

# Transmission Expansion Planning using Particle Swarm Optimization Method

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**ABSTRACT:** Transmission Network Expansion Planning (TNEP) consists of obtaining the plan to expand a transmission network use to reduce construction and operational cost. Transmission network expansion planning determine all the changes needed in the transmission network i.e. addition, modification or replacement of old facilities. Transmission expansion planning is a very complex problem to power system. The complexity of problem is due to its mixed integer, non-linear, non-convex nature. To solve such problem, Particle Swarm Optimization Technique is introduced. Particle Swarm Optimization (PSO), a population based stochastic optimization technique. It is a derivative free process and easy to implement. The main goal is to determine the optimum operating condition of the control variable and minimization of transmission losses at normal operating condition.

**KEYWORDS:** Transmission Network Expansion Planning, Particle Swarm Optimization, security constraints.

## I. INTRODUCTION

The majority of transmission system planning required is due to a continuing growth of electric demand. Even allowing for significant improvements in the efficiency of electric appliances and usage by a growing population and economy leads to increased demand for electric power.

The transmission network expansion planning problem consists of two mutually related tasks, namely, the investment and operation sub-problems [1]. Transmission expansion planning of electrical power systems is a complex task, involving the determination of where, when and which facilities must be built to guarantee an economic and reliable supply of the predicted load up to the horizon year. Afterwards, the planner has to determine the minimum cost plan, taking into account the available initial data and some reliability criterion.

The data available is: base-year topology, candidate circuits, forecast generation and demand of the planning horizon, investment constraints, etc. [2]. Techniques such as dynamic programming, linear programming [2], non-linear programming, mixed-integer programming, discrete evolutionary [13], vector-evaluated [13], Hierarchical decomposition, and Branch and Bound method have been used and are categorized as mathematical based approaches [4].

Kennedy and Eberhart first introduced particle swarm optimization (PSO) in 1995 as a new heuristic method. The old version of PSO was intended to handle only nonlinear continuous optimization problems. However, many advances in PSO development elevated its capabilities to handle a wide class of complex engineering and science optimization problems [5]. The optimization problem is solved using linear programming techniques. Such an approach has the following drawbacks: a linear mathematical model is used for power flow computing, reactive power flow is not tackled, real power losses are neglected, objective function (OBF) refers to the power system branch overloading cost minimization, etc. [6].

The main difficulties are due to the combinatorial nature of the planning process, which normally leads to an explosive increase in the number of alternatives that have to be analyzed even for moderately sized systems [7]. Multiple objectives are often considered simultaneously in practical transmission network planning [8].

## II. MATHEMATICAL MODEL

A DC model is used for modeling static TNEP problem here. System security is an important aspect and must be considered in any TNEP problem [2], [9].

$$\min v = \sum_{l \in \Omega} c_l n_l \quad (1)$$

s.t.

$$S f^k + g = d \quad (2)$$

$$f_l^k - \gamma_l (n_l^0 - n_l) (\Delta \theta_l^k) = 0, \text{ for } l \in 1, \dots, nl \& l \neq k \quad (3)$$

$$f_l^k - \gamma_l (n_l^0 - n_l - 1) (\Delta \theta_l^k) = 0, \text{ for } n = k, \quad (4)$$

$$|f_l^k| \leq (n_l^0 - n_l) \bar{f}_l, \text{ for } l \in 1, 2, \dots, nl \& l \neq k \quad (5)$$

$$|f_l^k| \leq (n_l^0 - n_l) \bar{f}_l, \text{ for } n = k \quad (6)$$

$$0 \leq n_l \leq \bar{n}_l \quad (7)$$

$$n_l \geq 0, \text{ and integer, for } 1, 2, \dots, \& n \geq l \& n_l \neq k (n_l + n_l^0 - 1) \geq 0, \text{ and integer, for } n = k$$

where,

$k=0$ , represents the base case without any line outage.

$S$ : branch-node incidence transposed matrix of the power system,

$f^k$ : vector with elements  $f_l^k$ ,

$\gamma_l$ : susceptance of the circuit that can be added to  $l^{th}$  right-of-way,

$n_l$ : the number of circuits added in  $l^{th}$  right-of-way,

$n_l^0$ : no. of circuits in the base case,

$\Delta \theta_l^k$ : phase angle difference in  $l^{th}$  right-of way when  $k^{th}$  line is out,

$f_l^k$ : total real power flow by the circuit in  $l^{th}$  right-of-way When  $k^{th}$  line is out,

$\bar{f}_l$ : maximum allowed real power flow in the circuit in  $l^{th}$  right-of-way,

$\bar{n}_l$ : maximum number of circuits that can be added in  $l^{th}$  right-of-way,

$\Omega$ : set of all right-of-ways,

$nl$ : total number of lines in the circuit

The objective of TNEP problem is to minimize the total investment cost of the new transmission lines to be constructed, satisfying the constraint on real power flow in the lines of the network.

