after some times and needs to be expanded again. In this paper, expansion planning has been implemented by merging lines loading parameter in the STNEP and inserting investment cost into the fitness function constraints using genetic algorithm. Expanded network will possess a maximum adequacy to provide load demand and also the transmission lines overloaded later. Finally, adequacy index could be defined and used to compare some designs that have different investment cost and adequacy rate. In this paper, the proposed idea has been implemented on the Garvers network. The results show that the network will possess maximum efficiency economically.

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. TNEP should satisfy required adequacy of the lines for delivering safe and reliable electric power to load centers along the planning horizon [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]. The majority of the generating plants are located far from the load centers Thus the investment for transmission network is huge. Due to this fact static transmission network expansion planning (STNEP) problem should be evaluated carefully.

After presenting Garvers paper in 1970, various methods such as GRAS [2], bender decomposition [5], genetic algorithm [1, 6, 7, 8], Tabu search [9], HIPER [10], branch and bound algorithm [11], sensitivity analysis [12] and simulated annealing [13] were proposed to solve the STNEP problem. But in these methods, transmission line loading rate has not been mentioned. Loading rate of Lines will assign overloading time and miss network adequacy after the end of planning horizon.

The network adequacy is necessary to provide load demands when the network is expanding because its lack (i.e. lines overloading) caused to load interrupting. Consequently, if expanded network is more reliable and therefore its lines overloaded later, will be more economic and caused to utilize favorably.

But it is obvious that the transmission network adequacy is proportional to the investment cost. In fact, the network adequacy increases by increasing the investment cost and using the exact planning and the proper genetic algorithm. On the other hand, with a low costing, the network operates weakly to support load demand and becomes overloaded early. Therefore, with compromising between two parameters, i.e. investment cost and network adequacy rate and finally defining a total index, static transmission network expansion planning can be implemented in order to have a network with maximum efficiency technically and economically.

In this paper, expansion planning has been implemented by inserting lines loading parameter in the STNEP problem and investment cost in fitness function constraints using genetic algorithms. Accordingly, expanded network will possess a maximum adequacy to support load demand and also the transmission lines overloaded later. Finally, adequacy index could be defined and used to compare some designs that have got different investment cost and adequacy rate.

II. OBJECTIVE FUNCTION AND SOLUTION METHOD OF THE PROBLEM

Calculating the economic value of lines annual adequacy is very intricate and affected by multiple parameters. Therefore, the network expansion investment cost and lines annual adequacy have been separated from each other. In a new approach, investment cost is inserted to problem constraints and fitness function will only include the network adequacy rate. Thus, the fitness function can be defined as follows:

$$Fitness = T_{overload} \tag{1}$$

where:

Fitness: Fitness function in genetic algorithm approach.
$T_{overload}$: Required time for missing the expanded network adequacy (year).

It is assumed that if only a line of the network is overloaded in each year, network adequacy is missed.

According to [5, 7] the problem constraints are:

$$f_{ij} - \gamma_{ij}(n_{ij}^0 + n_{ij})(\theta_i - \theta_j) = 0 \tag{2}$$

$$Sf + g - d = 0 \tag{3}$$

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

$$C \le C_{\max}$$

N-1 Safe Criterion

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

where:

S: Branch-node incidence matrix.
f: Active power matrix in each corridor.
g: Generation vector.
d: Demand vector.
N: Number of network buses.
θ: Phase angle of each bus.
γ_{ij} : Total susceptance 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.
$\overline{f_{ij}}$: Maximum active power in corridor i-j.
$C_{\max}$: Maximum investment for expanding the network.
Ω : Set of all corridors.

By defining the fitness function as relation (1), an expansion design will be acquired that represents possible maximum adequacy according to a specified investment cost ($C_{\max}$).

In this paper, the goal is obtaining number of required circuits for adding to the network until it is brought to a maximum adequacy with minimum cost during one specified horizon year. Accordingly, the unknowns of the problem are discrete time parameters. Therefore, optimization problem will be an integer programming problem that some various methods such as classic mathematic and non-classic mathematic exist for solving this problem. In this research, the decimal codification genetic algorithm (DCGA) has been used due to flexibility, simple implementation and the advantages that are mentioned in [6].

