APPLICATION OF ARTICICIAL INTELLIGENCE ALGORITHMS TO TRANSMISSION PLANNING

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ABSTRACT

Application of articicial intelligence (AI) algorithms such as Genetic (GA) and Tabu Search (TS) to transmission expansion planning (TEP) problem is presented. The need for such AI algorithms comes from the improved formulation of the TEP objective function and operating constraints. The new formulation incorporates the corona power loss which reveals a nonlinear objective finction. Practical number of transmission line sub-conductors (1, 2, 3, and 4) have been tried.

Nomenclature

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

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 network which feeds the loads with the required degree of quality and realizes a pre-specified reliability level. The TEP problem can be divided into long-term expansion (20 years ahead), medium-term expansion (10 years ahead), and short-term expansion (5 years ahead). 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 an heuristic one.

To the authors' knowledge, all TEP approaches reported in the literature formulated their objective functions and the corresponding constraints to account for the cost of investment and/or the cost of ohmic power loss. In a recent work conducted by Al-Hamouz [1], it was found that the corona power loss associated with high-voltage transmission lines has a considerable value compared to the transmission line ohmic loss, especially on moderately and lightly loaded lines. The linear programming (LP) technique has been adopted by many investigators [2-4]. Other investigators have adopted the integer (IP) or mixed integer programming technique [5,6] The quadratic programming (QP) technique has been utilized in [7-9] where the exact ohmic power loss is considered in the expansion process. Zero-one implicit enumeration programming is also another mathematical programming approach that receives the attention of investigators [10] Nonlinear programming (NLP) is one of the very old mathematical programming tools used for the TEP problem [11,12]. The simulated annealing (SA) method has been applied successfully to large-scale TEP problems [13]. In a recent paper [14] a parallel SA method was adopted for the same TEP problem.
The genetic algorithm (GA) method is another type of newly adopted optimization approaches for the solution of the TEP problem [15-18]. GA is based on the mechanics of evolution and natural genetics. A combination of the GA and neural networks (NN) has also been applied to the TEP problem [19]. Very recently, the Tabu search (TS) algorithm was applied to the TEP problem [20-22]
In this 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 and TS algorithms are utilized to minimize the objective function subject to the system constaints. The new formulation has been tested on Garver's 6-bus transmission systems.

2. MATHEMATICAL FORMULATION

To the authors' knowledge, 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 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:

Minimize:

S cost of investment + S cost of ohmic loss + S cost of corona loss (1)

The cost of corona loss, which is the third term, is expressed as [23]:

$$\text{S cost of corona loss} = K_C \sum_{j=1}^{AD} \frac{CL_j \times l_j}{b} \tag{2}$$

where:

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

$CL_{jm}(dB)=$

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

where:

$$\begin{aligned} K_1 &= 13 \quad for\, n \le 4 \\ &= 19 \quad for\, n > 4 \end{aligned} \tag{5}$$

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

$$\begin{aligned} K_2 &= 10 \cdot \log\frac{I}{1.676} \quad , \quad for\, I \le 3.6\, mm/h \\ &= 3.3 + 3.5 \cdot \log\frac{I}{3.6} \quad , \quad for\, I > 3.6\, mm/h \end{aligned} \tag{6}$$

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

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. TEST SYSTEM

The new formulation of the TEP problem is applied to the well-known Garver's 6bus network. Figure 1 shows the initial network with the possible routes. The system data is given in [2].

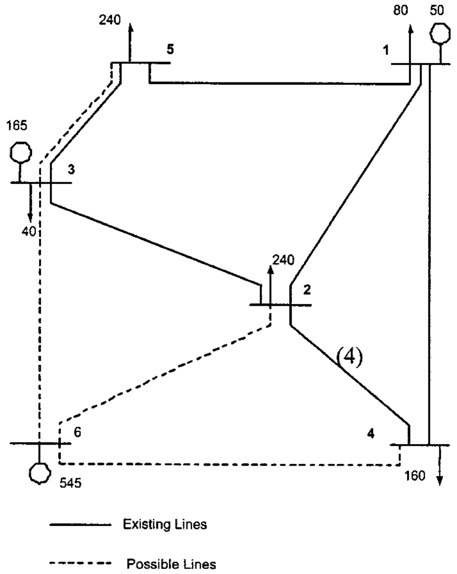

Fig. 1: Initial network with possible routes

4. 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 and TS 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.

A comparison between the power flow values carried by each circuit (line) for the three Algorithms is given in Table 1.

Table 1: Comparison between the power flows through each line as obtained by GA and TS algorithms.

Line Number	From Bus	To Bus	GA	TS
1	2	1	26.78	19.87
2	4	1	46	37.78
3	1	5	42.86	27.67
4	2	3	-3.54	5.69
5	4	2	25.8	27.71
6	3	5	197.6	211.8
7	6	4	231.8	227.48
8	6	2	236.2	237.2
9	6	3	75.8	81.18

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.

Table 2 shows the total cost at assumed tariffs in cent/ kWh. It should be mentioned that the total cost includes the capital investment as well as the cost of energy lost due to ohmic and corona losses.

Table 2: Total Expansion Costs in $US Million

Cent/ kWh	GA	TS
1	230.1	239.14
2	295.22	298.29
4	425.45	416.59
6	555.68	534.8
8	685.9	653.18
10	816.14	771.48

5. 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. A comparison of the total costs for rainy and fair weather condition cases (when the corona is included) is also reported. It has been found that including the corona power loss term leads to a more economical expanded network in both fair and rainy weather conditions, i.e., the total expansion cost of investment, ohmic power loss and corona power loss is less for a certain range of tariff prices.

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