Research Article

Impacts of the Load Models on Optimal Planning of Distributed Generation in Distribution System

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The optimal planning (sizing and siting) of the distributed generations (DGs) by using butterfly-PSO/BF-PSO technique to investigate the impacts of load models is presented in this work. The validity of the evaluated results is confirmed by comparing with well-known Genetic Algorithm (GA) and standard or conventional particle swarm optimization (PSO). To exhibit its compatibility in terms of load management, an impact of different load models on the size and location of DG has also been presented in this work. The fitness evolution function explored is the multiobjective function (FMO), which is based on the three significant indexes such as active power loss, reactive power loss, and voltage deviation index. The optimal solution is obtained by minimizing the multiobjective fitness function using BF-PSO, GA, and PSO technique. The comparison of the different optimization techniques is given for the different types of load models such as constant, industrial, residential, and commercial load models. The results clearly show that the BF-PSO technique presents the superior solution in terms of compatibility as well as computation time and efforts both. The algorithm has been carried out with 15-bus radial and 30-bus mesh system.

1. Introduction

The practical system comprises various kinds of loads. Many researchers have explored efficient siting and sizing methods for distribution system. However, most of them have assumed constant load models. Constant load shows insensitivity to variations of frequency as well as voltage profile of the system. This depicts the ideal situation of the system. Thus all those methods fail to present the practically sound solution. It is observed that actual practical system comprised industrial, residential, and commercial loads. The Genetic Algorithm (GA) is genetic based evolutionary search algorithm. The basic concepts and applications of the Genetic Algorithms (GAs) including the various fields of optimizing the complex problems in a practical way for different functions have been analyzed in [1–3]. The standard or conventional particle swarm optimization (PSO) based optimization approach is given in [4–6]. The butterfly-particle swarm optimization (butterfly-PSO or BF-PSO) technique is based on the characteristic, behavior, and intelligence of the butterfly swarm search process for food, hence attraction towards food (or

nectar) source which is described in [7, 8]. The simple and efficient method for solving load flow case radial distribution networks proposed by [9] involves only the evaluation of a simple algebraic expression of voltage magnitudes. The multiobjective function is based on system performance indices to determine the location and size of distributed generation with the load models in the distribution system by [10, 11]. The new concept for the network reconfiguration problem considering the distributed generation (DG) to minimize the real power loss and voltage profile improvement of the distribution system is reported in [12]. The analysis of several performance indexes for multiobjective function approach in distribution network with different power factor (PF) of DG and also considering the wide range of technical issues for distribution system are presented by [13]. The different power flow methodologies to solve load flow problems are described in [14–16]. The DG planning for mesh system with several techniques is reported in [17, 18].

This paper presents the optimal sizing and siting of distributed generation (DG) with the different type of load models. Then DG is considered as an active power source

FIGURE 1: The convergence of multiobjective function (FMO) with iterations of 15-bus radial system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

at load bus. The optimal site allocation and sizing of DG with the different objective indices such as active power loss index (PLI), reactive power loss index (QLI), and voltage deviation index (VDI) based multiobjective function have been evaluated as fitness function. The presented results exhibit the impacts of the different load models on the overall performance of the distributed system. The evaluated results show that the BF-PSO leads GA and PSO in terms of computational time and efforts. In spite of that, the better performance characteristics can be obtained by using BF-PSO.

2. Problem Formulation and Load Models

To find the optimal sizing and siting of the distributed generation (DG) in the radial system with the various objectives is achieved by the accompanying multiobjective function (FMO) as

$$\text{FMO} = k_1 \times \text{PLI} + k_2 \times \text{QLI} + k_3 \times \text{VDI}, \quad (1)$$

where $\sum_{i=1}^3 k_i = 1$ and k_i is the weight factor for the different index. The values of k_1 , k_2 , and k_3 are 0.45, 0.25, and 0.3, respectively. The details to select the weight factor of the indices are given in [11, 12, 14].

