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# STUDYING THE EFFECT OF LOSSES COEFFICIENT ON TRANSMISSION EXPANSION PLANNING USING DECIMAL CODIFICATION BASED GA

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**Abstract-** The main goal of transmission network expansion planning (TNEP) is minimizing the network construction and operational cost while delivering safe and reliable electric power to load centers during the planning horizon. After publication of Garver's paper, much research has been done on the field of static transmission network expansion planning (STNEP) up till now. But in all of them, the effect of losses coefficient on transmission expansion planning has not been investigated. Thus, the goal of this paper is to solve the STNEP problem considering the effect of losses coefficient on transmission networks with different voltage levels using decimal codification genetic algorithm (DCGA). Finally, the effectiveness of proposed idea is tested on Garvers 6 bus network. The results analysis show that although the losses coefficient has not any role in determining of network configuration and arrangement, but it has important effect on the rate of investment return and subsequent transmission expansion planning. Also, it can be said, considering the effect of losses coefficient in expansion planning of a transmission network with various line and substation voltage levels is caused the operational costs and therefore capital saving cost is calculated more exactly.

**Keywords:** Transmission Network Expansion Planning, Losses Coefficient, Operational Costs, DCGA.

## 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 added to the network. 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 have 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 these methods, the problem has been solved regardless to effect of losses coefficient on transmission expansion planning. 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 losses coefficient effect on transmission expansion planning 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, the effect of losses coefficient has 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 losses coefficient effect 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 safely and reliably to load centers.

As mentioned in Ref. [33], the losses coefficient is equal to the square of the area under the load duration curve (LDC) and its rate is between 0 and 1. With respect to this fact that LDC is different for various networks, and also this coefficient has important role in the rate of losses growth, evaluating effect of this coefficient on transmission expansion planning can be useful and effective. Accordingly, in this paper, the effect of losses coefficient on the static expansion planning of a transmission network with various voltage levels is studied. For this reason, the losses cost and also the expansion cost of related substations from the voltage level point of view is included in objective function. The studied voltage levels are 230 and 400 kV. The results evaluation reveals that although considering the effect of losses coefficient for solution of the STNEP problem is not caused the network arrangement is changed but it caused that the total expansion cost (sum of expansion and losses costs) for transmission network is obtained more exactly and therefore rate of investment return is calculated exactly.

## II. STNEP PROBLEM MODEL

The STNEP problem is a mixed-integer nonlinear optimization problem. Due to studying the role of losses coefficient in static expansion planning of a transmission network with various voltage levels and subsequent adding expansion cost of substations to expansion costs, the proposed objective function is defined as follows:

$$C_T = \sum_{i,j\in\Omega} CL_{ij} n_{ij} + \sum_{k\in\Psi} CS_k + k_{loss}(8760 \times C_{MWh} \times \sum_{i=1}^{NY} loss_i) \tag{1}$$

$$loss = \sum_{i,j\in\Omega} R_{ij} I_{ij}{}^2 \tag{2}$$

where,

$C_T$ : Total expansion cost of network.
$CS_k$ : Expansion cost of $k^{\text{th}}$ substation.
$CL_{ij}$ : Construction cost of each line in branch *i-j*. (is different for 230 and 400 KV lines)
$k_{loss}$: Losses coefficient.
$C_{MWh}$: Cost of one MWh ($US/MWh).
*Loss*: Total losses of network.
$n_{ij}$ : Number of all new circuits in corridor *i-j*.
$R_{ij}$ : Resistance of branch *i-j*.
$I_{ij}$ : Current of branch *i-j*.
$\Omega$ : Set of all corridors.
$\Psi$ : Set of all substations.
*NY*: Expanded network adequacy (in year).
The Calculation method of $CS_k$ is given in [33].

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):

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

$$f_{ij} - \gamma_{ij}(n_{ij}^0 + n_{ij})(\theta_i - \theta_j) = 0 \tag{4}$$

$$\left|f_{ij}\right| \le (n_{ij}^0 + n_{ij})\overline{f_{ij}} \tag{5}$$

$$0 \le n_{ij} \le \overline{n_{ij}} \tag{6}$$

$$0 \le g \le \overline{g} \tag{7}$$

$$\mathit{Line\_Loading} \le LL_{max} \tag{8}$$

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

*S*: Branch-node incidence matrix.
*f*: Active power matrix in each corridor.
*g*: Generation vector.
*d*: Demand vector.
$\theta$: Phase angle of each bus.
$\gamma_{ij}$ : 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*.
$\overline{g}$ : Generated power limit in generator buses.
$\overline{f_{ij}}$ : Maximum of transmissible active power through corridor *i-j* which will have two different rates according to voltage level of candidate line.
*Line_Loading:* Loading of lines at planning horizon year and start of operation time.
*LLmax:* Maximum loading of lines at planning horizon year.

