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A GENETIC ALGORITHM BASED TRANSMISSION EXPANSION PLANNING

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Abstract: This paper presents a new approach for formulating and solving the transmission expansion planning (TEP) problem. The main improvement is in introducing the corona power loss in the objective function and operating constraints. Introducing this new term reveals a nonlinear objective function which is solved by the genetic algorithms technique (GA). The corona power loss term has been tried for a practical number of sub-conductors (1, 2, 3, and 4) and practical sub-conductor radii. In order to test and justify this new formulation, it has been applied to Garver's 6-bus test sytem The outcome of the expansion process is the optimal scenario which defines the number of lines to be added. For each added line, the number and radii of sub-conductors, phase spacing, height, and bundle radius are also generated as a result of the expansion process. When compared to previously reported TEP attempts, simulation results show a reduction in the total cost of the expanded network

Key Words: Planning, Transmission lines, Genetic Algorithms, Optimization, Corona, Power Loss.

1. INTRODUCTION

The general form of the transmission expansion-planning (TEP) problem can be stated as follows, given: (1) the load-generation pattern at a target year, (2) the existing network configuration, (3) all possible routes (length and rights- of- way), and (4) line types, estimate the optimum objective function in which a new term, i.e. the cost of corona power loss, is considerd.

The revised objective function is minimized subject to constraints that assure the transmission capacity for load supply. It can be written as:

<u>Minimize:</u>

$$\Sigma \text{ cost of investment} + \Sigma \text{ cost of ohmic loss} + \Sigma \text{ cost of corona loss} \quad (1)$$

The cost of corona loss is expressed as (Maruvada, 2000):

$$\Sigma \text{ cost of corona loss} = K_C \sum_{j=1}^{AD} \frac{CL_j \times l_j}{b} \quad (2)$$

where:

network which feeds the loads with the required degree of quality and realizes a pre-specified reliability level. Two main approaches have been adopted in solving the TEP problem. The first approach is based on mathematical programming or artificial intelligence techniques (optimization techniques) while the second approach is a heuristic one.

To the authors' knowledge, all TEP approaches reported in the literature formulated their objective functions and the corresponding constraints to account only for the cost of investment and/or the cost of ohmic power loss. Linear, integer, mixed integer, quadratic, zero-one implicit enumeration, nonlinear, simulated annealing (SA), genetic algorithm (GA), and Tabu search (TS) programming were used as tools to solve the TEP problem [1-12]. In the present paper, a new formulation of the TEP problem, in which the corona power loss has been added to the objective function, is presented. A GA algorithm is utilized to minimize the objective function subject to the system constaints

2. MATHEMATICAL MODELING OF TEP

The TEP problem objective function reported in the literature takes into account the cost of investment of new lines and the cost of ohmic power loss of existing and new lines. In this paper, the authors propose a revised formulation of the

$$CL_j(kW/km) = \sum_{m=1}^{3} 10^{\frac{CL_{jm}(dB)}{10}} \quad (3)$$

$CL_{jm}(dB)=$

$$14.2 + 65\log\frac{E_{jm}}{18.8} + 40\log\frac{d}{3.51} + K_1 \cdot \log\frac{n}{4} + K_2 + \frac{A}{300} \quad (4)$$

where:

$$K_1 = 13 \quad for\ n \le 4$$
$$= 19 \quad for\ n > 4 \quad (5)$$

K_2 is a term that adjusts corona loss for rain intensity RI, and is given as (Maruvada, 2000):,

$$K_2 = 10 \cdot \log \frac{RI}{1.676} \quad , \quad for\ RI \le 3.6\ mm/h$$

$$= 3.3 + 3.5 \cdot \log \frac{RI}{3.6} \quad , \quad for\ RI > 3.6\ mm/h$$

(6)

For average rainy conditions, RI = 1.676 *mm/h* and for fair weather conditions, 17 dB should be subtracted from average rainy weather loss.

Where:

AD : total number of lines added to the network

b : KW base

CL_j : corona power loss in the jth line (kW / km)

CL_{jm} : corona power loss in the mth phase of the jth line (dB)

d : diameter of sub-conductor (cm)

E_{jm} : rms electric field in the mth phase of the jth line (kV/cm)

K_C : cost coefficient of corona power loss (p.u. cost / p.u. power)

l_j : length of the jth line (km)

n : number of sub-conductors in a bundle

Subject to:

Power balance at each bus, Kirchoff's voltage law on each closed basic loop., Line flow, line height, phase spacing, & bundle radius constraints.

3. PROPOSED GENETIC ALGORITHM BASED EXPANSION METHOD

3.1 Expansion Algorithm

The proposed GA based expansion method is shown in Fig.1.

3.2 Genetic Algorithm

Genetic algorithms are directed random search techniques, which can find the global optimal solution in complex multidimensional search spaces. GA was first proposed by Holland [14] and has been applied successfully to many engineering and optimization problems [15].