## III. PARAMETER CONTROL

One of the advantages of PSO is that PSO take real numbers as particles. It is not like GA, which needs to change to binary encoding, or special genetic operators have to be used. We can use the standard procedure to find the optimum. The searching is a repeat process, and the stop criteria are that the maximum iteration number is reached or the minimum error condition is satisfied [2].

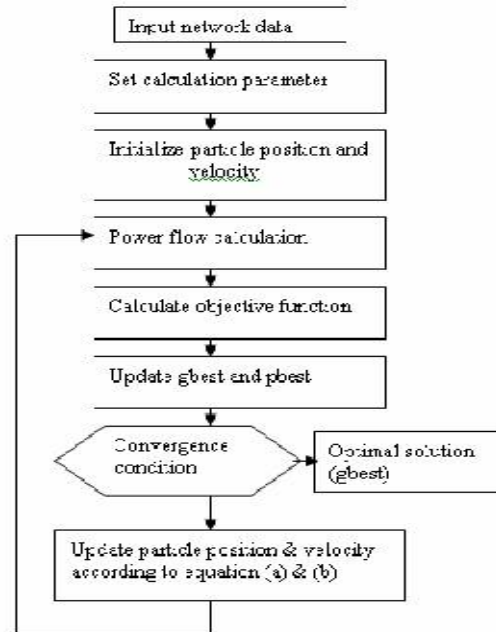


Fig. 1 Flow Chart of Transmission Planning Expansion Problem (TNEP) using Particle Swarm Optimization

#### IV. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization respect the n- dimensional search space, the velocity and the position of particle as  $X_i = (x_{i1}, x_{i2} \dots x_{in})$  and  $V_i = (v_{i1}, v_{i2} \dots v_{in})$  respectively. The particle and the group best position of population is represented by  $Pbest_i = (X_{i1}^{Pbest}, X_{i2}^{Pbest} \dots X_{in}^{Pbest})$  and  $Gbest = (X_{i1}^{Gbest}, X_{i2}^{Gbest} \dots X_{in}^{Gbest})$  respectively [10].

$$V_i^{k+1} = \omega V_i^k + c_1 rand_1 * (Pbest_i^k - X_i^k) + c_2 rand_2 * (Gbest_i^k - X_i^k) \quad (8)$$

Where,

- $V_i^k$  velocity of individual i at iteration
- $\omega$  weight inertia factor
- $c_1, c_2$  weight factor
- $rand_1, rand_2$  random number between 0 and 1
- $Pbest_i^k$  best position of i at iteration k
- $Gbest_i^k$  best position of group at iteration k
- $X_i^k$  position of particle i at iteration k

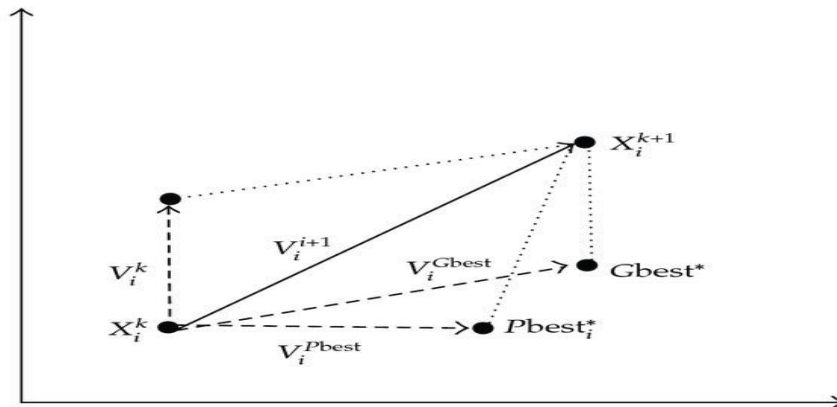


Fig.2 representation of Particle Swarm Optimization Algorithm

### Advantages of PSO

One of the advantages of PSO is that PSO take real numbers as particles. It is not like GA, which needs to change to binary encoding, or special genetic operators have to be used.

- It is a derivative free algorithm
- Flexible to form hybrid tools
- Less sensitive to the nature of the objective function
- Easy to implement and program

Population size:15

$V_{max}$  : It determines the maximum change one particle can take during one iteration. Usually  $V_{max}$  is set at about 10-20% of the dynamic range of the variable on each dimension.

