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# Optimization of transmission lines loading in TNEP using improved discrete honey bee mating optimization algorithm

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**ABSTRACT**

Transmission Network Expansion Planning (TNEP) is a basic part of the power system planning that verifies where, when and how many new transmission lines should be added to the network. In this paper, expansion planning has been implemented by merging lines loading parameter in the TNEP problem using an improved Discrete Honey Bee Mating Optimization (DHBMO) algorithm. Expanded network will possess a maximum adequacy to provide load demand and also the transmission lines overloaded later. DHBMO algorithm combines the power of genetic algorithms and simulated annealing with a fast problem specific local search heuristic to find the best possible solution within a reasonable computation time. For this reason, the potential of the proposed approach for optimal solution of TNEP problem has been investigated and tested on the Garvers network and a real transmission network in Iran in comparison with the Discrete Particle Swarm Optimization (DPSO) method. The results evaluation show that the using the proposed DHBMO based method, the expansion costs is significantly reduced and the network adequacy is increased considerably than the DPSO algorithm. Also, regarding the convergence curves of both approaches, it can be seen that precision of the proposed algorithm to solve the TNEP problem is more than DPSO one.



## Introduction

The main goal of Transmission Network Expansion Planning (TNEP) is to determine where, when and which kind of transmission lines should be installed in the network to ensure an adequate level of energy supply to load centers during the planning horizon. Its goal is to minimize the network construction and operational cost, while meeting imposed technical, operational and security constraints [1-2]. The long-term TNEP is a hard, large-scale and highly non-linear combinatorial optimization problem that generally, can be classified as static or dynamic. Static expansion verifies 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 [3].

After Garver’s paper that was published in 1970 [4], many methods have been reported for the solution of TNEP problem in the literature. Some of them are related to problem solution method. Some others have been presented different approaches for solution of this problem considering various parameters. Chanda and Bhattacharjee [5] solved transmission expansion planning problem in order to obtain a maximum reliable network. reliability criteria are relating to actual systems that considering them help to maintain a higher degree of reliability of the system. Later, they [6] reported a new method for designing a maximum reliable network when failure probabilities of the lines are fuzzy in nature instead of deterministic as mentioned in Ref. [5]. However, optimization of transmission lines loading in TNEP has not been investigated in their literatures. Sohtaoglu [7] has studied the effect of economic factors on transmission expansion planning using load flow methods and the aim is minimization of the capital, variable and power losses costs. The effects of economic parameters have been incorporated as a variable coefficient in cost function. But, the lines adequacy of transmission network has not been considered. Also, some authors investigated TNEP problem and generation expansion planning together [8], but the transmission lines adequacy rate has not been considered. Grandville et al. [9] formulated the Static TNEP (STNEP) problem by a linearlized power flow model and used the Benders decomposition method for its solution. However, classical decomposition approaches, e.g., Benders decomposition may fail to converge for optimal solutions due to the non-convex nature of the STNEP problem. To cope with this non-convexities difficulties, a Benders hierarchical decomposition approach (HIPER) was proposed by Romero and Monticelli [10], where, the power network constraints were represented by a chain of three model. Nevertheless, the non-convexities still exist in the mathematical model used and application of this method to networks with a large number of candidate circuits is limited by computational limitations. Binato et al. [2], presented a heuristic approach, called Greedy Randomized Adaptive Search Procedure (GRASP) to solve the transmission expansion planning problem. GRASP is an expert iterative sampling method that due to its generality and simplicity, is a useful alternate technique that can be applied for many other kinds of decision problems. However, this technique is the most time consuming and the local search procedure used in this approach leads to some difficulties related with pruning by comparison. Lee et al. [11] adopted branch and bound (B&B) algorithm in a way to preserve the discrete nature of investments for solution of STNEP problem. However, some

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problems such as being too slow the convergence of algorithm regarding the problem complexity and difficult implementation are when a planner uses this technique. Periera and Pinto [12] represented a method based on sensitivity analysis for expansion of transmission network. But difficulty of the proposed method is that if the number of nodes or number of participants is large, the planning for expansion is combinatorial complicated and that makes it very difficult to find reasonable solutions within short computational time. Romero et al. [13] presented Simulated Annealing (SA) for optimizing the investment cost and loss of load of the network in static transmission expansion planning. SA is a robust optimization algorithm with a strong theoretical base. However, in hard combinational problems such as STNEP problem, both the number of alternatives to be analyzed and the number of local minimum points increase with the dimension of the network. This fact can negatively affects on computing time and solution quality of the problem.