GA employs different genetic operators to manipulate individuals in a population of solutions over several generations to improve their fitness gradually. Normally, the parameters to be optimized are represented in a binary string. To start the optimization, GA use randomly produced initial solutions created by random number generator. This method is preferred when a priori knowledge about the problem is not available. The flow chart of a simple GA is shown in Fig. 2. There are basically three genetic operators used to generate and explore the neighborhood of a population and select a new generation

These operators are selection, crossover, and mutation. After randomly generating the initial population of say N solutions, the GA use the three genetic operators to yield N new solutions at each iteration. In the selection operation, each solution of the current population is evaluated by its fitness normally represented by the value

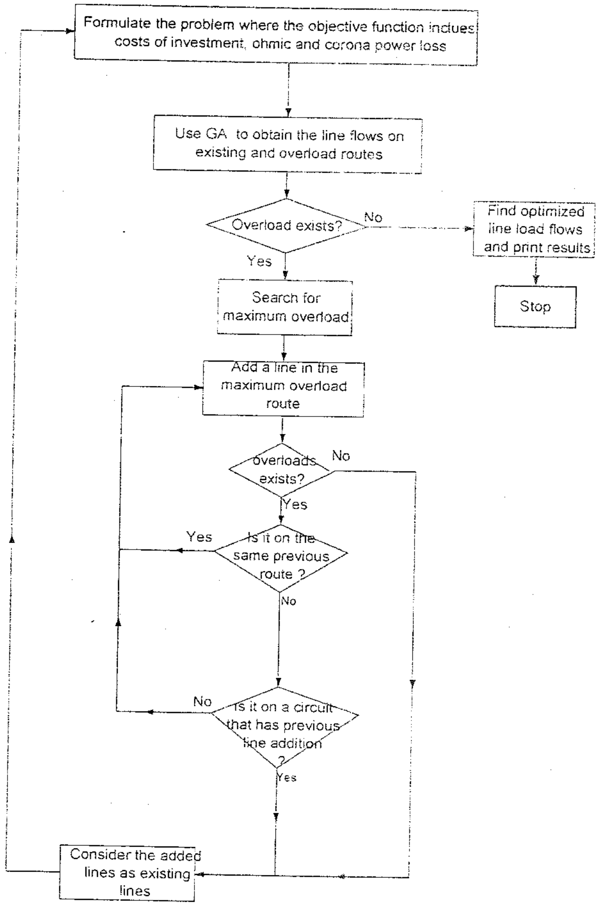

Fig.1- Flowchart of the expansion process

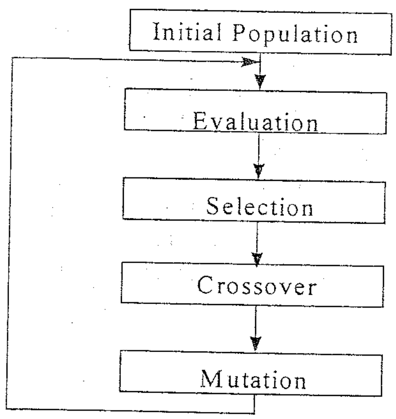

Fig. 2- Flow Chart for a Simple Genetic Algorithm.

of some objective function, and individuals with higher fitness value are selected. Different selection methods such as stochastic selection or ranking-based selection can be used.

The crossover operator works on pairs of selected solutions with certain crossover rate to yield *N* new solutions. The crossover rate is defined as the probability of applying crossover to a pair of selected solutions. There are many ways of defining this operator. The most common way is called the one-point crossover, which can be described as follows. Given two binary coded solutions of certain bit length, a point is determined randomly in the two strings and corresponding bits are swapped to generate two new solutions.

The *N* new solutions generated by the crossover operation are subjected to mutation. Mutation is a random alteration with small probability of the binary value of a string position. This operation will prevent GA from being trapped in a local minimum. The fitness evaluation unit in the flow chart acts as an interface between the GA and the optimization problem. Information generated by this unit about the quality of different solutions is used by the selection operation in the GA. The algorithm is repeated until predefined number of generations has been produced or no more improvements in the value of the objective function are observed. Finally, one solution out of the *N* solutions corresponding to the minimum value of the objective function is selected. More details about GA can be found in [15] and [16].

4. TEST SYSTEM

The new formulation of the TEP problem is applied to the well-known Garver's 6-bus network. Figure 3 shows the initial network with the possible routes. The system data is given in [1].