The active power loss index (PLI) is

$$\text{PLI} = \frac{\text{PL}_{\text{DG}}}{\text{PL}_{\text{No-DG}}}. \quad (2)$$

The reactive power loss index (QLI) is

$$\text{QLI} = \frac{\text{QL}_{\text{DG}}}{\text{QL}_{\text{No-DG}}}. \quad (3)$$

The voltage deviation index (VDI) is

$$\text{VDI} = \max_{j=2}^n \left(\frac{V_{\text{ref}} - V_{\text{DG}j}}{V_{\text{ref}}} \right), \quad (4)$$

where PL_{DG} and $\text{PL}_{\text{No-DG}}$ are real power loss with and without DG. The QL_{DG} and $\text{QL}_{\text{No-DG}}$ are reactive power loss with and without DG. The V_{ref} and $V_{\text{DG}j}$ are the reference or rated voltage and with-DG case voltage at bus j .

The load models for the particular loads can be mathematically expressed as

$$\begin{aligned} P_i &= P_{oi} V_i^a, \\ Q_i &= Q_{oi} V_i^r, \end{aligned} \quad (5)$$

FIGURE 2: Active power loss of 15-bus radial system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

TABLE 1: The exponent values for load models.

Load type	a	r
Constant	0	0
Industrial load	0.18	6
Residential load	0.92	4.04
Commercial load	1.51	3.4

where P_i and Q_i are real and reactive power at bus i , P_{oi} and Q_{oi} are the active and reactive operating points at bus i , V_i is the voltage at bus i , and a and r are active and reactive power exponents. Table 1 gives the load models exponent values [10, 11, 13].

3. Butterfly Particle Swarm Optimization (BF-PSO) Technique

The butterfly-PSO (BF-PSO) algorithm is essentially based on the nectar probability and the sensitivity of the butterfly swarm [7]. In process for computing the optimal solution, the degree of node in every flight of butterfly is assumed as approximately equal to 1 because of assuming the maximum connectivity in each flight. The butterfly swarm based search process investigates the optimal location depending upon the sensitivity of butterfly toward the flower and the probability of nectar. The information about the optimal solution communicates directly or indirectly between all the butterflies

by different means of communication intelligence (such as dancing, colors, chemicals, sounds, physical action, and natural processes) [8]. The butterfly leaning based particle swarm optimization algorithm has developed to ascertain the optimal solutions including the random parameters, acceleration coefficients, probability, sensitivity, lbest, and gbest. In the butterfly-PSO, lbest solutions are selected by the individual's best solution. After that, the gbest solution identified was based on the respective fitness. The locations (location) of the nectar (food) source represent the probable optimal solution for the problem and the amount of nectar (food) represents the corresponding fitness. The detail implementation of the butterfly-PSO (BF-PSO) technique is given below. The general ranges of the sensitivity and probability are considered from 0.0 to 1.0. The velocity limits can be set based on the limits of the problem variables. Hence, the function of inertia weight, sensitivity, and probability as a function of iterations can be given as [7, 8]

$$\begin{aligned}
 w_k &= 0.9 - \left(\frac{(0.9 - 0.4)}{\text{ITER}_{\max}} \right) * \text{ITER}_k, \\
 s_k &= \exp - \frac{(\text{ITER}_{\max} - \text{ITER}_k)}{\text{ITER}_{\max}}, \\
 p_k &= \frac{\text{FIT}_{\text{gbest},k}}{\sum (\text{FIT}_{\text{lbest},k})},
 \end{aligned} \tag{6}$$

FIGURE 3: The reactive power loss of 15-bus radial system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

where $ITER_{\max}$ is maximum number of iterations and $ITER_k$ is k th iteration count. And $FIT_{lbest,k}$ is fitness of local best solutions with k th iteration and $FIT_{gbest,k}$ is fitness of global best solutions with k th iteration.

Then the equations of BF-PSO technique given below for the velocity and position updating are

$$\begin{aligned}
 v'_{(k+1)} &= w * v_k \\
 &+ s_k (1 - p_k) c_1 r_1 (lbest_k - currentpop) \\
 &+ p_k c_2 r_2 (gbest_k - currentpop), \\
 x_{(k+1)} &= x_k + v'_{k+1}.
 \end{aligned} \tag{7}$$

The detail algorithm to find the optimal sizing and location of DG using GA, PSO, and butterfly-PSO (BF-PSO) technique is given as follows:

- (1) Read and input the systems data (bus data, line data, generation data, etc.).
- (2) Run and execute the NR-power flow results for no-DG case including load models.