Al-Saba and El-Amin [14] applied 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. Contreras and Wu [15] included the network expansion costs and transmitted power through the lines in fitness function and the goal is optimization of both expansion costs and lines loading. However, lines adequacy in transmission network has not been studied. Braga and Saraiva [16] considered the voltage level of transmission lines 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.

The lines adequacy of network is necessary to provide load demands when the network is expanding because its lack (i.e. lines overloading) is 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.

Recently, global optimization techniques like Genetic Algorithm (GA) [17] and Tabu search [18] have been proposed for the solution of STNEP problem. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators. Although, these methods seem to be good methods for the solution of TNEP problem, However, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded efficiency to obtain global optimum solution and also simulation process use a lot of computing time. In order to overcome these drawbacks, Shayeghi et al. [19] employed the Discrete PSO (DPSO) algorithm for optimization of transmission lines loading in TNEP problem. They concluded that ability of DPSO method for finding the more optimal solutions is more than GA. Also, it is shown that the convergence speed of the DPSO is more than GA method. However, during the running of the DPSO algorithm, the particles become more and more similar, and cluster into the best particle in the swarm, which make the swarm premature convergence around the local solution. This phenomenon is caused that the precision of obtained solutions decreases and the best solution is not resulted. In order to overcome these drawbacks and considering lines loading rate, in this paper, an improved Discrete Honey Bee Mating optimization (DHBMO) algorithm is proposed to solve TNEP problem. The lines loading parameter has been included in fitness function of STNEP and investment cost in problem constraints. The proposed DHBMO algorithm is a new swarm-based approach to optimization, in which the search algorithm is inspired by the social organization of honey bees and their process of reproduction and has emerged as a useful tool for engineering optimization [20]. It is a hybrid evolutionary algorithm which integrates the principles of genetic algorithm, simulated annealing, dedicated local search heuristics and some innovations for its self-adaptation. The genetic algorithm corresponds to the breeding procedure; the simulated annealing reproduces the mating process of honeybees and the process of feeding the broods and queen bees are simulated by the application dependent local search [21]. Thus, the proposed DHBMO based method combines the power of general meta-heuristics with problem specific heuristics to search a large solution space efficiently and effectively and obtain the best possible solution within a reasonable computing time.

The proposed algorithm is tested on the Garver's 6-bus system and a real transmission network of the Azerbaijan regional electric company in comparison with DPSO approach in order to illustrate its effectiveness and robustness for solution of the STNEP problem. The results evaluation confirms that the network adequacy is more increased in comparison with DPSO. Also, expanded network will possess a maximum adequacy to support load demand and also the transmission lines overloaded later. Finally, by comparing between the convergence curves of the proposed DHBMO based approach and DPSO, it can be concluded that the precision of the proposed algorithm for the solution of the STNEP problem is more than DPSO method one.

## Problem Formulation

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

$$Fitness = \sum_{i,j\in\Omega} CL_{ij} n_{ij} + C_0 T_{overload} \quad (1)$$

Where:

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

$CL_{ij}$: Total construction cost of each line in branch *i-j*.

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. [4, 22] for more details):

$$Sf + g - d = 0 \quad (2)$$

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

$$|f_{ij}| \le (n_{ij}^0 + n_{ij})\overline{f_{ij}} \quad (4)$$

$$0 \le n_{ij} \le \overline{n_{ij}} \quad (5)$$

$$C \le C_{\max} \quad (6)$$

*N-1 Safe Criterion* (7)

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.

$\theta$: 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*.

$\overline{f_{ij}}$ : 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.

$\Omega$ : 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 aim is finding 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. In this study, the DHBMO technique is used to solve the STNEP problem due to flexibility, simple implementation and high precision for finding the best solutions.

**Discrete HBMO Algorithm**

HBMO is a new swarm based meta-heuristic intelligence technique which is inspired by the social organization of honeybees and their marriage process. Honey bees are one of the social groups of insects which make their own community and live as a colony. Their community consists of three groups: the queen, the drones and the workers. The queen is fed with 'royal jelly' [23]. The artificial queen has a genotype, a set of genes, which can be considered as a complete solution to the problem under consideration. Drones live about eight weeks and are sole function to mate with the queen. A drone's eyes are noticeably bigger than the other castes which helps them to spot the queens when they are on their nuptial flight. At the end of the season any drones left, are considered non-essential and will be driven out of the hive to die. Artificial drones have only half of a genotype similar to the real drones which are haploid. In the artificial model, for the problem under investigation a drone has a genotype which is a complete solution and a mask which is used to mask half of the genes selected randomly. To avoid inbreeding, drones are generated independently of the queen; therefore, they are assumed to be unrelated [21].