III. DECIMAL CODIFICATION GENETIC ALGORITHM

Standard genetic algorithm is a random search method that can be used to solve non-linear system of equations and to optimize complex problems. The principle of this algorithm is according to the selection of individuals. It does not need a good initial estimation for the sake of problem solution, In other words, the solution of a complex problem can be started by weak initial estimations and then be corrected in evolutionary process of fitness [14].

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. The genetic algorithm generally includes the three fundamental genetic operators of reproduction, crossover and mutation. These operators conduct the chromosomes toward better fitness.

For increasing of convergence speed and simple implementation, a new idea has been used for creating the chromosome and performance of the operators. According to this idea, each chromosome is a set of non-minus integer numbers.

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 then changes its value randomly. Reproduction operator, similar to standard form, produces each chromosome proportional to value of its objective function. Therefore, the chromosomes which have better objective functions will be selected with more probable than other chromosomes for the next population (Elitist Strategy).

IV. CHROMOSOME STRUCTURE OF THE PROBLEM

According to [6], 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 owing to prevent the production of completely different offspring from their parents and subsequent occurring of divergence in mentioned algorithm [6]. Thus,

each gene in the selected chromosome includes number of transmission circuits (the both of constructed and new circuits) in each corridor. Figure 1 illustrates a typical chromosome with 12 corridors.

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

Figure 1. Typical chromosome

Finally, the flowchart of proposed approach has been represented in Figure 2.

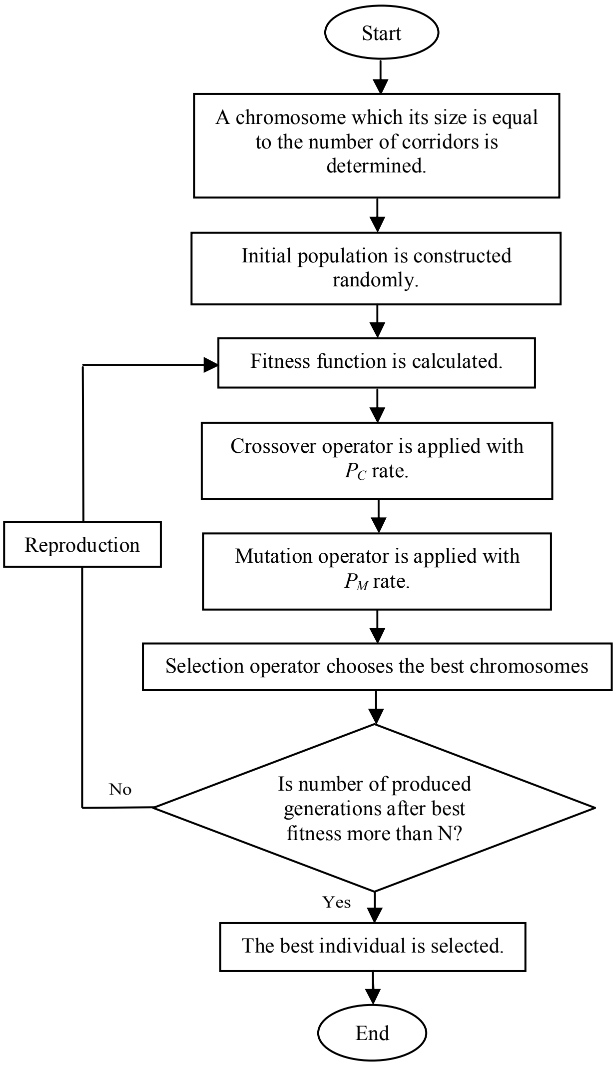

Figure 2. Flowchart of the proposed method

V. CASE STUDY

The test network, in this paper, is Garvers network. This network is shown in Figure 3 and its details are described in [7]. In this network, existed lines are 230 kV and substations 1, 3 and 6 are generator substations. It must be mentioned that the planning horizon year is 2016 (6 years later).

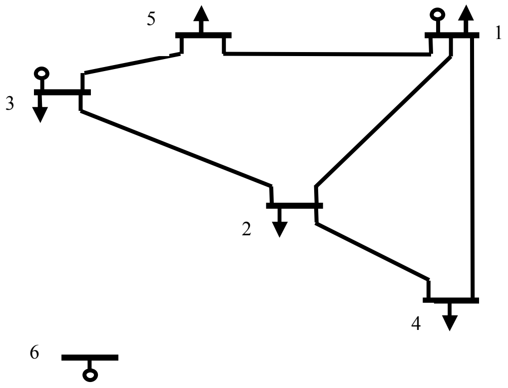

Figure 3. Garvers 6-bus network

VI. SIMULATION RESULTS

By implementing the proposed method on the network according to various investment costs ($C_{\max}$ changes between 50 to 100 million dollars by 10 million steps), the results are obtained as follows (numbers into the tables are required lines for adding to the network until planning horizon year):

