COST MINIMIZATION BASED TRANSMISSION NETWORK EXPANSION PLANNING WITH DISTRIBUTED GENERATION PENETRATION

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Abstract—**Expansion of the electricity sector and liberalized electricity market leads to more jobs challenging the designer of the transmission network. In order to match with the load growth and generation patterns schemes optimal transmission network expansion planning (TNEP) has to be done. Transmission network expansion planning (TNEP) is one of the important aspects of power system planning. It will find out where, when and how many new transmission lines should be added to the network. In order to meet the load growth and generation patterns to maintain the system reliability, stability, and economic constraints, transmission network expansion planning problem is highly complex in nature. Further, as network size increases system analysis becomes difficult. The objective of TNEP was to minimize the transmission network investment cost required to meet the growing load and the added constraints. From the recent past, renewable energy resources are becoming major attraction part to the power sector. Large-scale integration of distributed generation (DG) affects the electrical industry and as well as the strategy of the transmission network expansion. Static TNEP problem is modeled by using DC power flow model and to solve this problem a population search based algorithm named, Gbest Artificial Bee Colony (GABC) optimization algorithm is proposed. To show the effectiveness of the proposed method, it is evaluated on Garver's 6-bus network, and IEEE 24-bus test system. Results obtained are compared with the previous published literature.**

Keywords—DC power flow, distributed generation, G-best artificial bee colony algorithm, investment cost, resizing, transmission expansion planning.

I. INTRODUCTION

Nowadays modern electric power systems consist of large- scale and highly complex interconnected transmission systems and also due to the market restructured environment, transmission expansion planning (TEP) is now a significant power system problem. Transmission planning state's the problem of reinforcement of an existing transmission network to work with the growing electricity demand. Transmission expansion planning is to determine when and which types of new transmission facilities are required in the power system. It also ensures that there are no overload paths in to build new lines connections during the planning horizon [1].

As per present scenario demand of electric power generation is increasing. It is difficult for utility to provide economical and technical solution to their customers. This imputes to use new source of energy such as renewable energy as decentralized power. In recent years, distribution generation (DG) has been one of the most attractive research areas in the field of power generations. In general, DG can be defined as electric power generation within distribution networks or to the customer side of the network. Hence, it is essential to study the impacts of DG in the transmission network expansion planning (TNEP).

TNEP problems are generally, classified as static and dynamic transmission network expansion planning methods. Static transmission network expansion planning determines where and how many new transmissions lines connected with the system, whereas dynamic transmission network expansion planning is timing based method. Mostly in power systems, generating sources are located away from the load centers. Therefore, TNEP problem receives an important role in power system planning. Also as the network size increases more computational effort is required to solve the TNEP problem.

Under these situations, transmission investment cost involved is huge [2]. Thus, the Static transmission network expansion-planning problem receives an important role in power system planning and must be appraised carefully. As the system size increases, rigorous amount of calculation is needed for selection of new lines. TNEP become large, nonlinear, mixed integer and non-convex optimization problem, many conventional and new meta-heuristic optimization techniques are applied to solve it. Firstly in 1970, Garver's applied linear programming approach to solve the TNEP problem [1]. Many researchers have been worked to solve TEP problem by applying various techniques. This includes dynamic programming [3], interactive method [4], hierarchical decomposition [5], simulated annealing for long term TNEP [6], constructive heuristic algorithm (CHA) applied for solving AC TNEP problem in [7]. Application of CHA in a branch-and- bound to solve DC model static TEP problem is presented. Branch- and-Bound algorithm [9], Artificial techniques as, ANN [10], Fuzzy systems [11], discrete particle swarm optimization (DPSO) algorithm [12], and Projection- Adapted Cross Entropy method [13], novel differential evolution algorithm (DEA) [14] were applied to solve transmission expansion problem.

In this work, Artificial Bee Colony (ABC) algorithm is a population-based search procedure that is used as an optimization tool in solving complex, non-linear, and convex optimization problems. It has been applied to optimize other problem of power such as optimal allocation of Distributed Generation [15], unit commitment problem [16]. The proposed algorithm implemented to solve the DC power flow model based Static transmission network expansion planning problem with three test cases for without generation resizing and with resizing consideration. The rest of the paper is organized as follow: Section II describes the mathematical model for transmission expansion planning. Section III presents overview of Artificial Bee Colony Algorithm and its implementation to TNEP problem. Section IV presents the results obtained and discussion and finally conclusion in Section V.