Worker bees are the non-reproducing females which performs different tasks needed to maintain and operate of a bee hive. Workers born early in the season will live about 6 weeks while those born in the fall will live until the following spring. They make up the vast majority of the hive's occupants and are called house bees when young that work in the hive doing comb construction, rearing brood, tending the queen and drones, cleaning, regulating temperature and defending the hive. Older workers are called field bees and look for outside the hive to gather nectar, pollen, water and certain sticky plant resins used in hive construction [24].

In the marriage process, the queens mate during their mating flights far from the nest. A mating flight starts with a dance performed by the queen who then starts a mating flight during which the drones follow the queen and mate with her in the air. After the mating process, the drones die. In each mating, sperm reaches the spermatheca and accumulates there to form the genetic pool of the colony [20].

The HBMO algorithm starts with random generation of a set of initial solutions according to Fig. 1. Based on their fitness, randomly generated solutions are then ranked. The fittest solution is named queen, whereas the remaining solutions are categorized as drones (i.e., trial solutions). In order to form the hive and start mating process, the queen, drones and workers (predefined heuristic functions) should be defined. Each queen is characterized with a genotype, speed, energy and a spermatheca with defined capacity. In the next step, drones must be nominated to mate with the queen probabilistically during the mating flight. Mating flight can be considered as a series of state transitions in the solution space of an optimization problem. According to her speed the queen moves from a state to another and mates with the drone encountered at each state according to a probability rule. In each mating flight starting, the queen is initialized with some energy content that decrease during the flight and the queen returns to its nest when the energy reaches a critical point or when its spermatheca is full [21]. An annealing function is used to describe the probability of a drone ($D$) that successfully mates with the queen ($Q$) as follows [20, 25]:

$$prob(Q, D) = e^{\frac{-\Delta(f)}{S(t)}} \quad (8)$$

Where, $\Delta(f)$ is the absolute difference of the fitness of $D$ and the fitness of $Q$ and the $s(t)$ is the speed of queen at time $t$. The fitness of the resulting chromosomes of drone, queen or brood is determined by evaluating the value of the objective function. After each transition in space, the queen's speed and energy decays is given by:

$$S(t+1) = \alpha \times S(t) \quad (9)$$

$$E(t+1) = E(t) - \gamma \quad (10)$$

Where, $\alpha(t)$ is speed reduction factor and $\gamma$ is the amount of energy reduction after each transition ($\alpha, \gamma \in [0,1]$).

Due to non-reproducing female of worker bee, the role of the artificial worker bee is restricted to brood care and thus each worker may be regarded as a heuristic that acts to improve and/or take care of a set of broods. Thus, the worker is employed as a problem specific local search heuristic, which function is to improve the genotypes of broods, making it possible to obtain better solutions.

In general, the whole process of HBMO algorithm as shown in Fig. 1 can be summarized at the five main steps as follows:

*i)*: *Generate the initial drone sets and queen*: The algorithm starts with the mating flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone then selected from the list randomly for the creation of broods.

*ii) Flight matting*: This step does the flight matting of queen $Q$. The best drone $D_k$ with the largest $prob(Q, D)$ among the drone set *D* is selected the object of matting for the queen *Q*. After the flight matting the queen's speed and energy decay is reduced by Eq. (9). The flight matting is continues until the speed *S(t)* is less than a threshold *d* or the number of sperms of the queen's spermatheca is less than the one threshold.

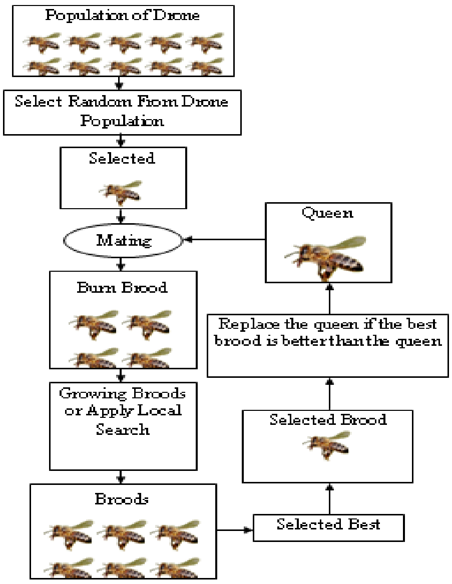



**Fig. 1. The proposed HBMO technique.**

*iii) Breeding process:* In this step, a population of broods is generated based on matting between the queen and the drones stored in the queen's spermatheca. The breeding process can transfer the genes of drones and the queen to the *j*-th individual based on the Eq. (11).

$$child = parent1 + \beta(parent2 - parent1) \quad (11)$$

Where, $\beta$ is the decreasing factor ($\beta \in [0,1]$).