TABLE 1
ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 50 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	3	47.432 million dollars
3-5	2	
4-6	2	
Time of missing the network adequacy (T_{overload}): 12 years after the expansion (year 2028)		

TABLE 2
ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 60 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	3	54.863 million dollars
3-5	2	
4-6	3	
Time of missing the network adequacy (T_{overload}): 14 years after the expansion (year 2030)		

TABLE 3
ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 70 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	4	67.432 million dollars
3-5	3	
4-6	3	
Time of missing the network adequacy (T_{overload}): 16 years after the expansion (year 2032)		

TABLE 4

ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 80 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	4	74.863 million dollars
3-5	3	
4-6	4	
Time of missing the network adequacy (T_{overload}): 18 years after the expansion (year 2034)		

TABLE 5

ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 90 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	4	82.667 million dollars
3-5	2	
4-6	2	
5-6	1	
Time of missing the network adequacy (T_{overload}):19 years after the expansion (year 2035)		

TABLE 6

ARRANGEMENT OF THE NETWORK WITH RESPECT TO C_{MAX} = 100 MILLION DOLLARS

Corridor	Number of Circuits	Expansion Cost
2-6	3	94.230 million dollars
3-5	2	
3-6	1	
4-6	4	
5-6	1	
Time of missing the network adequacy (T_{overload}): 20 years after the expansion (year 2036)		

It is noted that, by increasing the maximum investment cost, required lines which are appended to the network increase and the network lines are overloaded later. However, it seems that the higher relative adequacy of the network may be acquired with lower relative investment cost. Network adequacy versus network expansion cost has been shown in Figure 4.

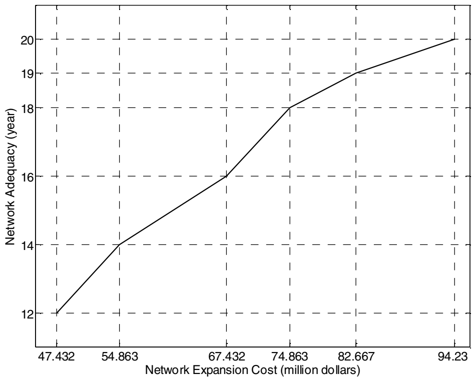

Figure 4. Adequacy curve with respect to network expansion cost

As shown in Figure 4, an increase in higher investment cost ($C_{\max}$ =80-100), changes the network adequacy slightly. Therefore, a parameter, named adequacy index on expansion cost rate, is defined for obtaining best design according to the investment cost and the network adequacy. This parameter is equal to network adequacy rate (years) division to the investment cost. Therefore, a high value is desirable for this index. This index has been acquired according to various investment costs presented in tables 1 to 6, as shown in Figure 5.

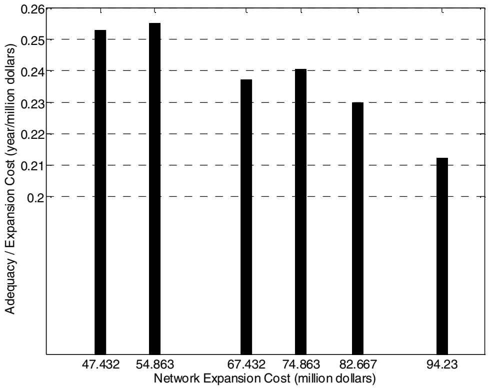

Figure 5. The curve of adequacy index on the expansion cost with respect to various the investment costs

According to Figure 5, the optimized point is 54.863 million dollars for the investment cost.

VII. CONCLUSION

By inserting the line adequacy parameter in the fitness function of STNEP problem, an optimized arrangement is acquired for the network expansion using genetic algorithm that is proportional to a specified investment cost value.

This arrangement possesses a maximum adequacy for feeding the load. The obtained conclusions from adequacy-cost curve show that a more robust network with respect to lines overloading has not been obtained proportional to more investment (indeed, adding more new lines to the network). Finally, using the adequacy index on the expansion cost, an optimized plan is acquired with less investment cost relatively, according to technical (line adequacy) and economic (investment cost) constraints.

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