II. MATHEMATICAL MODEL FOR TNEP

Generally, for the TNEP problem DC power flow model is used because of its more accuracy and fast operation. The other models, such as the transportation, hybrid and disjunctive models, which are used as an alternative to DC model [17].

A. Static TNEP model

The objective function for the TNEP problem is to minimize to the investment cost of the system. In this paper, the static transmission expansion-planning problem can be formulated based on lossless DC power flow model as follows [8-9, 17],

Minimize

$$C_{inv}=\sum_{i,k\epsilon\Omega} CL_{ik}\, n_{ik} \quad \text{equation (1)}$$

subjected to

$$f_{ik} = g_i + d_{gi} - d_i \quad \text{equation (2)}$$

$$f_{ik} - \gamma_{ik}(\overset{\circ}{n}_{ik} + n_{ik})(\theta_i - \theta_{k)} = 0 \quad \text{equation (3)}$$

$$|f_{ik}| \le \left(\overset{\circ}{n}_{ik} + n_{ik}\right) f_{ik}^{max} \quad \text{equation (4)}$$

$$g_i^{min} \le g_i \le g_i^{max} \quad \text{equation (5)}$$

$$dg_i^{min} \le dg_i \le dg_i^{\max} \quad \text{eqaution (6)}$$

$$0 \le n_{ik} \le n_{ik}^{max} \quad \text{equation (7)}$$

Where C_{inv} , CL_{ik}, n_{ik} and Ω represents, the total transmission investment cost in US $, construction cost of each line in branch *i-k* in US $ and the number of circuits added in each right way of *i-k*.Ω represents set of all right of way paths for candidate's network expansion. $f_{ik}$is power flow in branch *i-k,* $f_{ik}^{max}$is the thermal limit of the circuit g_i and d_i are the real power generation and the corresponding demand at each node i, θ_i and θ_k are the voltage angle at i and k bus, $\overset{\circ}{n}_{ik}, n_{ik}^{max}, n_{ik}$ are the number of existing circuits, maximum number of added circuits in branch, the total integer number of circuits added to the branch i-k.$\gamma_{ik}$is the susceptance between buses i and k,

g_i, g_i^{max}, g_i^{min} represents the real power generation, the maximum, lower limit of generation capacity at bus i, and dg_i^{max}, dg_i^{min} and dg_irepresents the maximum and minimum capacity of distributed generation and distributed generation at bus i respectively.

Equation (1) represents the total investment cost of new lines added, (2) and (3) represents power balance constraint at each node and voltage balance constraint in each loop both are based on Kirchhoff's law, (4) represents the power flow limit for each branch, (5) represents power generation limit at each bus, (6) represents distribution generation limit at each bus and (7) represents link expansion limit for each branch.

The objective is to minimize the total investment cost of the new transmission lines to be build, satisfying the constraints mentioned in above equation.

III. OVERVIEW OF ABC ALGORITHM

Several other nature inspired algorithm have been used for solving the optimization problems. Among them, the Artificial Bee Colony (ABC) algorithm is meta-heuristic algorithm based on intelligent behavior of honeybee swarm. The position of a food source signifies a possible solution of the optimization problem. Karaboga and Bastruk have proposed ABC algorithm, in that the colony of artificial bees colony consists of three groups of bees namely employed bees, onlooker bees, and scout bee [18]. Bees going to food source randomly, they carry information and share it with other bees waiting in the hive regarding location and the profitability of that particular food source are called employee bees. The bees waiting in the dance area for making decision to choose a food source based upon information given by the employed bees known as onlooker bees and a bee which carrying out random search around the swarm to find food source is scout bee.

In GABC algorithm, probable solution of the optimization problem is representing by the position of a food source, and the fitness solution of the problem a corresponding nectar amount of a food source.

GABC generates arbitrarily distributed initial population P of N_S vectors of candidate solutions as in (8)

$$P = [X_1, \dots . X_i, \dots ., X_{NS}]^T$$

(8)

Each candidate solution X_i is a D-dimensional vector, containing as many integer-valued parameters in (9) as D is the nmnber of optimized parameters.

$$X_i=[X_{1,j}, \dots, x_{j,i}, \dots, X_{D,i}] \ , \ i = 1, \dots, Ns$$

(9)

In order to update the new candidate food position, employee bee uses (10) to search for new position from the old in memory

$$V_{ij} = X_{ij} + \emptyset_{ij} * (X_{ij} - X_{kj}) \quad (10)$$

where$\emptyset_{ij}$ is a random number between [-1, 1], $k\epsilon\{l, 2..., Ns\}$ and $j\epsilon\{I, 2..., D\}$ are randomly chosen indexes.

