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The Optimal Distributed Generation Placement and Sizing Using Novel Optimization Technique

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Abstract: This paper exhibits the optimum location and size of distributed generation (DG) supported the combined optimal power flow (OPF) and Butterfly-particle swarm optimization (Butterfly-PSO or BF-PSO) strategies. The multi-objective operate has been developed on the premise of the assorted system indices. These indices decides the performance and quality of the system. The The proposed technique has been executed on on the 33-bus radial system. The comparison of outcomes has been reported for the proposed and existing method. The achieved result shows that improved voltage profile, increment in the economy, reduction in losses (active and reactive power loss) and therefore the improvement in the overall performances of the system.

Key words: Optimization Method · Distributed Generation (DG) · Optimal planning of DG · Optimal Power Flow (OPF) · Butterfly-particle swarm optimization (Butterfly-PSO or BF-PSO)

INTRODUCTION

The distributed generation (DG) is considered as active and reactive power generators in the system for the different such as small, medium and large system. The generation of distributed power in the various ranges as small size DGs, medium size DGs and large size DGs with the different scopes. The penetration of DG at a particular position is determined by several system performance and economic indexes. The impacts of DG planning include power-loss reduction, improve voltage, increase system capacity, better economy, reliability of the system and the overall performance of the system. In the present scenario the loads are uncertain in the system with the time, due to that the operation and control of the systems are more complex. There are many researchers have worked on the index based multi-objective function to find the optimal location and size of DG such as [1-2], also the network reconfiguration based concept given in [3]. The Butterfly-particle swarm optimization (Butterfly-PSO or BF-PSO) technique based on the butterfly swarm characteristic behavior, intelligence and search process identified in [4-5]). The many approaches for optimal allocation and sizing of DG in distribution systems are introduced by [6-17]. The concepts of the power flow and optimal power flow for the system are described by [13-15]. The calculation of available transfer capability (ATC) and the shift factors such as the power transfer distribution factors (PTDF) for the transmission system is discussed in [10-11].

This study presents the optimal sizing and siting of distributed generation (DG) with jointly operated methods OPF and Butterfly-PSO. Then consider DG source as an active power and reactive power sources at load bus. The optimal allocation and sizing of distributed generation (DG) with the different objective indices such as Generation Cost Index (CTI), Active Power Loss Index (PLI), Reactive Power Loss Index (QLI), Voltage Deviation Index (VDI), Load Balancing Index (LBI) and Shift Factor Index (SFI) based multi-objective function. The accomplished results demonstrate the overall performance of the system has enhanced with-DG.

The Performance Index Based Multi-objective Problem Formulation: The optimal power flow (OPF) based on the NR-method to minimize the total generation cost Cf [14, 18]. The real and reactive power consumption of the loads can be thought of as a single\combined or bundled

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commodity. The uniform nodal price value can be expressed on the basis of per MW or per MVAr [14]. Let us assume that the load is located at bus j and the prices of real and reactive power are λ_{Pj} and λ_{Qj} respectively. Then the per MW price of the bundled commodity is $\lambda_{Pj} + k_j * \lambda_{Qj}$ and similarly the per MVAr price is $\lambda_{Pj}/k_j + \lambda_{Qj}$,

where, $k_j = \frac{Q_{Dj}}{P_{Dj}} = \text{constant}$ ·

To find-out the optimal positioning and sizing of the distributed generation (DG) in the radial system with the various objectives achieves by the accompanying multi-objective function (Fmo) as:

$$F_{MO} = k_1 \times CTI + k_2 \times PLI + k_3 \times QLI + k_4 \times VDI + k_5 \times LBI + k_6 \times SFI \quad (1)$$

where, $k_1 + k_2 + k_3 + k_4 + k_5 + k_6 = 1$, and the k_1=0.12, k_2=0.28, k_3=0.2, k_4=0.16, k_5=0.14, k_6=0.1 are the indices weight factors. The detail concepts for selecting the weight factor of the indices given in [1, 2, 17].