*iv) Adaptation of worker's fitness*: The population of broods is improved by applying the mutation operators as follows:

$$Brood_i^k = Brood_i^k \pm (\delta + \varepsilon) Brood_i^k$$
$$\delta \in [0,1], 0 < \varepsilon < 1 \quad (12)$$

The $\delta$ is randomly generated and $\varepsilon$ is predefined. The best brood ($Brood_{best}$) with maximum objective function value is selected as the candidate queen. If the objective function of $Brood_{best}$ is superior to the queen, the queen replaces with the $Brood_{best}$.

*v) Check the termination criteria:* If the termination criteria satisfied finish the algorithm, else generate new drones set and go to step 2.

The algorithm continues with three user-defined parameters and one predefined parameter. The predefined parameter is the number of workers (*W*), representing the number of heuristics encoded in the program [8, 15]. The user-defined parameters are number of queens, the queen's spermatheca size representing the maximum number of mating per queen in a single mating flight and the number of broods that will be born by all queens. The speed of each queen at the start of each mating flight initialized at randomly.

The main features of the HBMO algorithm are natural metaphor, simplicity and high quality solutions. Also, it is combination of simulated annealing, genetic operator and swarm intelligence. Thus, it has a flexible and well-balanced mechanism to enhance the global and local exploration abilities unlike the other heuristic techniques.

Regarding the fact that parameters of the TNEP problem are discrete time type and the performance of standard PSO is based on real numbers, this algorithm can not be used directly for solution of the STNEP problem. There are two methods for solving the transmission expansion planning problem based on the HBMO technique [26]:

1) Binary honey bee mating optimization (BPSO).
2) Discrete honey bee mating optimization (DPSO).

Here, the second method is used due to avoid difficulties which are happened at coding and decoding problem, increasing convergence speed and simplification. In this method, the each gene is represented by three arrays: start bus ID, end bus ID and number of transmission circuits (the both of constructed and new circuits) at each corridor. In the DHBMO iteration procedure, only number of transmission circuits needs to be changed while start bus ID and end bus ID are unchanged in calculation, so the gene can omit the start and end bus ID. Thus, gene can be represented by one array. A typical gene with 12 corridors is shown in Fig. 2.

$$X_{typical} = (1, 2, 3, 1, 0, 2, 1, 0, 0, 1, 1, 2)$$

**Fig. 2. A typical particle**

In Fig. 2, in the first, second, third corridor and finally 12$^{th}$ corridor, one, two, three and two transmission circuits have been predicted, respectively.

Finally, breeding process and adaptation of worker's mechanism is updated by the following equations:

$$child = Fix(parent1 + \beta(parent2 - parent1)) \quad (13)$$

$$Brood_i^k = Fix(Brood_i^k \pm (\delta + \varepsilon) Brood_i^k) \quad (14)$$

Where, *fix* (.) is getting the integer part of *f*. The flowchart of the proposed algorithm for the solution STNEP problem is shown in Fig. 3.

In this study, in order to acquire better performance of the proposed algorithm, parameters which are used in improved DHBMO method have been initialized according to Table 1. It should be noted that DHBMO algorithm is run several times and then optimal results is selected.

