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BPSO Applied to TNEP Considering Adequacy Criterion

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Abstracts: Different methods have been proposed to solve the static transmission network expansion planning (STNEP) problem up to now. But in all of these studies, loading of transmission lines has not been studied using binary particle swarm optimization (BPSO) algorithm. BPSO is a good optimization method to solve nonlinear large-scale problems with discrete variables like STNEP. Thus, in this paper, STNEP problem is being studied considering network adequacy criterion using BPSO. The goal of this paper is obtaining a configuration for network expansion with lowest expansion cost and a specific adequacy. The proposed idea has been tested on the Garvers network. The results show that the network will possess maximum efficiency economically.

Keywords: BPSO, Adequacy Criterion, STNEP

1. Introduction

The main goal of transmission network expansion planning (TNEP) is to find the optimal expansion plans [1]-[3]. Calculation of investment cost for network expansion is difficult because it is dependent on the various reliability criteria [4]. TNEP is divided two types of static and dynamic. Static expansion determines numbers and place of new transmission lines that have to be constructed in the network at the beginning of the planning horizon. If the construction time of new lines is considered in the static expansion, the dynamic planning emerges [5], [6].

Much research has been published about TNEP since 1970 [7]. Some of them such as [8]-[22] is related to problem solution method. Some others, proposed different approaches for solution of this problem considering various parameters such as uncertainty in demand [11], [13], reliability criteria [1], [2], [23], [24], network losses [25], lines loading [26], and voltage level [27]. Also, some of them investigated generation expansion planning (GEP) [28] and this problem together [29], [30]. Recently, different methods such as GRASP [17], Bender decomposition [20], HIPER [16] and sensitivity analysis [21] have been proposed for the solution of STNEP problem. However, transmission planning considering network adequacy criterion using binary particle swarm optimization (BPSO) has not been studied. In [18], neural network was proposed to optimize the TNEP problem without considering the lines loading. In [10], transmitted power through the lines was included in objective function of TNEP problem, but network adequacy was not studied. In [31], dynamic transmission expansion planning considering voltage level, generation costs, and PNS (power not supplied) reliability criteria was evaluated regardless of network adequacy. Moreover, expansion planning has been studied as dynamic type and the adequacy criterion has not been considered.

Even though, recently, global optimization techniques like genetic algorithm [1], [18], [32], [33], simulated annealing [15], [22], and Tabu search [12] have been proposed to solve STNEP problem, their efficiency degrades when number of parameters to be optimized is large. In order to overcome this drawback and considering network adequacy criterion, expansion planning has been investigated by including adequacy parameter in the fitness function of STNEP problem using binary particle swarm optimization (PSO) algorithm in this paper. PSO is a novel metaheuristic optimization method that has a flexible mechanism and is useful tool for engineering optimization [34], [35].

In this paper, BPSO is used to solve the STNEP problem considering lines adequacy. The results evaluation reveals that expanded network will possess a proper adequacy to support load demand. Finally, adequacy index could be defined and used to compare some designs that have got different expansion costs for specified adequacy rates.

2. Modeling the Proposed STNEP Problem Mathematically

The problem is formulated using DC power flow model as objective function (1).

$$Fitness = \sum_{i,j\in\Omega} CL_{ij} n_{ij} - C_{Aw} \times (T - T_o)^2 \qquad (1)$$

Subject to [36]:

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

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

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

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

N-1 Safe Criterion (6)

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.

θ: Phase angle of each bus.

γ_{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.

CL_{ij}: Construction cost of each line in branch i-j.

n_{ij}: Number of new circuits in corridor *i-j*.

Ω : Set of all corridors.

C_{Aw}: Annual worth of transmission network adequacy (\$/(year)^2).

T_O: Required time for missing the expanded network adequacy (year).

T: Required time for missing the expanded network adequacy after planning horizon (year).

The goal is to determine number of new circuits in order to obtain maximum adequacy for network with minimum cost. Thus, the optimization problem is an integer programming problem. In this study, the BPSO is used to solve the STNEP problem.

