An Approach to Find Most Flexible Plan among Solutions of Transmission Expansion Planning (TEP) Problem

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Abstract. In this paper, a method to find the most flexible plan amongst transmission expansion candidates has been presented. The flexible plan is selected from the last generation of Genetic Algorithm (GA) based Transmission Expansion Planning (TEP) program. The flexible plan is a plan which can be converted to other suitable plan. In this paper, TEP is solved by GA. To determine the most flexible plan, 2 criteria, named *LE* and *DLN*, have been suggested. These criteria have been applied to the quasi optimal solutions of GA to determine the most flexible plan. Furthermore, another approach to generate the most flexible plan called "n+1 plan" is proposed, too. The results of TEP of Garver 6bus and Northern Brazil 87bus test systems show that *LE* criterion is suitable for large scale networks, but *DLN* is suitable for small ones.

Key words

Flexible plan, Transmission expansion planning, Uncertainty, Genetic Algorithm

1. Introduction

Several methods have been used in order to solve TEP problem. In general, these methods can be classified in two categories:

a) Mathematically Optimization and
b) Heuristic methods

The mathematical methods find an optimum expansion plan based on a calculation procedure that solves a mathematical formulation of the problem [1]. Some of these methods are listed here:

- Linear Programming [2]
- Dynamic Programming [3]
- Non-Linear Programming [4]
- Complex Programming [5]
- Benders [6]
- Hierarchical [7]

The transmission planning problem is nonlinear and nonconvex in nature. As a result, these methods face the many numerical convergence problems. The discrete and stochastic variables are another problem for these methods.

Therefore, the Heuristic methods are used instead of them. The word "Heuristic" can cover all methods that do not use the classical optimization methods. Heuristic methods have local search technique based on the logical experimental or heuristic laws. These laws are used for the classification of different solutions. The Heuristic procedure continues until the algorithm cannot find the better solution considering the algorithm criteria. These criteria are usually cost, overload and etc.

The first Heuristic method has been used by Fischl [8]. In comparison with other methods, Heuristic methods are more flexible, but there is not any guarantee that the solution is the global optimal solution.

The Genetic Algorithm (GA), which is used to solve the transmission expansion planning, can be based on the parallel processing techniques [1].

The other problem which should be considered is uncertainty. These uncertainties can be resulted in by the following parameters [9]:

- Electricity demand changes,
- Cooperation/Competition of utilities,
- Availability of fuel,
- Cost factors and financial parameters,
- Existing and future equipment application,
- Environmental considerations and
- Regulations and political options.

Without considering the uncertainties, the TEP becomes a technical-economical optimization problem. The uncertainty increases the complexity of the problem.

There are two methods to model the uncertainty in TEP problems. In the first group, the procedure of planning has following phases:

a) Uncertainty Modelling
b) Applying the optimization method (e.g. GA) to model
c) Presenting the final results

One of the most famous methods of this group is named scenarios method [10].

In second group, the procedure is as following:

a) Modelling (without uncertainty)
b) Applying the optimization method (e.g. GA) to model
c) Searching in the primary result considering the uncertainties

In this paper, The second approach has been used. This answer will be robust to the changes of designing parameters.

2. Proposed Method

It is assumed that, GA is applied to TEP. Then, the last generation of program is known data. This generation is a set of best candidates among the acceptable solutions. In

this step, the developed program finds a plan named "Flexible Plan", which has the highest similarity to other plans. The significant feature of this plan is its ability to be changed to any other plan, which satisfies network future conditions cost-effectively.
From the network planners point of view, the flexibility is the capability of the adaptation of the plan (generation and transmission system) to any unwanted problem which can happen during the construction [1]. The adaptation (changes) of the plan must be fast and with acceptable cost. It must be said that "Flexible Plan" is not the same as "Over-Planning".
In this method, each plan must be compared with others. The result of comparison of plan *i* with *j* is placed at the element (i,j) of similarity matrix. For example, if the result of comparison between plan 1 and plan 2 is 27, then the element (1,2) becomes 27.

$$\begin{bmatrix} 0 & 27 & \cdots \\ 27 & 0 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}$$

Fig.1: Similarity matrix

The sum of all elements of row *i* (or column *j*) shows the degree of similarity of plan *i* to others.
It must be mentioned that for the comparison of plans, many criteria can be suggested.
In this paper, three criteria named as *LE* (Line Existence), *DLN* (Difference of Line Number) and "n+1 plan" are introduced and applied to the plans.