Onlooker bee selects a food source according to the probability calculated by using (11) associated with that food source pp_i.

$$pp_i = fitness_{\ i} \ / \ \sum_{j=1}^{Ns} fitness_j$$

(11)

In ABC, if a position cannot be enhanced during set number of cycles, then it is assumed to be abandoned. This control parameter is named 'limit'. Assume that the abandoned source is X_1 and $j \ \epsilon \ \{I, 2..., D\}$, then the new food source found out by the scout replaced the abandoned one by using (12)

$$X_i^j = X_{min}^j + rand[0,1] * (X_{max}^j - X_{min}^j) \quad (12)$$

For each candidate source position v_{ij} is produced and estimated by the artificial bee, its quality is compared with its old one. If it's found better than old one, old one replaces it and if not old one is retained in memory.

In ABC algorithm the solution search equation described as in (10) has good at exploration but poor at exploitation. In order to achieve good optimization performance the exploration and exploitation abilities should be equally balanced. Therefore to achieve this, Eqn (10) is modified to improve the exploitation as follows

Where the term added in (10) g-best term is is the j^{th} element of the global best solution, and is a uniform random number in [0, C] where C is a non-negative constant. The modified ABC was named as G-best-guided ABC (GABC) algorithm.

A. Implementation of GABC to TNEP problem

This section provides application of GABC algorithm to solve STNEP problem as follows:

1) Input parameter and initialization step:

After receiving required input parameters such as population size, number of food source, number of employed bees, onlooker bees and limit value. Lower and upper bounds of candidate solution are specified. Algorithm generates randomly distributed initial population of Ns size by eq. (8). In this TNEP problem formulation, each candidate solution X_i is an integer value. $X_i = [n_{1,j}, \dots, n_{j,i}, \dots, n_{D,i}], i = \{1,2 \dots N_s\}$, D is the number of possible and n_{ji}represents the number of possible lines between each branch j and i.

2) ***Employee bees search phase:***

In this algorithm, to optimize food source employed bees select the position by using eq. (10). Penalty factor method is used to handle the constraints. After calculating the position, the value of objective functions will be calculated and it keeps the best solution obtained in memory.

3) ***Onlooker bees search phase:***

Based on the probabilities, find out from eq. (11), onlooker bees search for food source in swarm, and if the newly obtained food source dominates the old one by using eq. (10) that will updates its position.

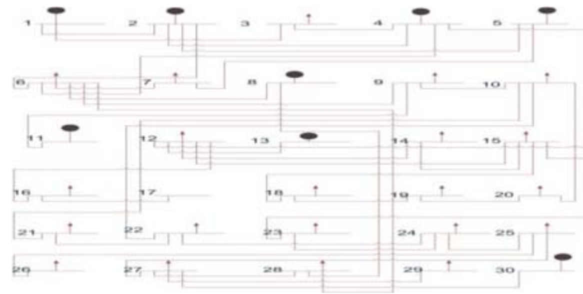
4) Scout bee search phase:

If a solution found in onlooker search phase cannot be improved further for certain numbers of cycles, then scout bee finds a new source randomly and replace the abandoned source using eq. (12). If the maximum number of cycles is not reached, jump to step 3. The algorithm is terminating when it reaches to its number of cycles.

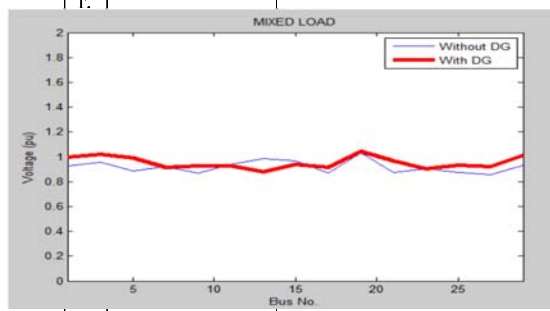
IV RESULTS AND DISCUSSION

Static transmission network expansion planning problem is solved for two test systems by applying proposed algorithm and is implemented in Matlab 7.9. The static TNEP is analysed for IEEE 30- bus system.