5 RESULTS AND DISCUSSION

Expansion including and excluding corona power loss has been made. A minimization of the objective function given by (1)-(6) subject to the constraints has been made using GA for cases where 1, 2, 3, and 4 sub-conductors are used with radii of 1.5 cm, 2 cm, and 2.5 cm in each case. Following the GA design procedure described in section 3.2 with single point crossover and mutation probabilities of 0.7 and 0.001 respectively, the optimal power flows and the number of added lines on the expanded network are shown on Fig. 4. The expansion scenario reveals that the optimal number of sub-conductors is 4, with a sub-conductor radius of 1.5 cm, a height of 14 m, a bundle radius of 0.25 m, and phase spacing of 6 m

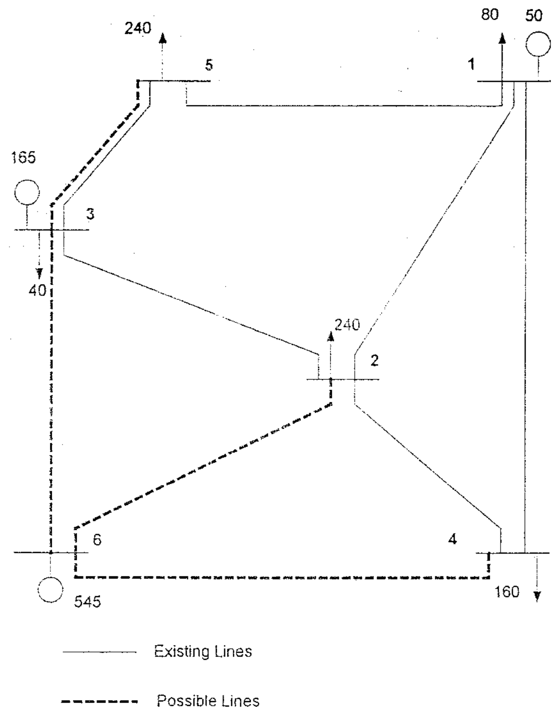

Fig. 3: Initial network with possible routes

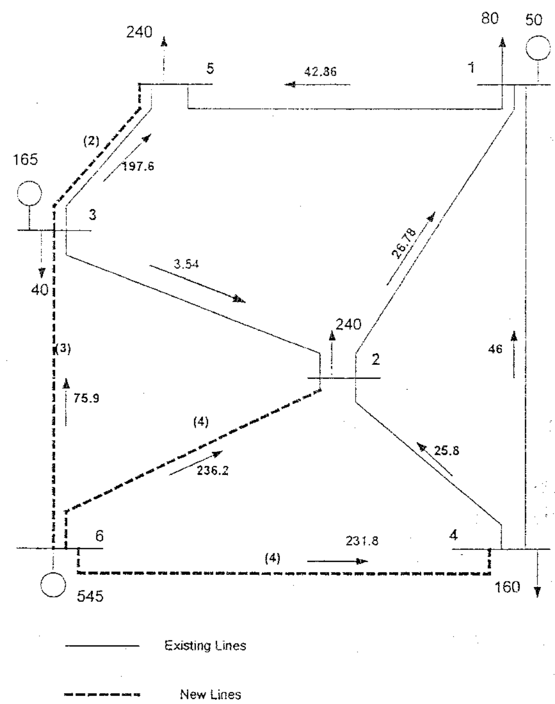

Fig- 4: Future network as obtained by GA method [(x): number of added lines

The comparison of total costs for cases where corona power is not included [2,3] and included [12] is shown in Fig 5. It can be seen that when the corona is not included in the objective function, the total cost of the present expansion is smaller than those of previously reported research [2,3] for tariffs of about 3 cent/kwh and higher. On the other hand, when comparing the total costs of the present work (when the corona is included in the objective function) with the previous work of Al-Hamouz and Al-Faraj [12], it can be seen that at tariffs of about 2.8 cent/kwh and higher, the present GA proposed network are less costly. In addition, comparing the total costs of the present GA algorithm (with and without corona power loss term) it is clear that the network when corona power loss term is included is less costly. Therefore, it is worth including this new term in the expansion process.

6. CONCLUSIONS

The objective function of the transmission expansion planning (TEP) problem has been modified to include a new term (corona power loss) in the optimization process. This reveals a nonlinear objective function which has been solved by Genetic Algorithms. The outcome of the expansion process is the optimal scenario which defines the number of lines to be added. For each added line, the number and radii of sub-conductors, phase spacing, height, and bundle radius are also generated as a result of the expansion process. To test the effect of the modified objective function on the final expansion scenario and the overall cost, it has been applied to Garver's 6-bus Garver test system. It has been found that including the corona power loss term leads to a more economical expanded network, i.e., the total expansion cost of investment, ohmic power loss and corona power loss is less for a certain range of tariff prices.

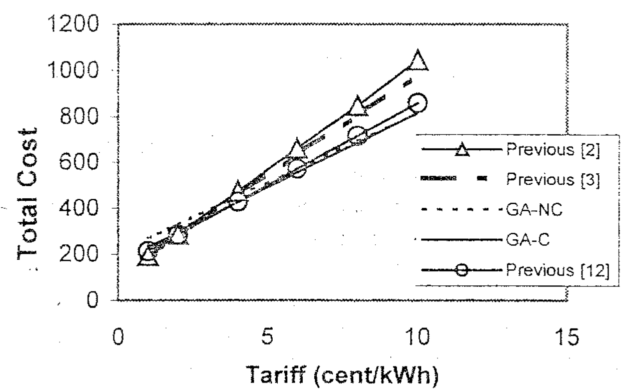

Fig. 5- Total Cost of Proposed Expanded Network as Compared to Previous Ones

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