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Performance comparison of distributed generation installation arrangement in transmission system for loss control

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ABSTRACT

Placing Distributed generation (DG) into a power network should be planned wisely. In this paper, the comparison of having different installation arrangement of real-power DGs in transmission system for loss control is presented. Immune-brainstorm-evolutionary programme (IBSEP) was chosen as the optimization technique. It is found that optimizing fixed-size DGs locations gives the highest loss reduction percentage. Apart from that, scattered small-sized DGs throughout a network minimizes transmission loss more than allocating one biger-sized DG at a location.

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1. INTRODUCTION

Following the report World Energy Outlook 2017, global energy needs would rise by 30% in 2040, led by India. Global economy growth of 3.4% a year, world population expansion and urbanisation process are the major influence for electrification [1]. With this elevating load demand, power providers must face few challenges, among others are extending existing power supply capacity and reducing system loss due to increasing reactive load. Power system that operates near to its maximum capacity calls for network expansion. However, simply adding conventional fuel power plant would incur high infrastructure cost as well as contribute to more pollution to the environment. On the other side, increasing reactive load could add to the transmission line heating losses resulting inefficient power transfer.

The study on adding distribution generation (DG) into power system network to increase the network's capacity has caught the attention of many researchers. Placing DG into a power network should be planned wisely as improper planning would cost the utility expenditure apart from the performance of the system itself [2]. DG sources could be in the form of small gas turbine and renewable sources such as solar, wind and biomass. Renewable energy (RE) sources has become the solution for countries seeking for adding clean energy access and improve energy security , due to their energy policy and continuously falling cost of, while improving, RE technology [3]. Photovoltaic (PV) array and wind turbine generator (WTG) are common DGs been inserted into distribution system in quest of improving the voltage stability and reducing the system losses [4, 5].

Numerous optimization techniques were used to determine the optimal size and location of distributed generation in power system network. The optimization techniques can be of mathematical techniques or heuristic techniques. Quadratic programming and Langragian-based approach are some mathematical techniques proposed to find optimal DG size and location [6, 7]. Whereas, some researches proposed heuristic techniques like Ant Lion Optimization, Flower Pollination, Intelligent Water Drop and Evolutionary programming (EP) to determine the optimal DG location and size [8–11]. Complexity of power system designs and its wide geographical dispersion are among factors that contribute to the increasing effort of combining several bio-inspired optimization techniques to suit the needs of a particular system [12].

This paper presents the performance comparison of DG installation arrangement in transmission system for loss control. It is different than other works as it compares whether it is best to let an optimization technique to decide on the best DG location and size to reduce system loss or to have one parameter fixed while the optimizer searches for the other. The paper would also answer the question of is it better to commission one DG which size is the same as the total of many smaller-size DGs to minimize system loss or not.

2. RESEARCH METHOD

2.1. Immune Brainstorm Evolutionary Programming

Immune Brainstorm Evolutionary Programming (IBSEP) combines Brainstorm Optimization (BSO), artificial immune system (AIS) and EP optimization techniques. Cloning operator of AIS and clustering approach of BSO are embedded into the main optimizer, EP. The overall process of IBSEP algorithm is as shown in Figure 1. The red dotted boxes emphasize the AIS and BSO components cascaded to the EP algorithm.