3. BPSO and Particle Structure of the Problem

Particle swarm optimization algorithm is based on the ability of human societies to process knowledge [37], [38]. Its roots found in artificial life and evolutionary computation. The concept of fitness and candidate solutions of the problem (particles) are found in evolutionary computation [39]. Particles are presented by vectors including problem variables. This optimization technique can be used to solve problems that are optimized by GA without facing some difficulties of genetic algorithms. It is the search method to improve the speed of convergence and find the global optimum value of fitness function.

In first step, a population of possible solutions (particles) is constructed randomly. Each particle includes D elements (variables). For example, position of *i*th particle is represented as $X_i = (x_{i1}, x_{i2},...,x_{iD})$. In this way, fitness value of *i*th particle is exhibited by $P_i = (p_{i1}, p_{i2},...,p_{iD})$. The best value of P_i is known as pbest. Also, the overall best value of PSO is called “gbest”. According to Eq. (8), each particle moves towards pbest and gbest using velocity vector. The position of the *i*th particle is changed by its velocity ($V_i= (v_{i1}, v_{i2}... v_{iD})$) as (8) [40]:

$$v_{id}(t+1) = \omega \times v_{id}(t) + c_1 r_1 (P_{id} - x_{id}(t)) + c_2 r_2 (P_{gd} - x_{id}(t)) \quad (7)$$

$$x_{id}(t+1) = x_{id}(t) + c v_{id}(t+1) \qquad (8)$$

Where, P_{id} and P_{gd} are *pbest* and *gbest*. ω is inertia weight that is adjusted in training process [40]. In (8), term of $c_1 r_1 (P_{id} - x_{id}(t))$ is indicator of individual movement and term of $c_2 r_2 (P_{gd} - x_{id}(t))$ describes the social behavior. t is the number of algorithm iterations and the velocity v_{id} (t+1) is a real number in [-V_{max}, V_{max}].

PSO cannot be used directly to solve the STNEP problem, because decision variables in TNEP are discrete time type, while this algorithm is performed for real numbers. Particle swarm optimization (BPSO) algorithm is a way to overcome this drawback. In this approach, the position of *i*th particle is stated by a binary string where, X_i ε {0,1}. Therefore, values of (P_{id} - $x_{id}(t)$) and (P_{gd} - $x_{id}(t)$) are 0 or ±1. The time-varying inertial weight does not improve the convergence of BPSO and a constant weight of 1.0 is suggested [41]. Therefore, velocity of particle *i* that is represented by circuit’s change of each corridor is updated by the following equation:

$$v_{id}(t+1) = v_{id}(t) + c_1 r_1 (P_{id} - x_{id}(t)) + c_2 r_2 (P_{gd} - x_{id}(t)) \quad (9)$$

Where,

$$\begin{aligned}
&P_{id}-x_{id}(t)=1; && if\ P_{id}=1, x_{id}=0\\
&P_{id}-x_{id}(t)=0; && if\ P_{id},\ x_{id}=0\ \ or\ \ P_{id}, x_{id}=1\\
&P_{id}-x_{id}(t)=-1; && if\ P_{id}=0,\ \ x_{id}=1\\
&P_{gd}-x_{id}(t)=1; && if\ P_{gd}=1, x_{id}=0\\
&P_{gd}-x_{id}(t)=0; && if\ P_{gd},\ x_{id}=0\ \ or\ \ P_{gd}, x_{id}=1\\
&P_{gd}-x_{id}(t)=-1; && if\ P_{gd}=0,\ \ x_{id}=1
\end{aligned}$$

In (9), t is the number of algorithm iterations and the velocity v_{id} $(t+1)$ is a real number in $[-V_{max}, V_{max}]$. An intermediate variable S (v_{id} $(t+1)$) is defined as (10) to provide possibility of adding the real value v_{id} $(t+1)$ to the binary value $x_{id}(t)$ in (9) [41]:

$$S(v_{id}(t+1))=\frac{1}{1+e^{-v_{id}(t+1)}} \tag{10}$$

Equation (10) maps the domain of $[-V_{max}, V_{max}]$ into the range of $[1/(1+e^{V_{\max}}), 1/(1+e^{-V_{\max}})]$, which is a subset of (0, 1). The value of S(v_{id} $(t+1)$) can be therefore interpreted as a probability threshold. A random number with a uniform distribution in (0, 1), R, is then generated and compared to S (v_{id} $(t+1)$). Thus, the position of the particle i can be updated as follows:

$$\begin{aligned}
&x_{id}(t+1)=1; && if\ R\langle S(v_{id}(t+1))\\
&x_{id}(t+1)=0; && if\ R\geq S(v_{id}(t+1))
\end{aligned} \tag{11}$$

The probability that x_{id} $(t+1)$ equals to 1 is S (v_{id} $(t+1)$) and the probability that it equals to 0 is 1- S (v_{id} $(t+1)$). The flowchart of the proposed algorithm is shown in Figure 1.