The total cost index (CTI) is:

$$CTI = \frac{CT_{DG}}{CT_{No-DG}} \quad (2)$$

The active power loss index (PLI) is:

$$PLI = \frac{PL_{DG}}{PL_{No-DG}} \quad (3)$$

The reactive power loss index (QLI) is:

$$QLI = \frac{QL_{DG}}{QL_{No-DG}} \quad (4)$$

The voltage deviation index (VDI) is

$$VDI = \max_{j=2}^{n} \left(\frac{V_{reff} - V_{DGj}}{V_{reff}} \right) \quad (5)$$

Where, n-is the total no. of buses.

The load balancing index (LBI) is:

$$S_j = \sqrt{P_j^2 + Q_j^2} \quad (6)$$

Then load balancing index is as:

$$LBI = \max_{j=1}^{n-1} \left(\frac{S_{DGj}}{S_{No-DGj}} \right) \quad (7)$$

The installation of DG with particular size will inject some power say x_{inj} at bus and due to this injection the change in power is Δx, then shift factor index (SFI) can be given as:

$$SFI = \max_{\substack{j=1 \\ j \neq slack\, and \\ pvbus}}^{n-1} \left| \frac{\Delta x_j}{x_{inj,j}} \right| \quad (8)$$

The Butterfly Particle Swarm Based Optimization (BF-PSO) Techniques: The Butterfly-PSO (BF-PSO) algorithm is essentially based on the nectar probability and the sensitivity of the butterfly swarm. The BF-PSO consists of intelligent behavior of the butterfly to find out the optimum amount of nectar. The butterfly particle swarm optimization learning algorithm (BF-PSO) is used to acquire the concept of optimal solutions not only using the random parameters and acceleration parameter, as well as it uses the effect of additional parameter's probability and sensitivity for fast convergence and more accurate optimal solution [4]. In process for computing the optimal solution, the degree of node in every flight of butterfly assumed as approximately equal to 1 because 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 the all butterflies by different means of communication intelligence (such as dancing, colors, chemicals, sounds, physical action and natural processes).

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. Afterward that the gbest solution identified 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 considering from 0.0 to 1.0. The velocity limits can be set based on the limits of the problem variables [4-5].

Hence the function of inertia weight, sensitivity and probability as a function of iterations can be given as:

$w_k = (ITER_{max} - ITER_k) / ITER_{max}$
$s_k = exp\text{-}(ITER_{max} - ITER_k) / ITER_{max}$

where, $ITER_{max}$ = maximum number of iterations and $ITER_k$ = k[th] iteration count.

$p_k = FIT_{gbest,k} / \Sigma(FIT_{lbest,k})$

where, $FIT_{lbest,k}$ = Fitness of local best solutions with k[th] iteration, $FIT_{gbest,k}$ = Fitness of global best solutions with k[th] iteration.

The Butterfly-PSO (BF-PSO) equations to update the velocity and the position are depends on the sensitivity of the butterfly and the probability of nectar, which can be given as [5]:

$$v'_k = w_k.v_{k-1} + s_k(1-p_k)c_1r_1(x_{lbest,k-1} - x_{k-1}) + p_kc_2r_2(x_{gbest,k-1} - x_{k-1}) \quad (9)$$

And,

$$x_k = x_{k-1} + \alpha_k.v'_k \quad (10)$$

where α_k is a varying probability coefficient, α_k = rand*p_k, rand-is the random number [0, 1].