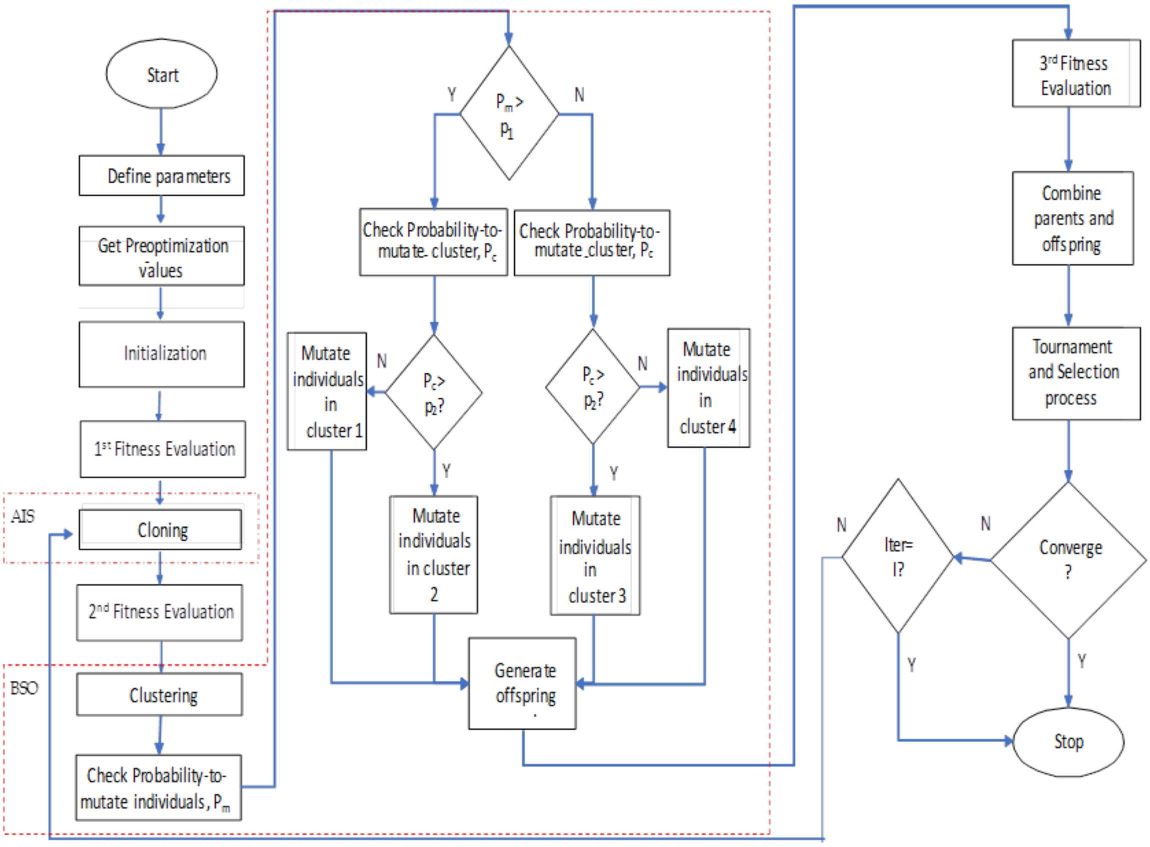

Figure 1. Overall process of IBSEP

The IBSEP algorithm starts with initialization process where the parameters and control variables for the optimization problem are defined. The parameters of the algorithm are population size *n*, number of clusters *l*, probability to mutate clusters *pm* and *pc*. Whereas, random location and size of the DG are the control variables. Total loss of the transmission system before optimization is calculated as a reference value. The control variables are accepted in the population if they satisfy the following constraint:

$$Loss_{total} \leq Loss_{pre-opt} \tag{1}$$

This is regarded as the first fitness calculation. The population size is 100 following reference [13]. This initial population is cloned 10 times, making the population now becomes 1000 individuals. The fitness of the new individuals will be calculated in the second fitness calculation step. These individuals, with their fitness values, are then clustered into five clusters by simple clustering, forming 200 individuals per cluster, ready for next process; mutation. Only one cluster will be mutated, depending on two probability parameters, p_m and p_c. The individuals in that cluster are mutated following (2).

$$x_{i+m,j} = x_{i,j} + N\left(0, \beta\left(x_{jmax} - x_{jmin}\right)\left(\frac{f_i}{f_{max}}\right)\right) \tag{2}$$

Where; $x_{i+m,j}$ is mutated parent (offspring), $x_{i,j}$ is parent, β is search step, x_{jmax} is maximum value of parent, x_{jmin} is minimum value of parent, f_i is fitness of ith random number and f_{max} is the maximum fitness. This process produces new individuals, termed as the offspring.

A final fitness calculation is then performed over these offspring before the parent and the offspring are combined in cascoded form. If the parent matrix and the offspring matrix are as represented by (3) and (4) respectively, then the combined matrix, C, will be in a form as in (5).

$$A_1 = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1,d} & f_1 \\ x_{21} & x_{22} & \dots & x_{2d} & f_2 \\ \vdots & \vdots & & \vdots & \vdots \\ x_{mn1} & x_{mn2} & \dots & x_{mnd} & f_{mn} \end{bmatrix} \tag{3}$$

$$A_2 = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1,d} & F_1 \\ X_{21} & X_{22} & \dots & X_{2d} & F_2 \\ \vdots & \vdots & & \vdots & \vdots \\ X_{mn1} & X_{mn2} & \dots & X_{mnd} & F_{mn} \end{bmatrix} \tag{4}$$

$$C = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} \tag{5}$$

C is now a matrix of 400 individuals.