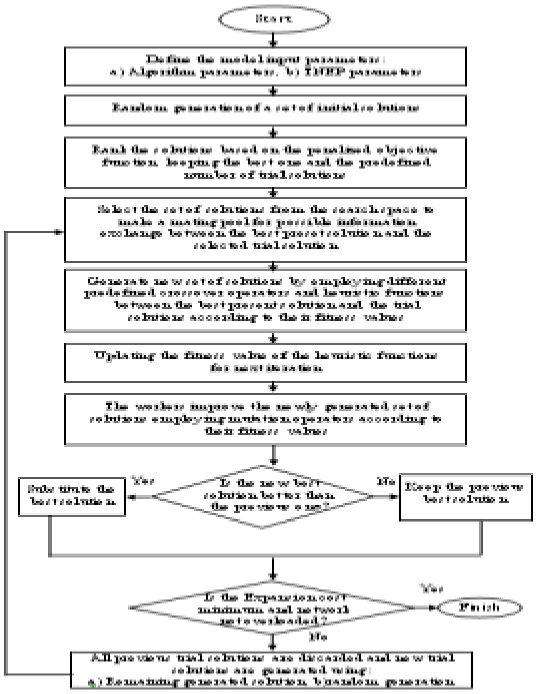


**Fig. 3. Flowchart of the DHBMO algorithm for TNEP solution**

**Table 1. HBMO control parameters for optimization**

| | |
|---|---|
| Queen speed at the start of a mating flight (*Smax*) | 1 |
| Queen speed at the end of a mating flight (*Smin*) | 0.2 |
| The number of drones (*ND*) | 20 |
| The number of workers (*NW*), | 40 |
| Number of broods (*NB*). | 10 |
| The size of the queen's spermatheca (*NS*) | 15 |
| The speed reduction schema ($\alpha$) | 0.98 |
| Coefficient of the new generation ($\beta$) | 0.95 |

## Results and Discussions

To assess the effectiveness and robustness of the proposed planning technique, it was applied to two test networks. First case is the IEEE Garver's 6-bus system and second is transmission network of the Azerbaijan regional electric company. The planning horizon year is considered 2014 (5 years ahead) for both case study systems. In following, test results of the proposed technique on the two test case study system will be described in comparison with DPSO method (see Ref. [19] for more details).

### A. Scenario 1: Garvers network

First test system that is studied is Garver's 6-bus system. The configuration of the network before expansion is given in Fig. 4. All characteristics of the network are detailed in [23].

By applying the proposed method (DHBMO) on the network according to various investment costs ($C_{max}$ changes between 50 to 100 million dollars by 10 million steps), the optimization results for different cases are shown in Fig. 5 and Table 2 (the dash lines into figures are number of required circuits for adding to the network until planning horizon year).

**Table 2. Expansion costs and years of missing the network adequacy for $C_{max}$ = 50-100 million $US using DPSO and DHBMO methods.**

| $C_{max}$ | Expansion cost (M$US) | | $T_{overload}$ | |
|---|---|---|---|---|
| | DHBMO | DPSO | DHBMO | DPSO |
| 50 | 46.99 | 47.0929 | 18 | 18 |
| 60 | 54.5630 | 56.8197 | 19 | 19 |
| 70 | 65.2110 | 65.6284 | 21 | 20 |
| 80 | 74.8630 | 78.6557 | 23 | 21 |
| 90 | 82.7660 | 87.0929 | 24 | 22 |
| 100 | 94.2300 | 99.9454 | 26 | 23 |

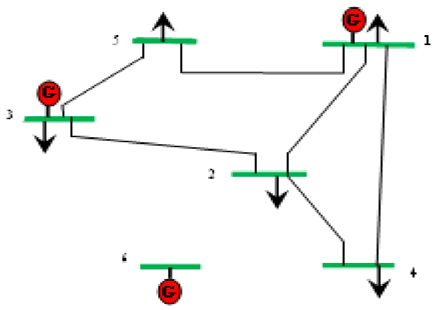
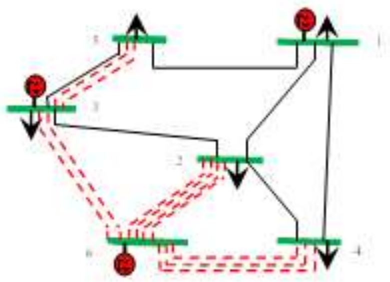
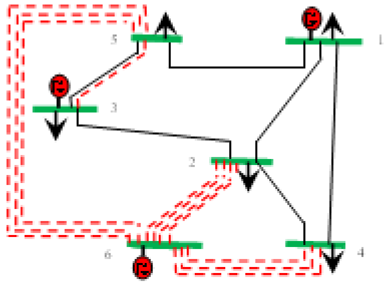



**Fig. 4. Garver's 6-bus network**



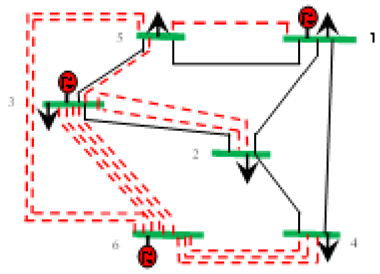
a)

**a) $C_{max}$=50**



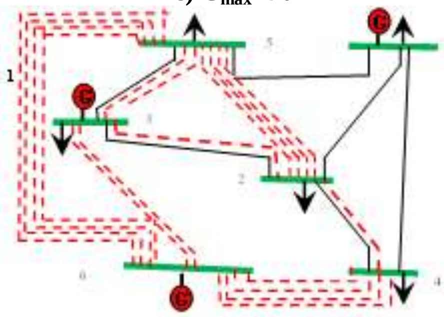
b)