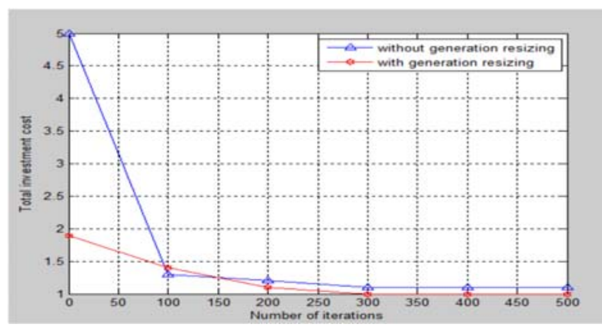
Before Expansion



S r.	Bus Type	Bus No.
		20,



Cost convergence curve for IEEE 30-Bus system without DG



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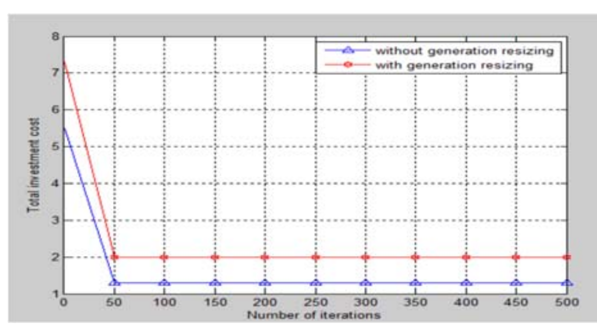
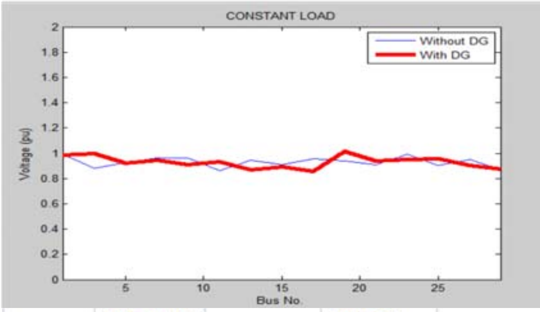


Voltage waveform for constant load in p.u.
Voltage waveform for mixed load in p.u.



	Without DG		With DG	
Sr.no	Bus no.	Voltage p.u.	Bus no.	Voltage p.u.
1	1	0.9895	1	0.9881
2	3	0.8804	3	0.9959
3	5	0.9284	5	0.9223
4	7	0.964	7	0.947
5	9	0.9637	9	0.907
6	11	0.863	11	0.9314
7	13	0.9459	13	0.8679
8	15	0.9121	15	0.8903
9	17	0.9582	17	0.8583
10	19	0.9363	19	1.0172
11	21	0.909	21	0.9401
12	23	0.9929	23	0.9485
13	25	0.9035	25	0.9558
14	27	0.953	27	0.9008
15	29	0.8709	29	0.8726

Voltage magnitude for constant load in p.u. with and without DG

	Without DG		With DG	
Sr.no	Bus no.	Voltage p.u.	Bus no.	Voltage p.u.
1	1	0.9279	1	0.997
2	3	0.9556	3	1.0214
3	5	0.8853	5	0.9927
4	7	0.9216	7	0.9148
5	9	0.8698	9	0.925
6	11	0.9388	11	0.924
7	13	0.9861	13	0.8796
8	15	0.9686	15	0.9382
9	17	0.8711	17	0.9173
10	19	1.0344	19	1.0436
11	21	0.8765	21	0.9697
12	23	0.9044	23	0.9033
13	25	0.8768	25	0.9343
14	27	0.8571	27	0.9189
15	29	0.9302	29	1.0152