The combined population, C will undergo a tournament and selection process whereby the individuals will be ranked by the fitness values. 20 fittest individuals are selected for convergence test. The optimization algorithm will stop if the best 20 individuals' fitness values comply to (6); else, the iteration process will carry on, as long as the maximum iteration number is not met.

$$Loss_{total(max)} - Loss_{total(min)} \leq 0.00001 \tag{6}$$

2.2. Problem formulation

In this paper, the effect of installing multiple DGs that are only capable of delivering real power is investigated. Example of this type of DG are Photovoltaic (PV), fuel cells and micro-turbines. This section describes the problem formulation for single objective function for IEEE-30 bus reliability test system (RTS), using IBSEP optimization technique. The objective function of this problem is to minimize the total system loss, which mathematically represented by (7):

$$OF = \min \sum_{i=1}^{n} P_{loss,i} \tag{7}$$

Where n is the number of lines in the system and P_{loss} are the power loss of each line calculated by (8):

$$P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} [\, \alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \tag{8}$$

Where, n is the bus number; P_i , P_j, Q_i and Q_j are active and reactive power at buses i and j , respectively,

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \text{ , and} \tag{9}$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j) \quad (10)$$

The objective function is subjected to the following power balance constraint:

$$\sum_{i=1}^{n} P_{Di} + P_{loss} = \sum_{i=1}^{n} P_{Gi} \quad (11)$$

and voltage constraint:

$$V_{min} \leq V_i \leq V_{max} \quad (12)$$

Where n is number of bus in the system, P_{Di} is the power demand at bus i, and P_{loss} is the real power loss of the system. P_{Gi} is the real power generation at bus i and V_i is the voltage at bus i. V_{min} and V_{max} should be 0.95 p.u and 1.05 p.u respectively, to maintain the health of the network.

2.3. DG installation scheme

The system losses were examined based on the three cases:

Case 1: The size and location of the DGs are determined by the IBSEP algorithm. Simulations were done for 1, 2 and 3 optimal DGs inserted in the IEEE-30 RTS system. Although there will be different number of DGs, the total size of the DGs has the same limit, that is 20MW. This number is chosen based on a reference in [14] that stated DGPV output varies from 3.05MW to 56.826MW. Furthermore, the generator at bus 2 of the IEEE-30 RTS is rated at 40MW. Hence, the DG size is chosen to be 20 MW as it fits the work in [14] as well as it is smaller than the generator size of the test system.

Case 2: The optimal location of the DGs was determined by the IBSEP algorithm. Simulations were done for 1, 2 and 3 optimal DGs inserted in the IEEE-30 RTS system. The sizes of the DGs will be fixed so that the total size is the same, that is 20MW.

Case 3: The optimal size of the DGs is determined by the IBSEP algorithm. Simulations were done for 1, 2 and 3 optimal DGs inserted in the IEEE-30 RTS system. The locations will be fixed at the weak buses, that is bus 26, 29 and 30. The weak buses are determined following the work in [15].

For ease of view, the nature of the experiment is shown in Table 1; value 1 is assigned when the value is pre-specified and 0 for optimal value to be specified by IBSEP algorithm.

Table 1. Cases and scenarios for DG installation

Case	Scenario	Location loc	Size s
	1 (DG_1)	0	0
1	2 (DG_1, DG_2)	0	0
	3 (DG_1, DG_2, DG_3)	0	0
	1 (DG_1)	0	1
2	2 (DG_1, DG_2)	0	1
	3 (DG_1, DG_2, DG_3)	0	1
	1 (DG_1)	1	0
3	2 (DG_1, DG_2)	1	0
	3 (DG_1, DG_2, DG_3)	1	0

2.4. Reactive load loading

In testing the ability of the algorithm to search for optimal DG in minimizing system loss, reactive load is increased at the weakest bus, i.e. bus 30. The load Q_{d30} were increased from 0 MVar to 20 MVar. The system losses are then recorded, both before and after DG installation for comparison.