**b) $C_{max}$=60**



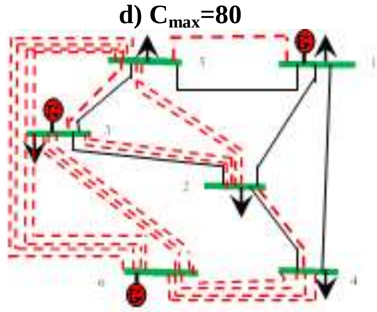

c)

**c) $C_{max}$=70**



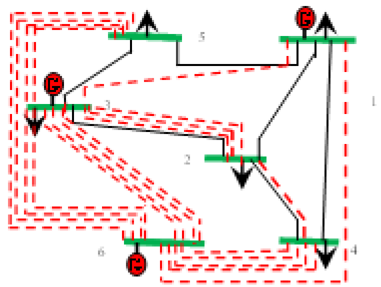
d)

**d) $C_{max}$=80**



e)

**e) $C_{max}$=90**



f)

**f) $C_{max}$=100**

**Fig. 5. Proposed configuration**

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 lower relative investment cost. Thus, the parameter of adequacy index on expansion cost rate is used for obtaining best design (see Ref. [23 for more details), as shown in Fig. 6. A high value is desirable for this index. It can be seen that the optimized point is 46.99 million dollars for the investment cost ($C_{max}$=50).

**Table 3. Proposed configurations for $C_{max}$=150-200 million $US**

| *$C_{max}$=150* | | *$C_{max}$=175* | | *$C_{max}$=200* | |
|---|---|---|---|---|---|
| **corridor** | *No. of circuit* | **corridor** | *No. of circuit* | **corridor** | *No. of circuit* |
| 1-11 | 1 | 1-9 | 1 | 1-2 | 1 |
| 1-9 | 1 | 1-18 | 2 | 1-3 | 2 |
| 1-18 | 1 | 2-8 | 1 | 1-9 | 1 |
| 2-5 | 1 | 2-7 | 2 | 1-13 | 1 |
| 2-8 | 1 | 2-13 | 1 | 1-18 | 1 |
| 2-12 | 1 | 2-17 | 1 | 2-7 | 1 |
| 2-18 | 1 | 3-6 | 1 | 2-12 | 1 |
| 3-5 | 1 | 3-8 | 1 | 3-5 | 1 |
| 3-6 | 1 | 3-11 | 1 | 3-11 | 1 |
| 3-7 | 1 | 4-13 | 1 | 4-9 | 1 |
| 3-8 | 1 | 4-14 | 2 | 7-9 | 2 |
| 3-9 | 1 | 4-16 | 1 | 7-18 | 1 |
| 3-18 | 1 | 4-18 | 1 | 8-16 | 1 |
| 4-7 | 1 | 5-12 | 1 | 8-18 | 1 |
| 6-8 | 1 | 5-16 | 1 | 9-12 | 1 |
| 8-17 | 1 | 6-16 | 1 | 9-13 | 1 |
| 8-18 | 1 | 6-17 | 1 | 9-15 | 1 |
| 9-11 | 1 | 7-9 | 1 | 11-17 | 1 |
| 10-18 | 1 | 7-13 | 1 | 11-18 | 3 |
| 11-18 | 1 | 8-11 | 1 | 12-16 | 1 |
| 14-16 | 1 | 9-16 | 1 | 14-16 | 1 |
| 16-17 | 1 | 12-16 | 1 | 14-17 | 1 |
| 17-18 | 1 | 12-17 | 2 | 15-17 | 2 |

In order to illustrate the efficacy and validity of the proposed method, DHBMO method is applied to the desired STNEP problem and simulation results (expansion costs and years of missing the network adequacy) versus maximum investments for both approaches are depicted in Figs. 7 and 8, respectively. Furthermore, fitness function values of both methods versus different iterations for various maximum investments are shown in Fig. 9 to compare the convergence rate and precision of the DHBMO algorithm. The performance of the DHBMO based optimized STNEP is quite prominent in comparison with the DPSO and the expansion cost and year of missing the network adequacy are significantly improved with the proposed algorithm.