In this study, the objective function is different from those which are mentioned in [1-20], [23-28], [30, 31] and in part of the problem constraints, $\overline{f_{ij}}$ and *Line_Loading* have been considered as two new additional constraints. It should be noted that $LL_{max}$ is an experimental parameter that is determined according to load growth coefficient (see Ref. [34] for more details).

The goal of the STNEP problem is to obtain number of lines and their voltage level to expand the transmission network in order to ensure required adequacy of the network along the specific planning horizon. Thus, problem parameters of the problem 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 and the advantages which were mentioned in [33]. In the proposed method, expansion and completion of objective function (for example, adding the network losses to objective function, extending the studied voltage levels to another levels and etc) would be practicable.

## III. DC 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.

There are three methods for coding the transmission lines based on the genetic algorithm method [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 following reasons.

- Avoiding difficulties which occur at coding and decoding the problem.
- Preventing the production of completely different offspring from their parents and subsequent occurrence of divergence in the 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). Consequently, the selected chromosome considering voltage level and also simplicity in programming was divided into the following parts as shown in Figure 1 for a network with 6 corridors. In part 1, each gene includes number of existed circuits (both of constructed and new circuits) in each corridor. Genes of part 2 describe voltage levels of existed genes in part 1. It should be noted that the binary digits of 0 and 1 have been used for representing voltage levels of 230 and 400 kV, respectively. If other voltage levels exist in the network, the numbers 2, 3 and etc., can be used for representing them in the genes of part 2. Therefore, the proposed coding structure would be extendable to other voltage levels. In Figure 1, in the first, second, third corridor and finally sixth corridor, one 400 kV, two 230 kV, three 400 kV and two 230 kV transmission circuits have been predicted, respectively.

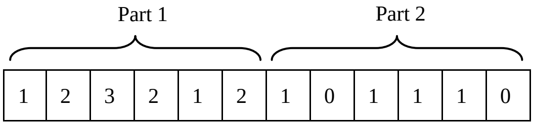

Figure 1. Typical chromosome structure

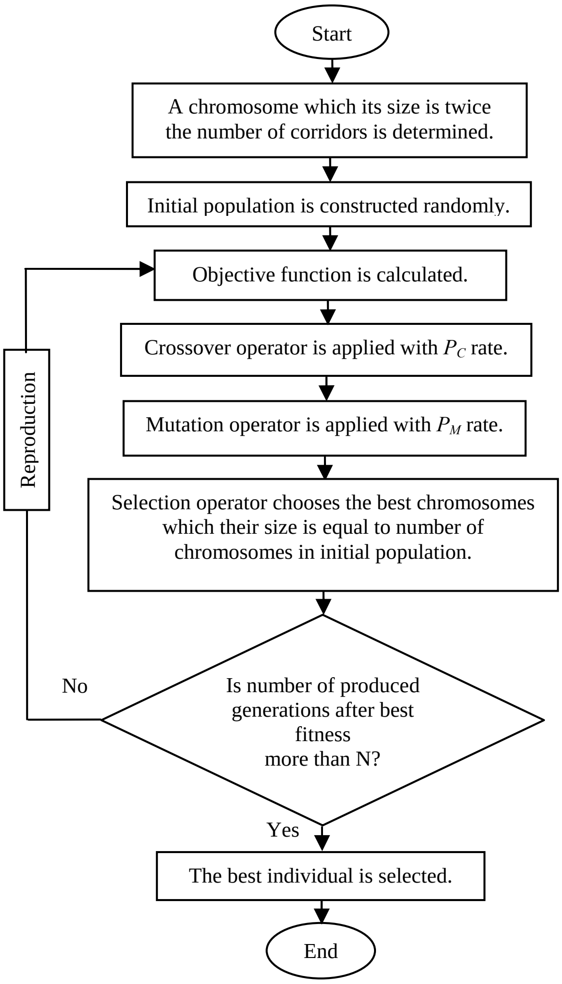

Figure 2. Flowchart of the proposed method

### A. 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 crossovers are used with probability of 0.3.

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. Due to the stochastic nature of the GA, there is no guarantee that different executions of the program converge to the same solution. Thus, in this study, the program has been executed for four times as continual i.e. after running of the genetic program, obtained results are inserted in initial population of next run and this process is iterated for three times. In addition to this continual run, 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 3500 generations has chosen.

## IV. CASE STUDY

Garver's network is used as a test system to demonstrate the effectiveness of the proposed idea. This network is shown in Figure 3. The network configuration, arrangement of the lines and substations, generation and load are given in Tables 1-3, respectively. Also, construction cost and characteristics of 230 and 400 kV lines are given in Appendix.