3. RESULTS AND ANALYSIS

3.1. Case 1: optimal DGs sizes and locations are determined by IBSEP algorithm

Reactive load at bus 30 was incremented from 0MVar to 20 MVAR. The results are shown in Table II. The pre-optimization losses were 17.5641MW, 18.1091MW and 19.5484MW for reactive load Q_{d30} of 0 MVAR, 10 MVAR and 20 MVAR respectively. These pre-optimized values are going to be used for all cases and scenarios.

From the results in Table 2, it can be seen that the total system loss with optimal DG insertion is reduced the most for all reactive loading Q_{d30} when only one optimal DG was inserted (as in bold font). As for the voltage profile, the pattern of enhancement cannot be concluded as the best enhancement is either when there is only one optimal DG or three optimal DGs based on the reactive load Q_{d30}.

Table 2. System loss and loss minimization results for case 1

Q_{d30} (MVar)	Total Loss (MW)			Loss Minimization (%)		
	1 DG	2 DGs	3 DGs	1 DG	2 DGs	3 DGs
0	**14.85**	15.31	15.29	**15.47**	12.9	12.97
10	**15.3**	15.75	15.69	**15.54**	13	13.34
20	**16.7**	17.15	16.99	**14.58**	12.3	13.09

Table 3 shows the optimal DGs sizes and location for Case 1, for all reactive load Q_{d30} variation. Total DG size was limited to 20MW. When only 1 DG was inserted, the optimal DG size was 19.9823W and located at bus 7. However, when two DGs and three DGs were to be inserted, the total DGs size were 17.0848W and 16.867 respectively, which are less than the DG capacity of Scenario 1. This could be the reason why there were more loss minimization when there was only one optimal DG.

Table 3. Optimal DGs locations and sizes for case 1

Total DG (Unit)	Total Size (MW)	S_1 (MW)	S_2 (MW)	S_3 (MW)	Loc. 1 (Bus)	Loc. 2 (Bus)	Loc. 3 (Bus)
1	19.9823	19.9823	*NA*	*NA*	7	*NA*	*NA*
2	17.0848	8.7188	8.366	*NA*	18	23	*NA*
3	16.867	4.1339	5.9229	6.8102	25	22	29

3.2. Case 2: optimal DGs locations are determined by IBSEP algorithm

In Case 2, the total DG size is fixed to 20MW. For example, when three DGs were to be inserted, the size of each DG is fixed to be 7MW, 7MW and 6MW. It was then the duty of the IBSEP optimization algorithm to suggest the location of these DGs, such that the total system loss was reduced as much as possible. Table 4 tabulates the power system total loss and voltage profile while Table 5 shows the size and optimal DG location searched by IBSEP algorithm.

Table 4. System loss and loss minimization results for case 2

Q_{d30} (MVAR)	Optimal Loss (MW)			Loss Minimization (%)		
	1 DG	2 DGs	3 DGs	1 DG	2 DGs	3 DGs
0	14.8438	**14.6983**	14.7459	15.49	**16.32**	16.05
10	15.2930	**15.0692**	15.1264	15.55	**16.79**	16.47
20	16.6712	**16.2775**	16.3678	14.72	**16.73**	16.27

Table 5. Optimal DGs locations and sizes for case 2

Scenario	S_1 (MW)	S_2 (MW)	S_3 (MW)	Loc. 1 (Bus)	Loc. 2 (Bus)	Loc. 3 (Bus)
1	20	*NA*	*NA*	7	*NA*	*NA*
2	10	10	*NA*	30	7	*NA*
3	7	7	6	23	30	21

From this result, it shows that two DGs of 10MW each optimally located at bus 30 and bus 7 would cause the system to have most minimal loss, followed by three DGs optimally located at bus 21, 23 and 30. In scenario 3 of Case 2, the size of two DGs are 7MW each and the size of the third DG is 6MW. This time, the Scenario 1 of one DG has the lowest loss minimization percentage compared to Scenario 2 and Scenario 3. Now, although the DGs in all scenarios has the same total size of 20MW, the distribution of the DGs does has certain impact on the system loss. Since both Scenario 2 and Scenario 3 have their optimal DG location at bus 30, which is the weakest bus, this could be the reason why scenario 1 is the scenario with highest loss.