- (3) Initialize all the parameters of GA (population, selection rate, mutation rate, iterations, etc.), PSO (c_1, c_2, w), and BF-PSO (c_1, c_2, w_k, p_k , and s_k). The variables can be defined as

$$x = [P_{dg1}, P_{dg2}, \dots, P_{DGN}; L_{dg1}, L_{dg2}, \dots, L_{DGN}], \tag{8}$$

where N is number of population for GA, number of swarm for PSO, and the number of butterfly swarm for BF-PSO. The P_{dg} and L_{dg} are DG size and location, respectively.

- (4) Update the variables within the algorithm using the different operators (selection, crossover, and mutation) for GA, equations (velocity and positions/locations) for PSO, and equations (velocity, locations, inertia weight, sensitivity, and probability) for BF-PSO.
- (5) After that, assign the DG size and location in the system excluding the slack and PV buses.
- (6) After that, call the NR-power flow and execute the results with DG condition including load models.

FIGURE 4: The voltage profile of 15-bus radial system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

- (7) Calculate the all indices value for the multiobjective function with each technique.
- (8) Evaluate the fitness value for each technique of multi-objective function.
- (9) Compare the variables from previous variables for each technique.
- (10) Check for termination criteria; if otherwise, repeat algorithm from step (3) to step (9).
- (11) Repeat this procedure up to maximum number of iterations.
- (12) Record and save all the output data of the system.

The parameters such as population size for GA and also swarm size for PSO and BF-PSO are assumed 30 in all the test systems. The iterations for GA, PSO, and BF-PSO are assumed to be 50, respectively, for all test systems.

4. Results and Discussions

This proposed algorithm has been tested on 15-bus radial system [9] and 30-bus mesh system [17, 18] with a base of 100 MVA. The range of DG size is 0.0 to maximum load (sum of all power demands) in the system. The DG is considered

at a unity power factor. The loads are dependent on the voltage; that is, real and reactive load demand depends on the voltage magnitude of the particular bus. The range of DG size is 0.0 to maximum load (sum of all power demands) in the system. All the results for proposed methodology are carried out with MATLAB (2009a)/Matpower4.1 tool with the system configuration Windows 8.1, AMD-E1-1500APU, 1.48 GHz, 2.0 GB RAM.

4.1. The 15-Bus Radial System. The data of 15-bus radial system is given in [9]. The performance results of the 15-bus radial system are shown in Figures 1–4. Figure 1 shows the results for the convergence of multiobjective function (FMO) with iterations for the constant, industrial, residential, and commercial loads. The convergence towards the optimal value of the function varies with an optimization technique as shown for GA, PSO, and BF-PSO. The comparative analysis indicates that the convergence of BF-PSO technique is better and faster than GA and PSO. Hence overall system performance is computed by BF-PSO technique.

The impacts of load models on the active and reactive power losses of 15-bus radial system are shown in Figures 2 and 3, respectively. The BF-PSO reveals that the active and reactive power loss of system with constant, industrial, residential, and commercial loads are varied in the same

FIGURE 5: The convergence of multiobjective function (FMO) with iterations of 30-bus mesh system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

proportion as size and the location of DG vary. The active power loss of system with DG using BF-PSO technique is less as compared to without- or no-DG case. The impacts of load models on sizing and siting as well as on the active power losses are different with DG. The reactive power losses without and with DG using BF-PSO technique for load models are given in Figure 3. The result shows the effect of the load models on the reactive power loss with DG condition.

The impact of different load models on the voltage profile using BF-PSO is shown in Figure 4. The voltage profiles of the system are distinguished for the different type of load models. The improvement in the voltage profile with DG-BF-PSO is more efficient for all load models. Table 2 gives the values of the system indices using different methods with DG condition. These values are the optimal solution values of different technique for load models. Value of the multi-objective function (FMO), size of DG, (PDG) and optimal bus location of DG are given in Table 3. Minimum value of the fitness function (FMO) is obtained using BF-PSO method for all load models, hence all system results evaluated for BF-PSO method. The value of FMO is 0.4335, PDG is 1.0355 and optimal bus location is 3 using BF-PSO for the constant load. The value of FMO is 0.4346, PDG is 0.9703 and optimal bus location is 3 using PSO for the constant load. The value of FMO is 0.4375, PDG is 1.1596 and optimal bus location is 3 using GA for the constant load. Similarly the impacts of industrial, residential and commercial load models on

TABLE 2: Objective indices of 15-bus radial system with different load models using GA, PSO, and BF-PSO.