2-1 LE; "Line Existence" Criterion

It is proposed that the *LE* criteria is equal to 1, if there is connection between bus *i* and *j*, otherwise it is equal to 0. This criteria will be introduced using an example in Table-1.

Line between buses	1-2	1-3	2-3
No. Of Lines (Plan A)	2	2	**2**
No. Of Lines (Plan B)	2	1	**0**
LE Criteria	1	1	**0**

Table-1: Comparison based on LE criteria

As given in this table, the plan A has 2 lines 1-2, 1-3 and 2-3. The plan B has 2 lines between buses 1 and 2 and one line between buses 1 and 3. In comparison of plans A and B, in the case 1-2 and 1-3, the *LE* is equal to 1 because there are at least one line between these buses, but in the case of buses 2 and 3, the *LE* is equal to zero, because there is no connection between buses of one of the plans.
This criterion shows the difference between the power flow paths in 2 plans.
The negative point of this criterion has been shown in the example. As it can be seen, *LE* is the same for the path 1-2 and 1-3, but they have not the same number of lines.

2-2. DLN (Difference of Line Number) criterion

In this section, the difference of line numbers in a power flow path of two plans has been proposed as a criterion named *DLN*. Finally, the sum of *DLN* of all paths shows the difference of two plans. For example, consider two plans of in Table-2:

Line between buses	1-2	1-3	2-3	1-4
No. Of Lines (Plan A)	**2**	**2**	**1**	**3**
No. Of Lines (Plan B)	**2**	**1**	**0**	**1**
DLN Criteria	**0**	**1**	**1**	**2**

Table-2: Comparison based on DLN criteria

As shown in this table, the plan A has 2 lines in the paths 1-2 and 1-3 and one line in the path 2-3 and 3 lines in the path 1-4. The plan B has 2 lines between buses 1 and 2 and one line in the paths 1-3 and 2-3. The result, i.e. DLN criteria are listed on the last row.
The merit of this criterion is obvious. Now, the difference of plans in the path with different number of lines can be determined.
As given in Table-2, *DLN* of paths 2-3 and 1-3 for both plans are the same, but there is no connection in the path 2-3 of plan B. This is a negative point for this criterion.

2-3. "n+1 Plan" Approach

In this method, the flexible plan is not chosen from the final results of GA. A new plan which is similar to other plans (as much as possible) is created in this approach. The start point of this approach is the last generation of GA. In this generation we have, say M solutions. The number of lines between bus *i* and *j* must be considered in all M solutions. If the *x* in the most repeated line numbers in this path, thus the element (*i*,*j*) of the matrix named "n+1 plan matrix" is equal to *x*. this matrix is shown in Fig-2. The all paths must be studied and this matrix must be completed.

$$\begin{bmatrix} 0 & 2 & \cdots \\ 2 & 0 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}$$

Fig-2: n+1 plan matrix

At the end of this approach, the new plan, i.e. plan n+1, must be checked from electrical point if view.

3. Planning Results

In this article, to compare different criteria, proposed methods are applied to Garver 6bus and Northern Brazil 87bus systems.

3-1. Graver 6bus test

The test system of Garver has been studied in this section. A program has been developed by [11], which is based on GA. The output of GA has 17 plans (solutions).

In this paper, the plans have been ordered considering their cost. The plan number one has the minimum cost, shown in Fig-3.

These 17 plans are the input of the program which should find the flexible plan based on proposed criteria.The plans have been ordered and listed in Table-3. for example, Plan 14 is the most flexible plan based on *DLN*.

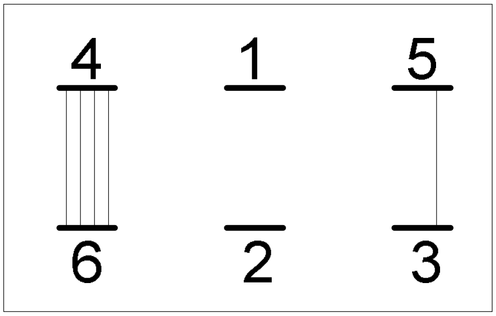

Fig-3: The Best Plan of Genetic Algorithm
Plan No.1

Table3: Order of plans for Garver Network based on *DLN* and *LE*

DLN	LE	Criteria
14	15	Plan Number
3	4	
4	9	
10	16	
15	12	
16	13	
17	14	
6	2	
7	3	
8	5	
13	7	
11	17	
12	11	
5	1	
1	6	
2	8	
9	10	

As shown in Table-3 the plans with the higher number are listed at the top of the table. This means the expensive plans are the flexible. To overcome this problem, the plans with the cost higher than the average are removed. The result has been presented in the Table-4.

