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Optimization of Transmission Lines Loading in TNEP Using Decimal Codification Based GA

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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 till 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 considered 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 costs and adequacy rates. In this paper, the proposed idea has been tested on the Garvers network. The results show that the network will possess maximum efficiency economically.

Keywords--Adequacy Optimization, Transmission Expansion Planning, 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. Its task is to minimize the network construction and operational cost, while meeting imposed technical, economic and reliability constraints. 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. Transmission expansion planning is a hard and highly non-linear 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, proposed different approaches for solution of this problem considering various parameters such as uncertainty in demand [5], reliability criteria [4, 26, 27], and economic factors [28]. Also, some of them investigated this problem and generation expansion planning together [29, 30]. Recently, different methods such as GRASP [3], Bender decomposition [6], HIPER [17], branch and bound algorithm [31], sensitivity analysis [15], genetic algorithm [1,11,20], simulated annealing [16,25] and Tabu search [12] have been proposed for the solution of STNEP problem. In all of them, transmission lines loading rate has not been studied. Loading rate of lines will assign overloading time and miss network adequacy after the end of planning horizon. In Ref. [8], authors proposed a neural network based method for solution of the TNEP problem with considering both the network losses and construction cost of the lines. But the loading rate of transmission lines 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 lines loading. In addition, the objective function is different from those which are represented in [6,11-12,15-17,20,31]. However, lines loading in transmission network have not been studied. In Ref. [32], 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 energy. Moreover, expansion planning has been studied as dynamic type and the lines adequacy has not been considered. Finally, in pervious author's papers [33, 34], the expansion cost of substations with the network losses have been considered for the solution of STNEP problem. The results evaluation in [33] was shown that the network with considering higher voltage level save capital investment in the long-term and become overload later. In [34], it was shown that the total expansion cost of the network was calculated more exactly considering effects of the inflation rate and load growth factor and therefore the network satisfies the requirements of delivering electric power more

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safely and reliably to load centers. However, the lines loading in transmission expansion planning has not been studied.

The lines adequacy of network 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 lines adequacy of transmission network is proportional to the investment cost. In fact, the lines adequacy is increased 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. Thus, 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 investigated by including 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.

This paper is organized as follows: Objective function and solution method of the problem is given in Sec. 2. Section 3 describes completely chromosome structure and the proposed GA based method for solution of the STNEP problem. The method of choosing selection, crossover and mutation operators for solving the STNEP problem is described in Sec. 4. Characteristics of case study and simulation results are given in Sec. 5. Finally, in Sec. 6 conclusion is represented.

II. OBJECTIVE FUNCTION AND SOLUTION METHOD OF THE PROBLEM

Since economic value calculation of lines annual adequacy is very intricate and affected by multiple parameters and its addition to network expansion investment cost is acquired with high determination, therefore, theses two parameters separate from each other, and correspondingly, fitness function will be expanded lines adequacy rate. In a new approach, investment cost is inserted to problem constraints to control lines adequacy growing by entering maximum cost for the network expansion. Therefore, the fitness function could be defined as follows:

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

Where,

$Fitness$: Fitness function in genetic algorithm approach.

$T_{overload}$: Required time for missing the expanded network adequacy (year).

It should be mentioned that with performing DC load flow to load growth for years after expansion, in each year that only a line of the network is overloaded, network adequacy is missed. 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 (see Refs. [5, 33] for more details):

$$Sf + g - d = 0 \tag{2}$$

$$f_{ij} - \gamma_{ij}(n_{ij}^0 + n_{ij})(\theta_i - \theta_j) = 0 \tag{3}$$

$$0 \le n_{ij} \le \overline{n_{ij}} \tag{4}$$

$$C \le C_{\max} \tag{5}$$

$$\text{N-1 Safe Criterion} \tag{6}$$

Where, $(i,j) \in \Omega$ and:

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 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*.

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

$C_{\max}$: Maximum investment for expanding the network.

Ω : Set of all corridors

By defining the foregoing fitness function, a design for transmission network expansion could be acquired to represent a maximum probabilistic adequacy according to a maximum value of specified investment cost ($C_{\max}$). In this paper, the goal is obtaining number of required circuits for appending to the network until it is brought to a maximum adequacy with minimum cost during one specified horizon year. Thus, problem parameters 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 [33].