Load type	PLI	QLI	VDI	Technique
Constant load	0.6123	0.5931	0.0324	BF-PSO
	0.6133	0.594	0.0338	PSO
	0.6188	0.6001	0.0302	GA
Industrial load	0.3782	0.3404	0.0187	BF-PSO
	0.402	0.3662	0.02	PSO
	0.5006	0.4483	0.022	GA
Residential load	0.5453	0.5093	0.0195	BF-PSO
	0.5637	0.5303	0.0212	PSO
	0.644	0.6003	0.0229	GA
Commercial load	0.6603	0.6285	0.0198	BF-PSO
	0.6715	0.6379	0.0188	PSO
	0.7387	0.7034	0.0227	GA

the multi-objective function (FMO), size of DG, (PDG) and optimal bus location of DG can be analyzed.

4.2. The 30-Bus Mesh System. The all data information about the 30-bus mesh system data have given in [17]. The proposed algorithm applied to minimize the multi-objective function for the 30-bus mesh system in this section. The results of the 30-bus mesh system are shown in Figures 5–8 and Tables 4–6.

FIGURE 6: Active power loss of 30-bus mesh system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

TABLE 3: Multiobjective function and DG size at optimal bus location with different load models for 15-bus radial system using GA, PSO, and BF-PSO.

Load Type	Fitness (FMO)	PDG	Bus	Technique
Constant load	0.4335	1.0355	3	BF-PSO
	0.4346	0.9703	3	PSO
	0.4375	1.1596	3	GA
Industrial load	0.2609	0.8549	3	BF-PSO
	0.2785	0.7232	4	PSO
	0.3439	0.5862	15	GA
Residential load	0.3786	0.672	3	BF-PSO
	0.3926	0.5697	4	PSO
	0.4467	0.4502	15	GA
Commercial load	0.4602	0.5505	3	BF-PSO
	0.4673	0.644	3	PSO
	0.5151	0.363	15	GA

The result for convergence of multi-objective function (FMO) with iterations for the constant, industrial, residential and commercial loads are shown in Figure 5. The convergence towards the optimal value of the function varies with an optimization technique for 30-bus mesh system as shown for GA, PSO and BF-PSO. The comparative analysis indicates

that the convergence of BF-PSO technique is better and faster than GA and PSO. Hence overall 30-bus mesh system performance is computed only for BF-PSO technique. The BF-PSO results for active power loss of system with constant, industrial, residential and commercial loads are shown in Figure 6. The result presents that the active power loss of system with DG using BF-PSO technique is less as compared to that without DG condition. The impacts of load models on size and location as well as on the active power losses of 30-bus mesh system are different with DG cases. The reactive power losses without and with DG using BF-PSO technique for 30-bus mesh system with load models are given in Figure 7. The result shows the effect of the load models on the reactive power loss of 30-bus mesh system with DG condition.

The voltage profiles of the system are dissimilar for the particular load models of the system. The change in voltage profiles of the system occurs due to variations in the size and location of DG. The impact of different load models on the voltage profile of 30-bus mesh system using BF-PSO is shown in Figure 8. The improvement in the voltage profile with DG-BFPSO is more efficient for all load models. The values of the system indices for 30-bus mesh system using different methods with DG condition are given in Table 4. These values are the optimal solution values of different technique for load models. The value of multiobjective function (FMO), size

FIGURE 7: The reactive power loss of 30-bus mesh system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

TABLE 4: Objective indices of 30-bus mesh system with different load models using GA, PSO, and BF-PSO.