Table-4: Order of plans for Garver Network after correction

DLN	LE	Criteria
3	4	Plan Numbers
4	9	
6	2	
7	3	
8	5	
5	7	
1	1	
2	6	
9	8	

The best plans based on EL and DLN criteria are shown in Fig-4.

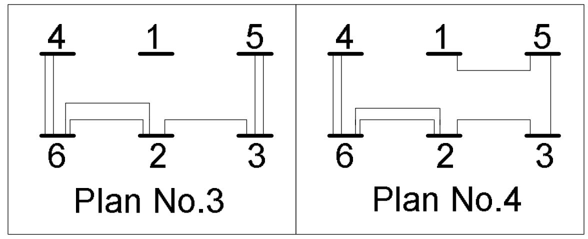

Fig-4: Best plans based on *EL* and *DLN*

In the column of *DLN*, the plans with low order are on top. As a result, this criterion is better than EL. The selected flexible plan and the plan, selected by GA, have been shown in Fig-5, too.

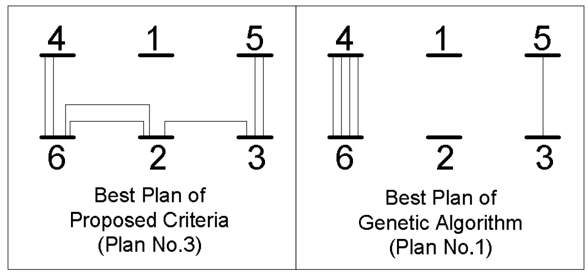

Fig-5: Most Flexible and cheapest Plan

As mentioned before, the n+1 plan approach can suggest another flexible plan, shown in Fig-6.

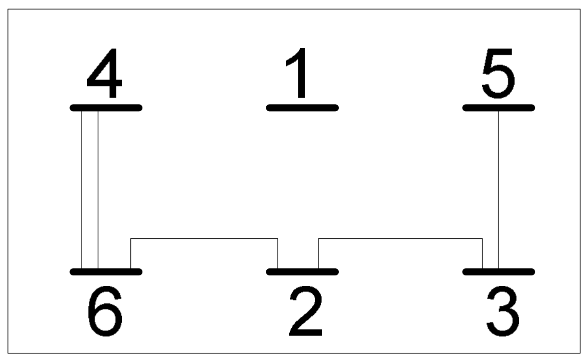

Fig-6: The best plan of N+1 criteria

3-2 Northern Brazil 87-bus System

In this section, the proposed approach is applied to 87bus Northern Brazil network. In this case, the output of GA has 20 plans given and ordered in [12]. The output of proposed program is listed in Table-5. Also, the best 10 plans are shown in this table.

Table-5: Order of plans of Northern Brazil Network based on *DLN* and *LE*

<table>
<tr><th>DLN</th><th>LE</th><th>Criteria</th></tr>
<tr><td>9</td><td>2</td><td rowspan="10">Plan Numbers</td></tr>
<tr><td>4</td><td>7</td></tr>
<tr><td>6</td><td>16</td></tr>
<tr><td>8</td><td>1</td></tr>
<tr><td>1</td><td>4</td></tr>
<tr><td>7</td><td>6</td></tr>
<tr><td>13</td><td>8</td></tr>
<tr><td>2</td><td>9</td></tr>
<tr><td>10</td><td>10</td></tr>
<tr><td>14</td><td>11</td></tr>
</table>

It can be seen that, the EL criterion has better results than DLN criterion. In this case, the “n+1 plan” approach results is the plan No.9, which is selected by *DLN* criterion.

4. Conclusion

In this paper, an approach has been presented to find the most flexible plans among TEP solutions. For small networks, the DLN criterion is a suitable criterion, while EL criterion is suitable for large scale networks, In other word, the result driven from DLN is more economical than the result of EL in case of small networks. It must be mentioned that, if the line construction projects are in series, i.e. one line should be constructed after finishing the other one, the “n+1 plan” approach is the best solution, Because in this case, the first line is a line which is common in most of plans. As a result, the planning should be started with this line, which is proposed by the “n+1 plan” approach. But if the line construction projects start in parallel, the output of EL criterion is suitable for small networks and the output of DLN criterion is suitable for large networks.

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