III. DECIMAL CODIFICATION BASED GA AND CHROMOSOME STRUCTURE OF THE 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 [33-34]. The genetic algorithm generally includes the three fundamental genetic operators of reproduction, crossover and mutation. These operators conduct the chromosomes toward better fitness. A new idea has been applied in the solution whose parameters are integer number for creating the chromosomes and operators performance that caused to increasing convergence speed and simplification. According to this idea, each chromosome is a set of non-minus integer numbers.

There are three methods for coding the transmission lines based on the genetic algorithm method [11, 33, 34]:

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 [34]:

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).

In this work, each gene in the chromosome includes number of transmission circuits (the both of constructed and new circuits) at each corridor. Fig. 1 illustrates a typical chromosome with 12 corridors.

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

Fig. 1. A typical chromosome

Also, the flowchart of proposed approach has been represented in Fig. 2.

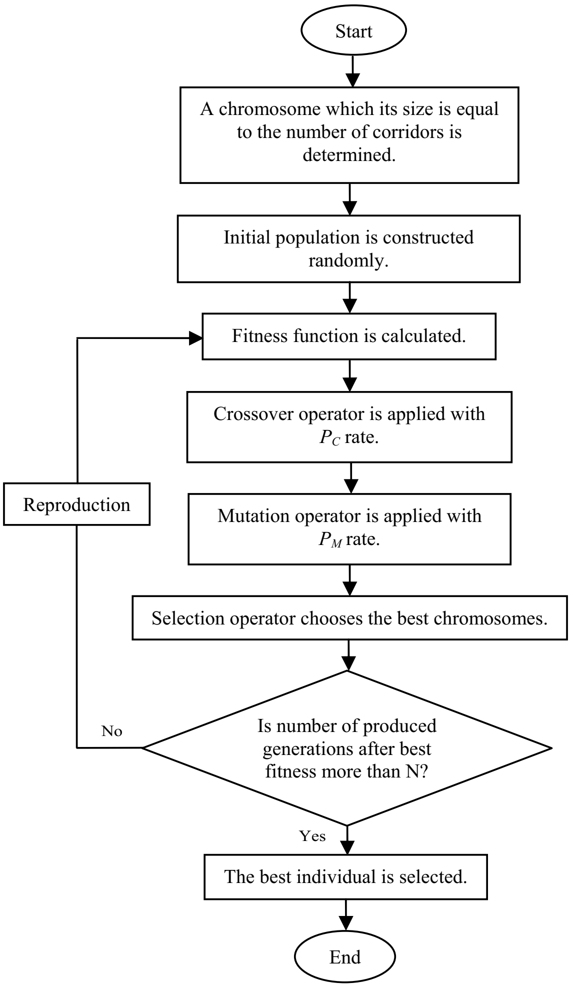

Fig. 2. Flowchart of the proposed method

IV. Selection, Crossover and Mutation Process

This 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. After selection of the pairs of parent strings, the crossover operator is applied to each of these pairs.

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 crossover is used with probability of 0.9.

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 to 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 loss 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. In this work mutation is used with probability of 0.1 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. In this study, 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 15000 generations has chosen.

V. RESULTS AND DISCUSSION

To prove the validity of the proposed planning technique, it was applied to the Garver's 6-bus system. The configuration of the test system before expansion is given in Fig. 3. The length of possible corridors and construction cost of 230 kV lines has been given in Tables 1 and 2 respectively. In this network, existed lines are 230 kV with capacity 400 MW. Resistance and leakage reactance per kilometer of each line are 0.00012 and 0.0004, respectively. Substations 1, 3 and 6 are generator busses that their generation limit are 100 MW, 250 MW and 450 MW, respectively. The load data has also given in Table 3. Finally the planning horizon year is 2018 (10 years ahead).