Voltage magnitude for mixed load in p.u. with and without DG

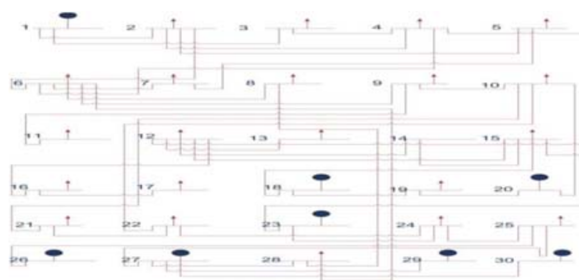
Without DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
With Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	7.3	2	2	2	2	2	2	2	2	2	2
Without DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
Without Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	5.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3

value for total investment cost without DG

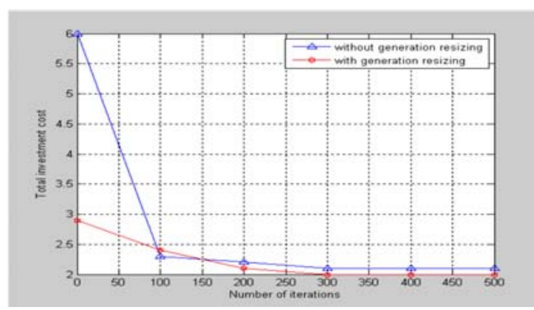
With DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
With Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	1.9	1.65	1.4	1.25	1.1	1.05	1	1	1	1	1
With DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
Without Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	5	3.15	1.3	1.25	1.15	1.1	1.1	1.1	1.1	1.1	1.1

Value for total investment cost with DG

After Expansion



Sr. No.	Bus Type	Bus No.
1	Slack/Referrence Bus	1,27,29
2	PQ Bus	2,3,4,5,6,7,8,9,10,11,12,13,15,16, 17,1921,22,24,25,28
3	PV Bus	18,20,23,26,30
4	None	14



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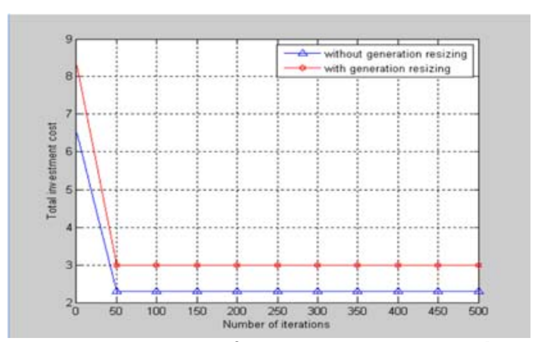

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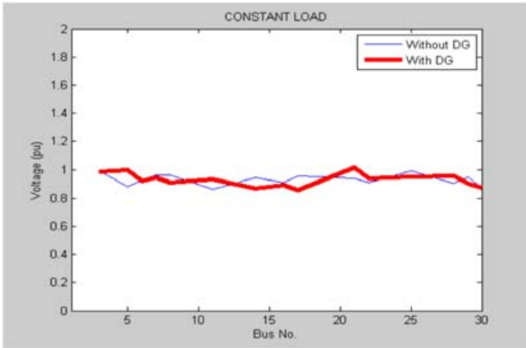

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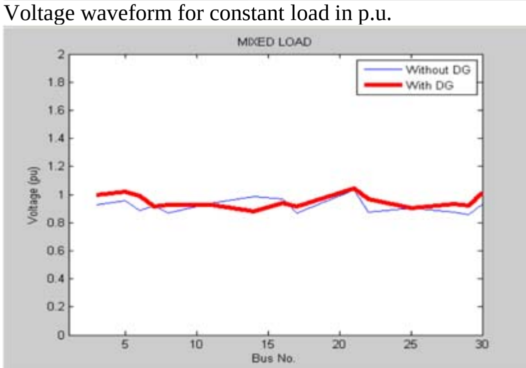

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Voltage magnitude for mixed load in p.u. with and without DG

Without DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
With Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	8.3	3	3	3	3	3	3	3	3	3	3
Without DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
Without Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	6.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3

Value for total investment cost without DG

With DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
With Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	2.9	2.65	2.4	2.25	2.1	2.05	2	2	2	2	2
With DG												
	Sr. No.	1	2	3	4	5	6	7	8	9	10	11
Without Generation Resizing	No. Of Iteration	0	50	100	150	200	250	300	350	400	450	500
	Total Investment Cost	6	4.15	2.3	2.25	2.15	2.1	2.1	2.1	2.1	2.1	2.1

Value for total investment cost with DG

V.CONCLUSION

G-best Artificial Bee Colony algorithm has been applied for static TNEP problem. IEEE 30-bus test system is used to solve the proposed problem and results indicate that without and with generation resizing, the proposed algorithm yields the
Optimum results for IEEE 30-bus system. Moreover, as the penetration level of distributed generation increases, the total investment cost decreases.

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