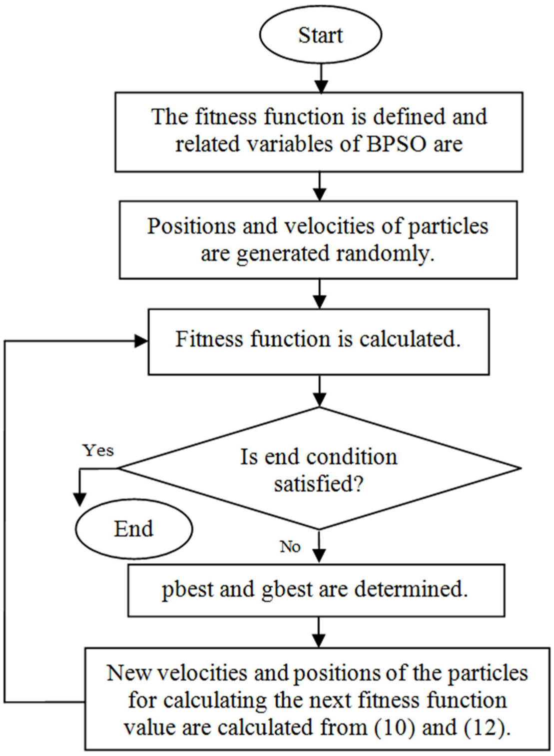

Figure 1. *Flowchart of the BPSO algorithm.*

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

Table 1. *Value of parameters for BPSO algorithm.*

Parameter	Value
Problem dimension	15
Number of particles	10
Number of iterations	500
C_1	1.7
C_2	2.3

4. Case Study

To prove the validity of the proposed planning technique, it was applied to the Garver's 6-bus system. The configuration of the test system before expansion is given in Figure 3. The length of possible corridors and construction cost of 230 kV lines has been given in Tables 2 and 3 respectively. In this network, existed lines are 230 kV with capacity 400 MW. Resistance and leakage reactance per kilometer of each line are 0.00012 and 0.0004, respectively. Substations 1, 3 and 6 are generator busses that their generation limit are 100 MW, 250 MW and 450 MW, respectively. The load data has also given in Table 4. Finally the planning horizon year is 5.

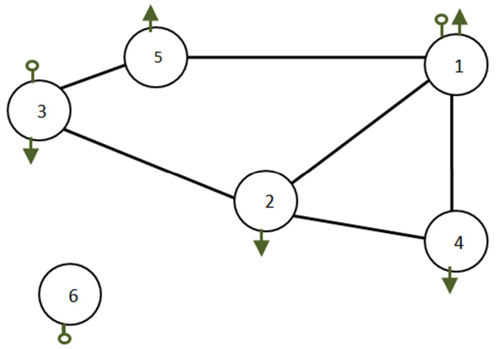

Figure 2. *Garver's 6-bus network.*

Table 2. *Configuration of the network.*

From bus	To bus	Length (Km)
1	2	100
1	3	95
1	4	150
1	5	60
1	6	170
2	3	55
2	4	110
2	5	65
2	6	75
3	4	155
3	5	50
3	6	120
4	5	157
4	6	85
5	6	160

Table 3. *Construction cost of 230 kV lines.*

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 4. *Arrangement of the load.*

Bus	Load (MW)	Bus	Load (MW)
1	80	4	160
2	240	5	240
3	40	6	0

Results are presented as follows after applying the proposed method (BPSO) to Figure 1 for various times of missing the expanded network adequacy (T_o). The dash lines into figures are number of required circuits for adding to the network until planning horizon year.