RESULTS AND DISCUSSIONS

The proposed algorithm is implemented on the 33-bus radial system [3, 9, 12, 13]. The base MVA during this work is 100 MVA. The range of DG size is considered from 0 to 50 for both MW and Mvar. The detail value of generator cost coefficients for both radial systems is given in [14]. In this work, the DG is considered to operate on unspecified power factor. The allocation of a DG is considered on the load buses not on the slack bus and voltage-controlled buses in the system. The all results for proposed methodology carried out with MATLAB (2009a)/Matpowe4.1 tool with the system configuration windows-8.1, AMD-E1-1500APU, 1.48 GHz, 2.0 GB RAM. The detail information about the 33-bus radial system has given in [3, 9, 12, 13]. The study considers the tie switches 33, 34, 35, 36 and 37 are open. The proposed Butterfly-PSO/BF-PSO algorithm applied to minimize the multi-objective function given in equation (1). The optimal minimum value of the multi-objective function decides the optimal value of indices and based on these optimal index values the optimal location and size of DG is determined. The performance results of 33-bus radial system shown in figures from 1 to 8. The variation of multi-objective function value with their respective index at a particular bus shown in Figure 1 and also the DG size, active power loss and active power loss on the respective bus are given in Figure 2. The result shows that the minimum value of the multi-objective function obtained at bus 6. Similarly, the variation of total generation cost and the nodal price of active and reactive power with and without DG respectively given in Figure 3, Figure 4 and Figure 5. The results in Figure 3 indicates that the minimum value of total generation cost obtained at bus 6. The nodal prices of active and reactive power with-DG are lower as compared to without-DG case for 33-bus radial system which is shown in Figure 4 and Figure 5.

The voltage profile values with-DG are more as compare to without-DG condition of 33-bus radial system which is shown in Figure 6. Similarly, the active and reactive power loss with-DG obtains the lower value as compared to without-DG condition of 33-bus radial system which is shown in Figure 7 and Figure 8. The optimum value of all the parameters using proposed Butterfly-PSO/BF-PSO algorithm is given in Table 1, Table 2 and Table 3 for 33-bus radial system. The minimum value of the objective function obtains at bus 6 with their optimal index value which is given in the Table 1 by yellow shading row. The whole Table 1 shows the global optimal solution values of the multi-objective function and their indices at each bus. The Table 2 shows the DG size (PDG, QDG), total generation cost (CT) and loss values (PL, QL) at each bus with corresponding objective function and index value. The Table 3 shows the voltage, active and reactive power nodal price on buses with and without DG case at each bus with corresponding objective function and index value of 33-bus radial system. The Table 1 give possible optimal solution results of the Butterfly-PSO/BF-PSO technique on each and every bus excluding the slack bus. These results conclude that the optimal value of the multi-objective function is 0.531234 at bus-6, which is the more optimal value from all of the buses. The corresponding the optimal value of the multi-objective function, the value of CTI, PLI, QLI VDI, LBI and SFI respectively, are 0.966572, 0.326145, 0.387892, 0.038297, 0.999987 and 1.002187 at bus-6. Similarly, the Table 2 shows the possible optimal solution results of the Butterfly-PSO/BF-PSO technique. The corresponding the optimal value of the multi-objective function the active power DG size (PDG), the reactive power DG size (QDG),

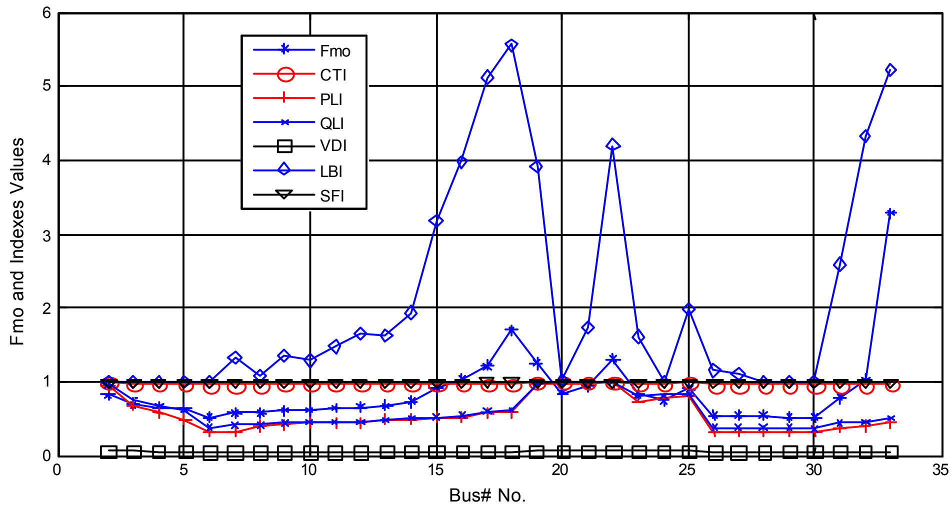

Fig. 1: The variation of multi-objective function and various indices at different buses for 33-bus radial system