Here  $V_{max} = 5$

Learning factors:  $c_1$  and  $c_2$  are usually equal to 2. However, other settings were also used in different papers. But usually  $c_1=c_2$  and ranges from [0, 4]

The stopping condition: the maximum number of iterations the PSO execute and the minimum error requirement. The maximum number of iterations is set to 100. This stopping condition depends on the problem to be optimized.

### Application of parallel PSO for TNEP

This section presents a Parallel Particle Swarm Optimization algorithm (PPSO) for solving long term transmission expansion planning. It shows that parallel PSO methods reduce computing time and increase the chance of finding global answer. There are two reasons for using parallel PSO [11].

**Step 1:** Selection of the parameter and initial population (N1)

**Step 2:** Solving network expansion planning problem by using standard PSO With selected parameters and the initial population with the number of repetition (N2)

**Step 3:** Storage of cost function and global optimal for (N2)

**Step 4:** Repeat step 2 and 3 until all N2 particle have different cost function (Remove particles have the same cost function and repeat step 2)

**Step 5:** Global optimum cost function taking values stored as part of the initial population for the second stage of the optimization problem

**Step 6:** Select (N1-N2) random initial population so all initial population is N1

**Step 7:** Solving PSO method [11].

### V. CASE STUDY

The Garver six-bus test system, shown in Fig. 3, was considered to show the performance of PSO in obtaining the optimal solution. The optimal solution of the six-bus system cannot be obtained by the Benders approach due to non-convexities. Generation capacities of buses 1 and 3 are 150, and 120 MW, respectively. Loads for buses 1 to 5 are 20, 60, 10, 40 and 60 MW. The load in each bus is increased four times for the planning horizon and a new bus with a generating capacity of 600MW is introduced to meet the future demand. Table 3 present the data for the planning horizon year [2], [12].

Bus	Generation (MW)	Demand (MW)
1	150	80
2		240
3	360	40
4		160
5		240
6	600	

Table.1 Bus data for six-bus garver system

Line	Resistance (p.u.)	Reactance (p.u.)	Investment cost US\$
1-2	0.1	0.4	40
1-3	0.09	0.38	38
1-4	0.15	0.6	60
1-5	0.05	0.2	20
1-6	0.17	0.68	68
2-3	0.05	0.2	20
2-4	0.1	0.4	40
2-5	0.08	0.31	31
2-6	0.08	0.3	30
3-4	0.15	0.59	59
3-5	0.05	0.2	20
3-6	0.012	0.48	48
4-5	0.16	0.63	63
4-6	0.08	0.3	30
5-6	0.15	0.61	61

Table.2 Line data for six-bus garver system

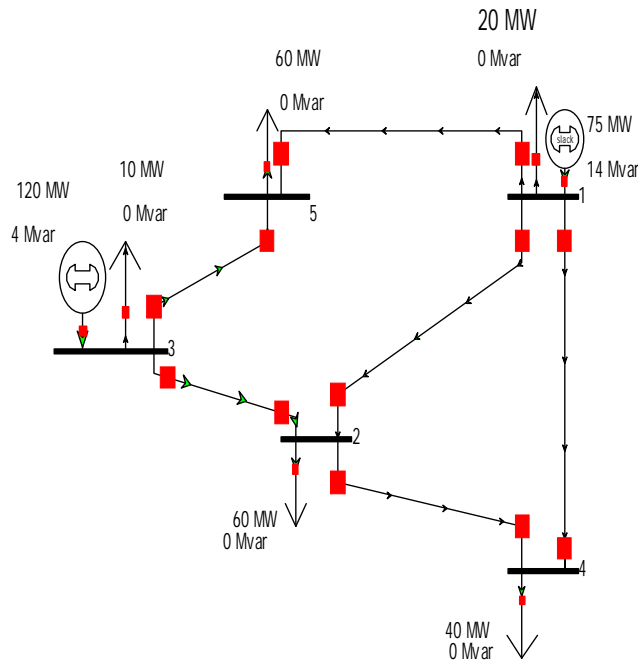


Fig.3 Original network of the six-bus Garver system.