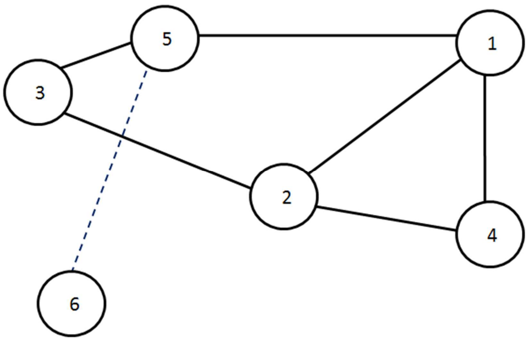

Figure 3. *Proposed plan for* T_o*=6.*

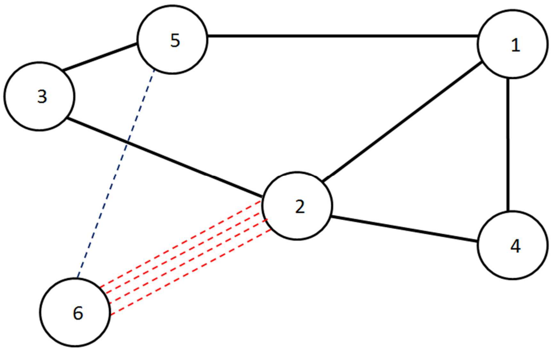

Figure 4. *Proposed plan for* T_o*=8.*

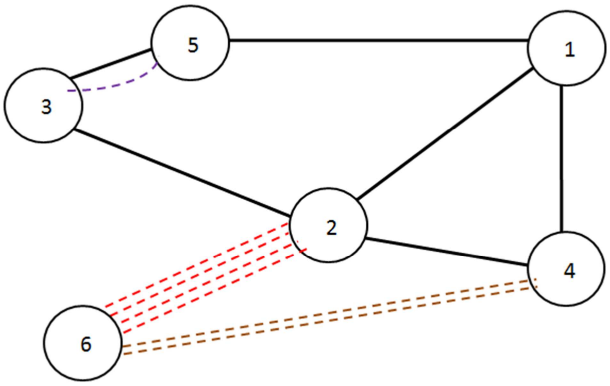

Figure 5. *Proposed plan for* T_o*=10.*

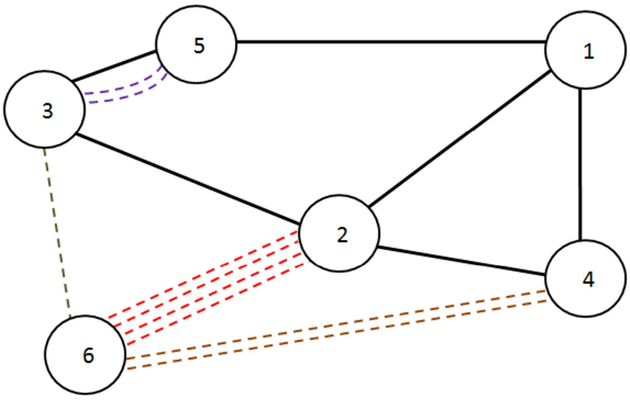

Figure 6. *Proposed plan for* T_o*=12.*

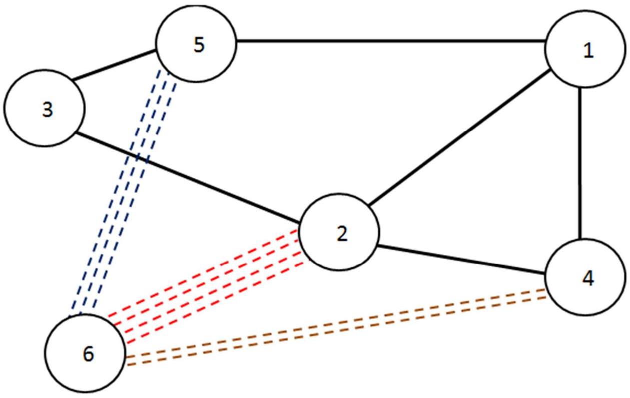

Figure 7. *Proposed plan for* T_o*=14.*

Also, Figure 9 shows expansion costs of above-mentioned configurations.