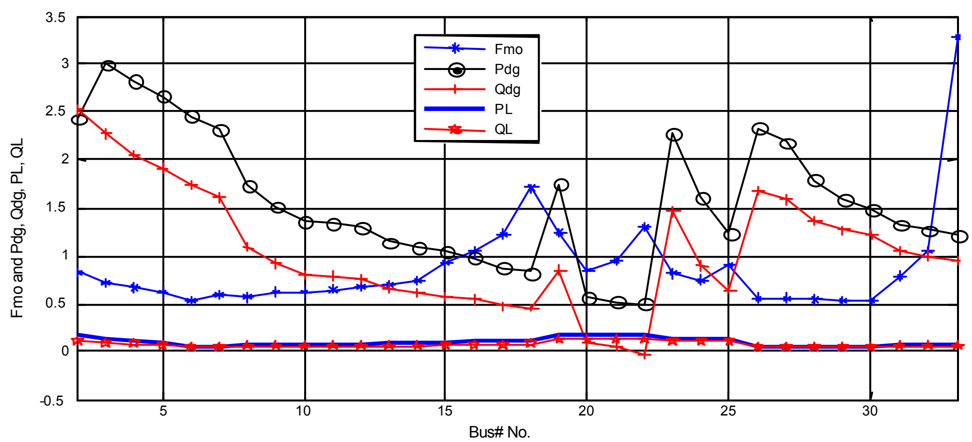

Fig. 2: The variation of DG size and system losses with multi-objective function value of 33-bus radial system

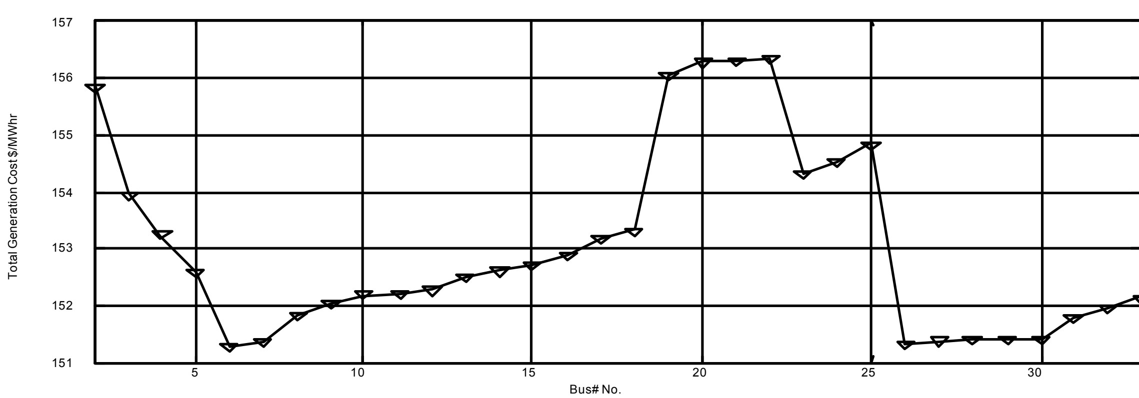

Fig. 3: The total generation cost curve at buses with-DG for 33-bus radial system

total generation cost with-out DG (CT-No-DG in $/Mw/hr), total generation cost with DG (CT-DG in $/Mw/hr), the active power loss with DG (PL-DG) and the reactive power loss with DG (QL-DG) values at bus-6 respectively are 2.4532, 1.7452, 156.509379, 151.2776, 0.060151 and 0.048482. The Table 3 gives the optimal values of the voltage with and without DG are 1.06 pu and 1.013 pu at bus-6. The active power nodal price with and