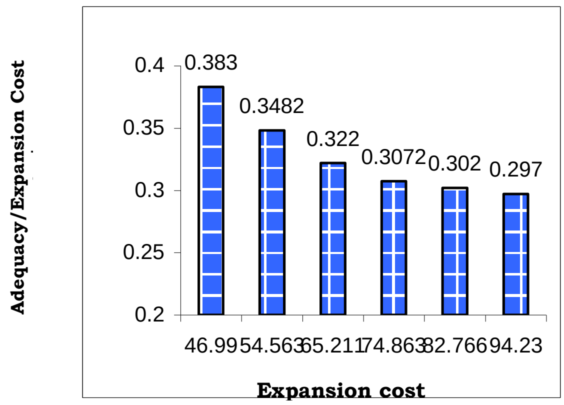



**Fig. 6. The curve of adequacy index on the expansion cost for $C_{max}$=50-100**

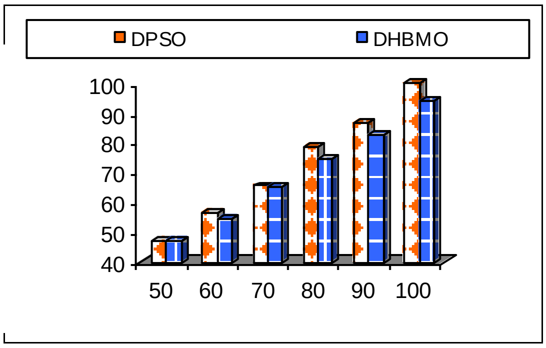



**Fig. 7. Diagram of expansion cost versus maximum investment for $C_{max}$=50-100**

B. Scenario 2: Azerbaijan Regional Electric Company Network Second network that is studied in this paper is transmission network of the Azerbaijan regional electric company. This actual network has been located in northwest of Iran and is shown in Fig. 10. All details of the test system are given in [27, 19]. Also, the characteristics of 400 kV lines are the same ones mentioned in Ref. [23]. As number of corridors for the real case study system is about 10 times more than Garvers network, practically, proposed value of $C_{max}$ should be selected more than previous section. Thus, the proposed method is tested on the case study system for $C_{max}$ = 150, 175 and 200 million dollars and the results are given in Table 3 and Fig. 11.

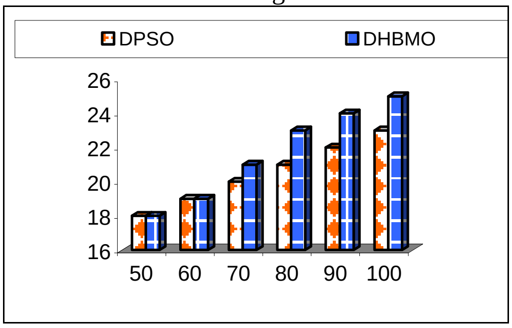



**Fig. 8. Diagram of year of missing the network adequacy versus maximum investment for $C_{max}$=50-100**

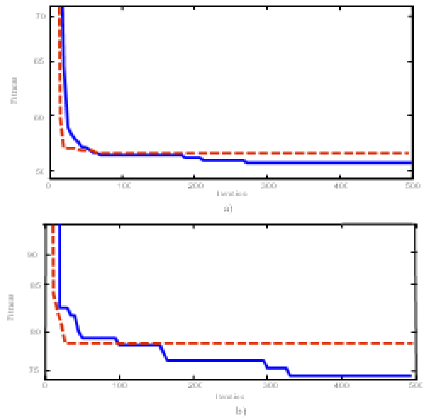


**Fig. 9. Convergence curves of DHBMO (Solid) and DPSO (Dashed); a) $C_{max}$=60 and b) $C_{max}$=80**

Also, DHBMO method is applied to the desired STNEP problem and expansion costs and years of missing the network adequacy versus maximum investments for both methods are depicted in Figs. 12 and 13, respectively.

According to adequacy index on expansion cost rate, as shown in Fig. 13, the optimal point is 161.23 million dollars for the investment cost ($C_{max}$=175).