In order to evaluate the effect of losses coefficient on transmission expansion planning and subsequent amount of investment return, the proposed idea is test on case study system, considering and neglecting the network losses, for different losses coefficients (0.16, 0.25, 0.36, 0.49 and 0.64). The results (lines which must be added to the network up to planning horizon year) are given in Tables 4 and 6. Also, Tables 5 and 7 show the expansion costs. The first and second configurations are obtained neglecting and considering the network losses, respectively. The planning horizon is 15 years (2023).

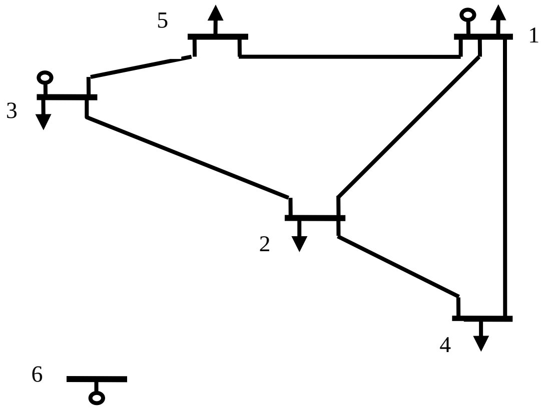

Figure 3. Garver's 6-bus network

Table 1. Configuration of the network

| From bus | To bus | Length (Km) |
|---|---|---|
| 1 | 2 | 200 |
| 1 | 3 | 190 |
| 1 | 4 | 300 |
| 1 | 5 | 100 |
| 1 | 6 | 340 |
| 2 | 3 | 100 |
| 2 | 4 | 200 |
| 2 | 5 | 150 |
| 2 | 6 | 150 |
| 3 | 4 | 300 |
| 3 | 5 | 100 |
| 3 | 6 | 240 |
| 4 | 5 | 315 |
| 4 | 6 | 150 |
| 5 | 6 | 300 |

Table 2. Arrangement of the lines

| Corridor | Voltage Level (kV) | Corridor | Voltage Level (kV) |
|---|---|---|---|
| 1-2 | 230 | 2-3 | 400 |
| 1-4 | 230 | 2-4 | 230 |
| 1-5 | 230 | 3-5 | 400 |

Table 3. Arrangement of the substations, generation and load

| Substation | Voltage Level (kV) | Load (MW) | Generation (MW) |
|---|---|---|---|
| 1 | 230/63 | 80 | 100 |
| 2 | 400/230 | 240 | 0 |
| 3 | 400/63 | 40 | 250 |
| 4 | 230/63 | 160 | 0 |
| 5 | 400/230 | 240 | 0 |
| 6 | 400/230 | 0 | 450 |

Table 4. First configuration: neglecting the network losses with $k_{loss}$= 0.16, 0.25, 0.36, 0.49 and 0.64

| Corridor | Voltage Level (kV) | Number of Circuits |
|---|---|---|
| 2-6 | 230 | 4 |
| 3-5 | 400 | 2 |
| 4-6 | 230 | 4 |
| 5-6 | 230 | 1 |

Table 5. Expansion cost of network with the first configuration

| | |
|---|---|
| Expansion Cost of Substations | 0 million $US |
| Expansion Cost of Lines | 96.175 million $US |
| Total Expansion Cost of Network | 96.175 million $US |

Table 6. Second configuration: Considering the network losses with $k_{loss}$= 0.16, 0.25, 0.36, 0.49 and 0.64

| Corridor | Voltage Level (kV) | Number of Circuits |
|---|---|---|
| 2-6 | 400 | 4 |
| 3-5 | 400 | 2 |
| 4-6 | 230 | 3 |

Table 7. Expansion cost of network with the second configuration

| | |
|---|---|
| Expansion Cost of Substations | 0 million $US |
| Expansion Cost of Lines | 108.415 million $US |
| Total Expansion Cost of Network | 108.415 million $US |

According to Tables 5 and 7, expansion cost of substations has obtained zero. The reason is that the voltage level of proposed lines for network expansion has been existed in their both first and end substations and therefore substations have not required expansion from voltage level point of view.

Total costs (sum of expansion and losses costs) of expanded network with the two proposed configurations for different losses coefficients have been shown in Figure 4.