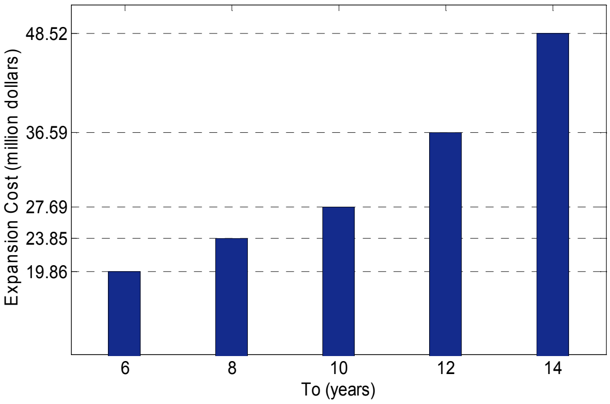

Figure 8. *Expansion costs of proposed plans versus* T_o*.*

It is noted that, by network adequacy (T_o) increasing, required lines which could be appended to the network is expanded and therefore expansion cost of the network is increased. However, it seems that the network adequacy may be acquired with lower relative expansion cost. Network adequacy versus network expansion cost has been depicted in Figure 9.

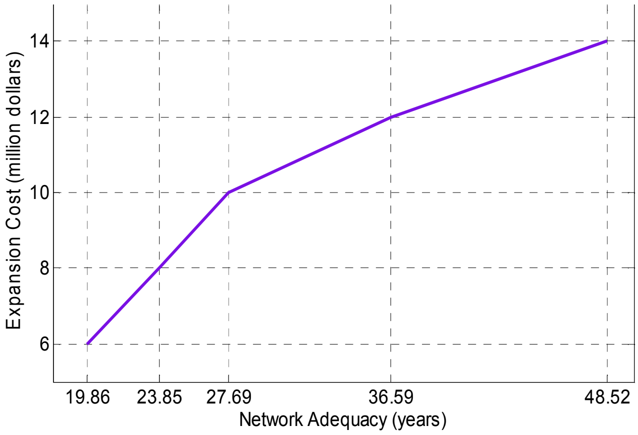

Figure 9. *Adequacy curve with respect to network expansion cost.*

As shown in Figure 9, increasing in higher expansion cost (36.59 to 48.52 million dollars), changes the network adequacy more slightly than other expansion costs. Thus, a parameter, named expansion cost index on adequacy rate, is defined for obtaining best design according to the expansion cost and the network adequacy. This parameter is the expansion cost per the network adequacy rate (year). Thus, a low value is desirable for this index. As shown in Figure 10, this index has been acquired according to various expansion costs indicated in Figure 8. According to Figure 10, the optimized point is 27.69 million dollars for expansion cost (T_o=10 years).

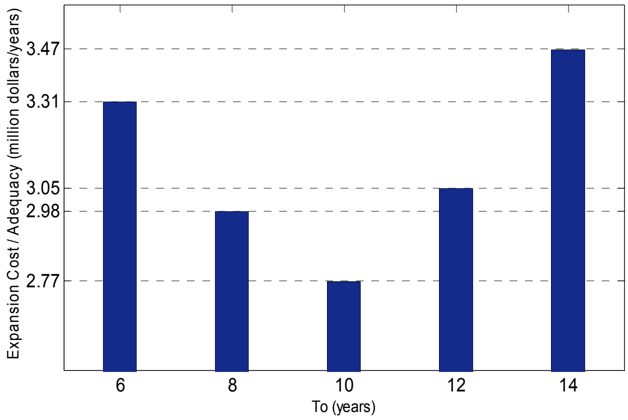

Figure 10. *The curve of the expansion cost index on adequacy rate versus* T_o.

5. Conclusions

By including the network adequacy criterion in the fitness function of STNEP problem, an optimized arrangement is acquired for the network expansion using binary particle swarm optimization algorithm that is proportional to a specified adequacy rate. This arrangement possesses a proper adequacy for feeding the load with a respectively lower cost. The obtained conclusions from adequacy-cost curve show that a more robust network with respect to lines overloading has not been obtained for more expansion cost (indeed, adding more new lines to the network). Finally, using the expansion cost index on the adequacy, an optimized plan is acquired with respectively lower expansion cost, according to a specified adequacy.

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