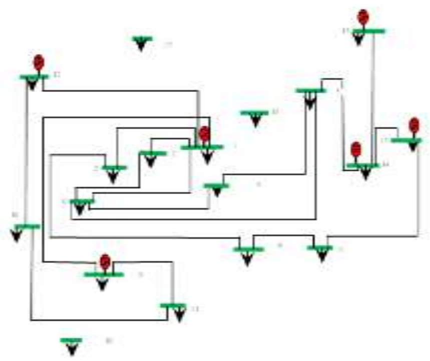


**Fig. 10. Transmission network of the Azerbaijan regional electric company**

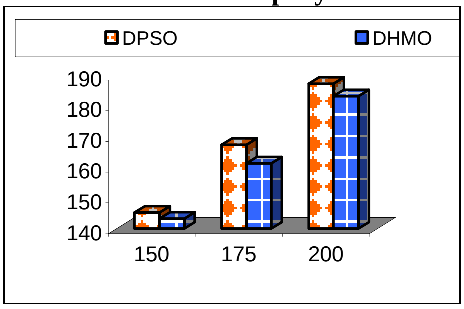



**Fig. 11. Diagram of expansion cost versus maximum investment for $C_{max}$=150-200**

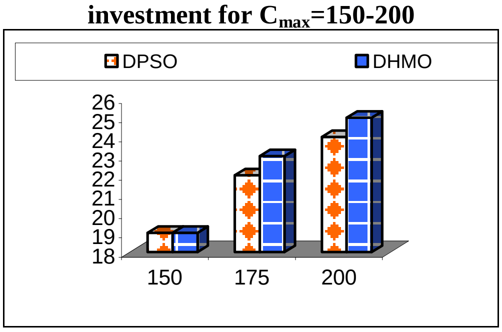



**Fig. 12. Diagram of year of missing the network adequacy versus maximum investment for $C_{max}$=150-200.**

From the above simulation results, it is evident that solution of the lines loading optimization problem by DHBMO is caused that the expansion cost and the network adequacy are more decreased and increased, respectively in comparison with DPSO. Moreover, it can be seen that convergence rate of DHBMO algorithm for different cases show the fitness function is optimized more and faster than DPSO one. Thus, it can be concluded that optimization of lines loading in TNEP by discrete HBMO algorithm is more precise, faster and finally better than DPSO approach.

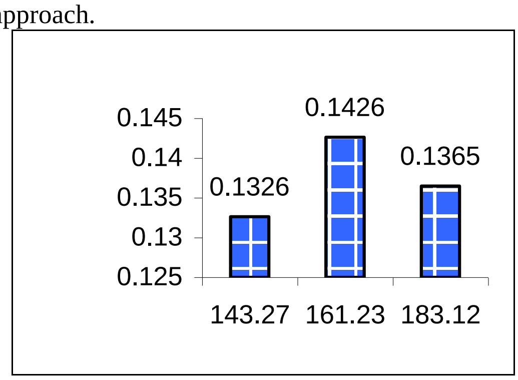



**Fig. 13. The curve of adequacy index on the expansion cost for $C_{max}$=150-200**

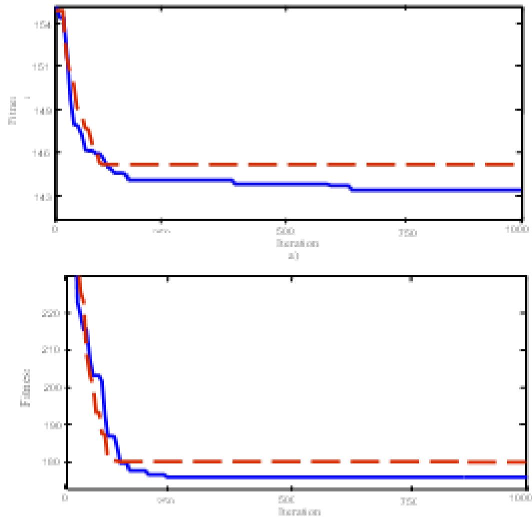


**Fig. 14. Convergence curves of DHBMO (Solid) and DPSO (Dashed) for a) $C_{max}$=150 and b) $C_{max}$=200**

**Conclusions**

An improved discrete HBMO algorithm has been successfully applied for optimization of transmission lines loading in STNEP problem. HBMO is a novel swarm based search technique which combines the advantage of genetic algorithm, simulated annealing and dedicated local search heuristics to find the best optimal possible solution. With including the line adequacy parameter in the fitness function of STNEP problem, an optimized arrangement is acquired for the network expansion that is proportional to a specified investment cost value. This arrangement possesses a maximum adequacy for feeding the load. Using the adequacy index on the expansion cost show that not only a more robust network with respect to lines overloading has not been obtained for more investment, an optimized plan is acquired with the lowest investment cost, according to technical (line adequacy) and economic (investment cost) constraints. Furthermore, comparing results of the proposed method with DPSO one, shows the robustness of the proposed algorithm and their ability to provide quickly and effectively solution for the TNEP problem and its superiority in computational complexity and success rate. Moreover, it can be seen that optimization of lines loading in transmission expansion planning using the proposed DHBMO method is caused that the network adequacy is more increased in comparison with DPSO one.

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