It can be seen that the start points of second curves (cost curves of second configuration for various losses coefficients) are upper than start points of first curves (cost curves of first configuration for same losses coefficients) on the vertical axis, but this curves for $k_{loss}$= 0.16, 0.25, 0.36, 0.49 and 0.64 cut the first curves about 9, 7, 5, 5 and 4 years after planning horizon (expansion time), respectively. Although it seems that the first configuration (most of lines are 230 kV) is more economic. However, the second configuration is more economic if the network is studied considering the network losses after planning horizon time. The reason is that the annual network losses cost of the first configuration will become large in comparison with the second configuration for related losses coefficients after these times (9, 7, 5 and 4 year after planning horizon). Thus, in the second configuration, investment cost is returned after these years. In other words, investment return of second configuration with respect to first one for $k_{loss}$= 0.16, take places about 9 years after expansion time and for $k_{loss}$= 0.64 happens about 4 years after planning horizon. By increasing the rate of $k_{loss}$, second curve cuts the first curve earlier and therefore process of investment return becomes faster.

Its reason is that, increasing the losses coefficient is caused total cost of annual network losses (operation costs) is increased. On the other hand, with respect to this fact that power losses of lines with higher voltage levels (in here, 400 kV) is less than other ones (lines with lower voltage level, in here 230 kV), therefore the second configuration which its most of lines are 400 kV reduces total cost (expansion and losses costs) more than another configuration and consequently this configuration becomes earlier economic (first one) with increasing this coefficient.

However, with respect to Tables 4 and 6, increasing of losses coefficient has not any effect on network configuration and arrangement. Because, although by increasing of this parameter the network losses cost is increased, but expansion cost of lines (230 and 400 kV) and substations for changing of network configuration can not compete with this cost.

Finally, it can be concluded that although the losses coefficient has no role in determining the network arrangement, but this coefficient has important effect on operational costs and subsequent total cost of network expansion. Thus, with studying network after expansion it can be seen that considering the losses coefficient effect on transmission expansion planning is caused the TNEP becomes more optimal and total cost of network is calculated more exactly.

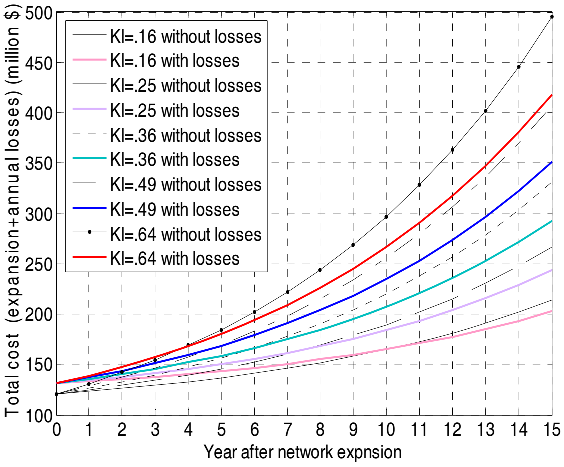

Figure 4. Total cost of the network with the two proposed configurations for different losses coefficients

## V. CONCLUSIONS

In this paper, the effect of losses coefficient on static transmission network expansion planning is studied using the decimal codification based genetic algorithm. Because, rate of losses coefficient is determined according to load duration curve and this curve is different for various networks. The simulation results reveal that increasing of losses coefficient is caused the network losses cost is increased and therefore curve of second configuration which its most of lines are 400 kV cuts the curve of first one (its most of lines are 230 kV) earlier and subsequent process of investment return becomes faster. But, this coefficient has not any role in determining of network configuration and arrangement. However, considering its effect in expansion planning of transmission networks with various voltage levels is caused the total cost of the network (expansion and losses costs) is reduced considerably and therefore the STNEP problem is solved more exactly and correctly. From added voltage level of lines and also transmitted power through the lines point of view, configurations which its most of lines are 400 kV is more economic and becomes overloaded later than ones which its most of 230 kV lines in mid-term and long term.

## APPENDICES

### A. Construction Cost and Characteristics of 230 and 400 kV Lines

Tables 8 and 9 show the construction costs of 230 and 400 kV lines. Also, characteristics of these lines are listed in Table 10.

Table 8. Construction cost of 230 kV

| 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 9. Construction cost of 400 kV

| Number of Line Circuits | Fix Cost of Line Construction ($\times 10^3$ dollars) | Variable Cost of Line Construction ($\times 10^3$ dollars) |
|---|---|---|
| 1 | 1748.6 | 92.9 |
| 2 | 1748.6 | 120.2 |

Table 10. Characteristics of 230 kV lines

| Voltage Level | Maximum Loading (MVA) | Reactance (p.u/Km) | Resistance (p.u/Km) |
|---|---|---|---|
| 230 | 397 | 3.85e-4 | 1.22e-4 |
| 400 | 750 | 1.24e-4 | 3.5e-5 |

### B. GA and Other Required Data

Load growth coefficient = 1.08; Inflation coefficient for loss = 1.15; Loss cost in now = 36.1($\$/MWh$); Number of initial population = 5; End condition: 3500 iteration after obtaining best fitness (N=3500); $LL_{max}$ = 30%.

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