3.3. Case 3: optimal DGs sizes are determined by IBSEP algorithm

The experiment was continued by fixing the location of the DGs while optimizing the DG sizes. The results of this setting were shown in Table 6 and Table 7. From the results, it can be seen that even the total size of the DGs was not the same for all three scenarios, but when the DGs are scattered at weak busses, the total system loss can be further reduced. With Case 3 setting, it can be concluded that as more weak bus is compensated with DG, albeit smaller in size, more loss can be minimized.

Table 6. System loss and loss minimization results for case 3

Q_{d30} (MVAR)	Optimal Loss (MW)			Loss Minimization (%)		
	1 DG	2 DGs	3 DGs	1 DG	2 DGs	3 DGs
0	15.1545	15.1267	**15.0727**	13.72	13.88	**14.18**
10	15.4951	15.4934	**15.4402**	14.43	14.44	**14.74**
20	16.6718	16.6867	**16.633**	14.72	14.64	**14.91**

Table 7. Optimal DGs locations and sizes for case 3

Scenario	Total Size (MW)	S_1 (MW)	S_2 (MW)	S_3 (MW)	Loc. 1 (Bus)	Loc. 2 (Bus)	Loc. 3 (Bus)
1	19.9892	19.9892	NA	NA	30	NA	NA
2	18.0568	9.5441	8.5127	NA	30	26	NA
3	18.4596	5.9229	5.7265	6.8102	30	29	26

The tables presented earlier however, cannot concretely conclude on which case or scenarios would be the best approach in finding best DG arrangement to minimize power system loss. Hence, Tables VIII is presented to analyse different cases of same scenarios. Case 1, Case 2 and Case 3 are labelled as C1, C2 and C3 respectively. The lowest system loss is in bold. As an extension, a new scenario was introduced, titled C4, abbreviated for Case 4. For C4, the location of the DGs were fixed as the ones determined in Case 2 while the total optimal size was capped to 20MW. The idea of this was to compare which approach is the best practice: fixing the location based on the status of it as weak bus; or fixing the location based on the ones determined by the IBSEP algorithm as in Case 2. Thus, for C4, the location chosen was bus 30, 7 and 21. Bus 7 and 30 were chosen as their occurrences are high from Case 1 to Case 3; while bus 21 is just selected over bus 23.

It can be seen from the Table 8 that system loss is the most minimized when Case 2 is used for all scenarios. The second-best case is Case 4, i.e. optimizing the DG size with known location based on early information from previous cases. Fixing the location of DGs at weak buses does not guarantee that the loss will be most reduced as the total loss of C3 is higher than that of C4 (for multi-DG installation) and of C1 (for single DG installation).

Table 8. System loss for different DG arrangement

Q_{d30} (Mvar)	Total Loss for 1 DG (MW)			Total Loss for 2 DGs (MW)				Total Loss for 3 DGs (MW)			
	C1	C2	C3	C1	C2	C3	C4	C1	C2	C3	C4
0	14.9	**14.8**	15.2	15.3	**14.7**	15.1	14.9	15.3	**14.8**	15.1	14.9
10	15.3	**15.3**	15.5	15.8	**15.1**	15.5	15.3	15.7	**15.1**	15.4	15.3
20	16.7	**16.7**	16.7	17.2	**16.3**	16.7	16.5	17.0	**16.4**	16.6	16.6

A comparison is then made between the percentage of loss reduction for each case and scenario. Table 9 tabulates the result when the reactive load Q_{d30} is 10 MVar. It shows that the optimal DGs reduce the loss most during Case 2 with Scenario 2 (C2S2), then C2S3 followed by C2S1.

Table 9. Percentage of loss reduction (%), when Q_{d30}=10 MVAR

Scenario	C1	C2	C3	C4
S1	15.54	15.55	14.43	▨
S2	13.02	**16.79**	14.44	15.44
S3	13.34	16.47	14.74	15.47

4. CONCLUSION

This paper has presented performance comparison of distributed generation installation arrangement in transmission system for loss control. It is found that fixing the DGs sizes while optimizing the DGs location is the best method to obtain highest loss reduction percentage. It is also best to have small-sized DGs spread throughout the network than having big-sized DG located at a location for loss control. Should a utility provider need to fix the DG locations, IBSEP algorithm is able to suggest the location; simply choosing weakest bus may not be the best approach in controlling the transmission loss.

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