Load type	PLI	QLI	VDI	Technique
Constant load	0.3073	-0.2643	-0.0048	BF-PSO
	0.3071	-0.2634	-0.0046	PSO
	0.3185	-0.2528	-0.006	GA
Industrial load	0.3111	-0.2296	0.0004	BF-PSO
	0.3155	-0.2266	-0.0002	PSO
	0.3197	-0.2215	-0.0004	GA
Residential load	0.3078	-0.2032	-0.001	BF-PSO
	0.3085	-0.2034	-0.0012	PSO
	0.317	-0.1799	0.0001	GA
Commercial load	0.3059	-0.1791	-0.0016	BF-PSO
	0.3068	-0.179	-0.0018	PSO
	0.3061	-0.1765	-0.0012	GA

of DG (PDG), and optimal bus location of DG are given in Table 5. The minimum value of fitness function (FMO) is obtained by using BF-PSO technique for different load models; hence all system results are evaluated for BF-PSO method. The value of FMO is 0.0708, PDG is 202.9922, and optimal bus location is 6 using BF-PSO for the constant load. The value of FMO is 0.0710, PDG is 199.2922, and optimal

TABLE 5: Multiobjective function and DG size at optimal bus location with different load models for 30-bus mesh system using GA, PSO, and BF-PSO.

Load type	Fitness function (FMO)	PDG	Bus	Technique
Constant load	0.0708	202.9922	6	BF-PSO
	0.0710	199.2922	6	PSO
	0.0784	226.1614	6	GA
Industrial load	0.0827	203.2873	7	BF-PSO
	0.0853	216.8522	7	PSO
	0.0884	223.5097	6	GA
Residential load	0.0874	206.3894	7	BF-PSO
	0.0876	210.8828	7	PSO
	0.0977	179.2814	7	GA
Commercial load	0.0924	210.0633	6	BF-PSO
	0.0925	215.0907	6	PSO
	0.0932	201.9343	6	GA

bus location is 6 using PSO for the constant load. The value of FMO is 0.0784, PDG is 226.1614, and optimal bus location is 6 using GA for the constant load. Similarly, the impacts of industrial, residential, and commercial load models on

FIGURE 8: The voltage profile of 30-bus mesh system for (a) constant load, (b) industrial load, (c) residential load, and (d) commercial load.

TABLE 6: The comparative analysis of 30-bus radial system.

Cases	Parameter			
	Active power loss (MW)	Active power loss reduction (%)	Reactive power loss (MVar)	Reactive power loss reduction (%)
Without-DG (base case)	17.557	—	67.69	—
With-DG				
Existing (7.5% DG penetration)	7.0973 [17]	59.57%	NA	NA
Proposed (DG-BFPSO)	5.396	69.27%	26.32	61.11%

the multiobjective function (FMO), size of DG (PDG), and optimal bus location of DG can be analyzed.

The comparative analysis of the proposed and the existing methodology is given in Table 6 for the 30-bus mesh system. This analysis shows that the reduction in active power loss with existing methodology is 59.57%. The reduction in active and reactive power losses with the proposed methodology is 69.27% and 61.11%, respectively, for 30-bus mesh system. This result analysis accomplishes the idea that the more power loss reduction is achieved by proposed methodology as compared to existing methodology.

5. Conclusions

The proposed methodology is implemented on the 15-bus radial and 30-bus mesh system and the comparative analysis

for 30-bus mesh system with proposed and the existing methodology is given in Section 4. It shows that reduction in active power loss with existing methodology is up to 59.57%, whereas the reduction in active and reactive power losses with the proposed methodology is up to 69.27% and 61.11%, respectively, for 30-bus mesh system. Hence the more power loss reduction is obtained by proposed methodology than the existing one. This result analysis demonstrates that the BF-PSO technique based algorithm is an efficient algorithm on the basis of hybridization of butterfly and the particle swarm techniques. It is observed that the hybridization of two allegiant techniques provides the unique combo to evaluate the system performance. In this work also the presented results are compared between with- and without-DG cases using GA, PSO, and BF-PSO technique. The effect of different types of load in the system is assumed, while tackling the

optimal sizing and siting of DG problems in the system. It is clearly shown in the results that the performance of the system such as reduction in losses and increase in voltages has improved. Also, the size and location of DG vary with different load models for GA, PSO, and BF-PSO technique.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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