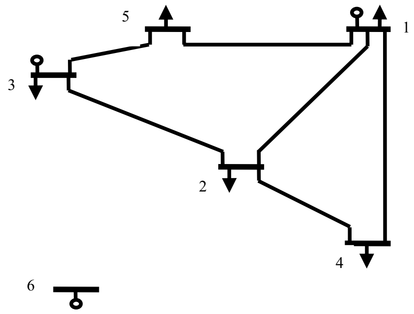

Fig. 3. Garver's 6-bus network

TABLE I
CONFIGURATION OF THE NETWORK

From bus	To bus	Length (Km)
1	2	100
1	3	95
1	4	150
1	5	60
1	6	170
2	3	55
2	4	110
2	5	65
2	6	75
3	4	155
3	5	50
3	6	120
4	5	157
4	6	85
5	6	160

TABLE II
CONSTRUCTION COST OF 230 KV LINE

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

TABLE III
ARRANGEMENT OF THE LOAD

Bus	Load (MW)	Bus	Load (MW)
1	80	4	160
2	240	5	240
3	40	6	0

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 IV
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=50 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	3	47.432 M$US
3-5	2	
4-6	2	
Year of missing the network adequacy ($T_{overload}$): 12 years after the expansion (year 2030)		

TABLE V
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=60 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	3	54.863 M$US
3-5	2	
4-6	3	
Year of missing the network adequacy ($T_{overload}$): 14 years after the expansion (year 2032)		

TABLE VI
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=70 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	4	67.432 M$US
3-5	3	
4-6	3	
Year of missing the network adequacy ($T_{overload}$): 16 years after the expansion (year 2034)		

TABLE VII
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=80 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	4	23.7 M$US
3-5	3	
4-6	4	
Year of missing the network adequacy ($T_{overload}$): 18 years after the expansion (year 2036)		

TABLE VIII
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=90 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	4	82.667 M$US
3-5	2	
4-6	2	
5-6	1	
Year of missing the network adequacy ($T_{overload}$): 19 years after the expansion (year 2037)		

TABLE IX
PROPOSED CONFIGURATION AND COST FOR NETWORK EXPANSION WITH RESPECT TO C_{max}=100 MILLION $

Corridor	Number of required circuits	Expansion cost
2-6	3	94.230 M$US
3-5	2	
3-6	1	
4-6	4	
5-6	1	
Year of missing the network adequacy ($T_{overload}$): 20 years after the expansion (year 2038)		

It is noted that, by investment cost limit increasing, required lines which could be appended to the network is increased and overloaded later. However, it seems that the network adequacy may be acquired with low relative investment cost. Network adequacy versus network expansion cost has been depicted in Fig. 4.

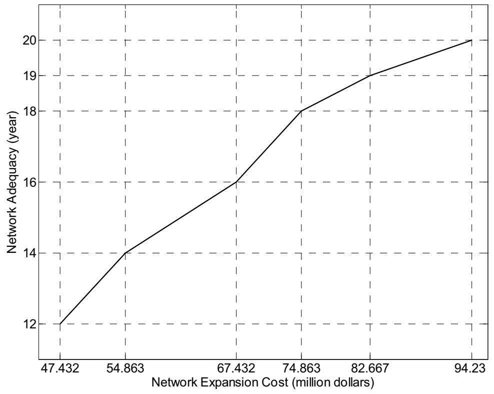

Fig. 4. Adequacy curve with respect to network expansion cost

As shown in Fig. 4, increasing in higher investment cost (C_{max}=80-100), changes the network adequacy slightly. Thus, 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 the network adequacy rate (years) per 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 Fig. 5. According to Figure 5, the optimized point is 54.863 million dollars for the investment cost.

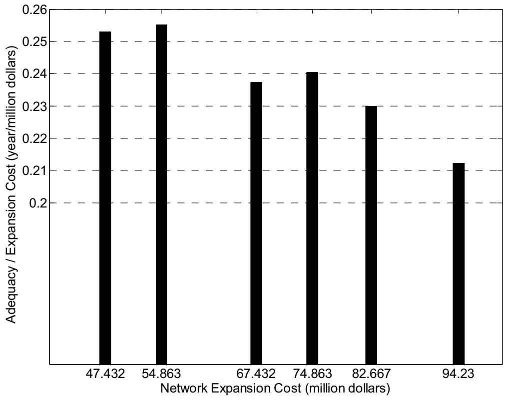

Fig. 5. The curve of adequacy index on the expansion cost with respect to various the investment costs

V. CONCLUSION

By including 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 for 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.

APPENDIX

A. GA and other required data

Load growth coefficient = 1.07
Number of initial population = 5
End condition: 1500 iteration after obtaining best fitness (N=1500).

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