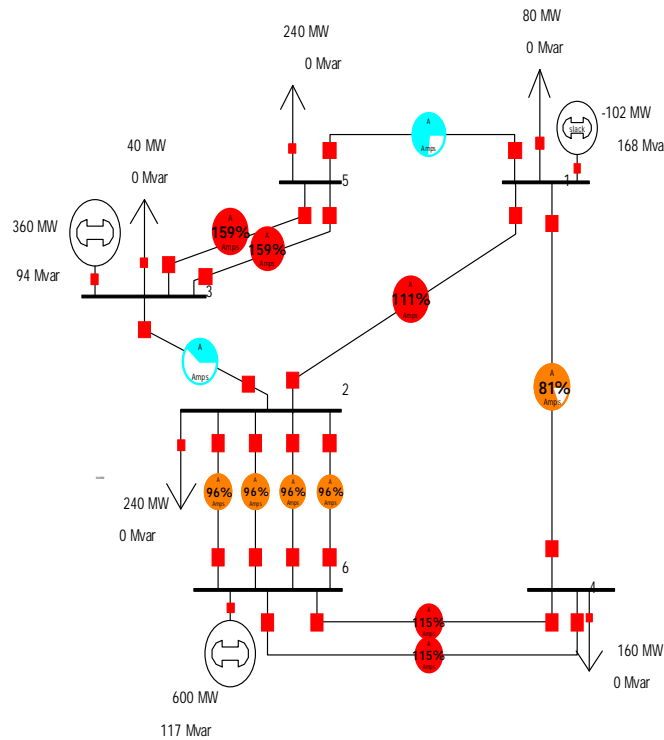
**VI. EXPERIMENTAL RESULTS**

The Garver system has six buses, 15 candidate branches, a total demand of 760MW.

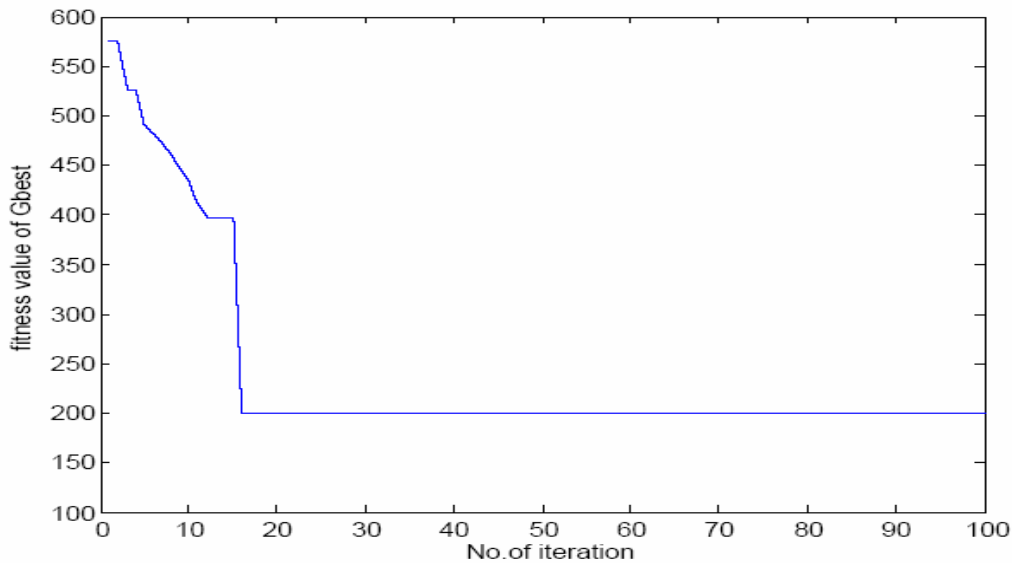
Generation Plan G1	$n_{2-6} = 4, n_{3-5} = 1, n_{4-6} = 2$
Total Number of Lines	7
Investment cost [104 US\$]	200

Generation Plan G2	$n_{2-6} = 4, n_{3-5} = 2, n_{3-6} = 1, n_{4-6} = 3$
Total Number of Lines	10
Investment cost [10 <sup>4</sup> US\$]	298

**Table.3** Results for TNEP without security constraints for generation plan for G1 and G2.



**Fig.4** Existing conditions of the six-bus Garver system.



**Fig.5** Convergence curve of PSO for Garver six-bus system.

## VII. CONCLUSION

Transmission network planning is a multi-objective mathematical optimal problem, which should be solved by a multi-objective mathematical model. In this paper, a particle swarm optimization method for transmission network expansion planning is presented in which a novel constructive heuristic algorithm that works directly with the DC model. In case of PSO based algorithms, the potential solutions (particles) are associated with a random velocity, spreading through the problem space by following the best particles. For low and medium complexity systems PSO algorithm presents excellent performance. The principal advantage of the algorithm is that it works directly with the solution given by the DC model with relaxed integer variables. The resulting information is of excellent quality for use as a sensitivity index.

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