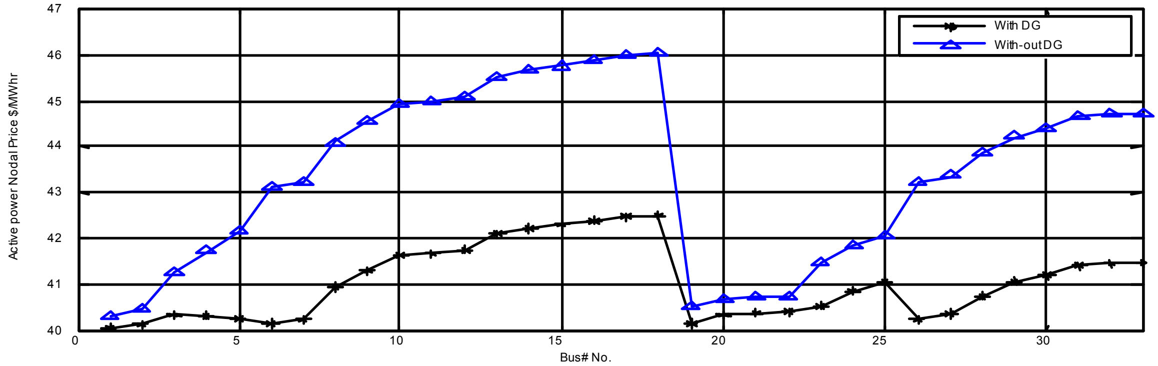

Fig. 4: The nodal price of active power with and without DG for 33-bus radial system

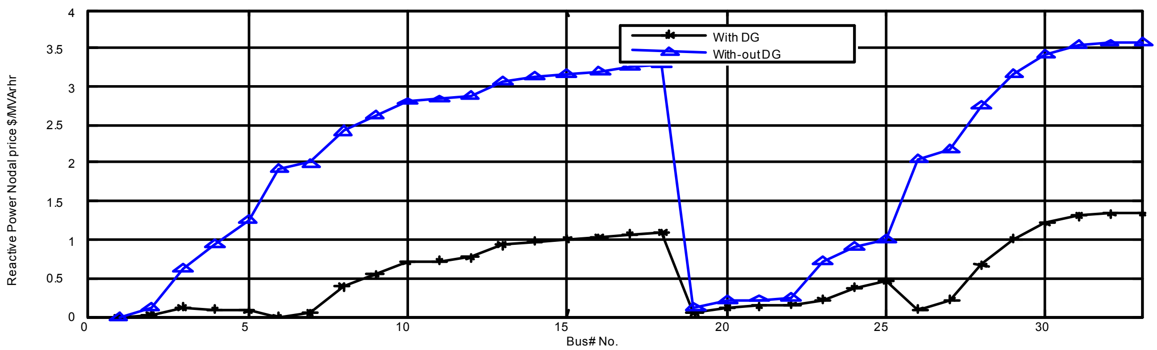

Fig. 5: The nodal price of reactive power with and without DG for 33-bus radial system

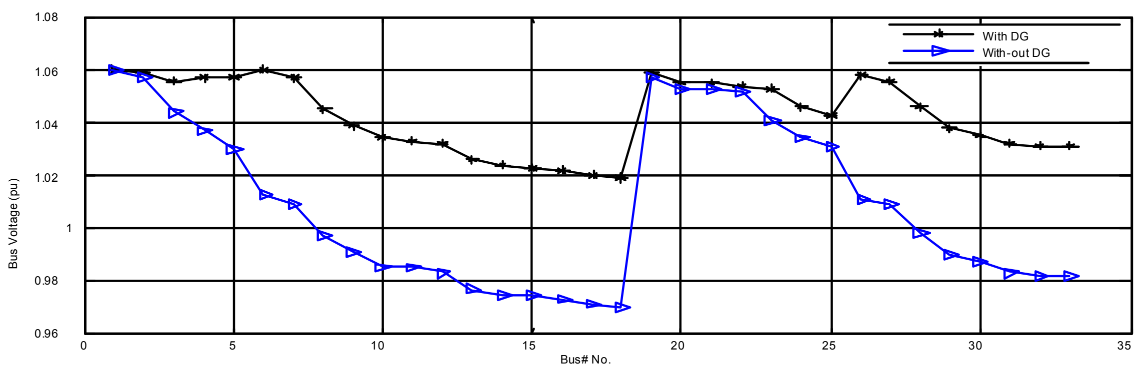

Fig. 6: The voltage profile with and without DG for 33-bus radial system

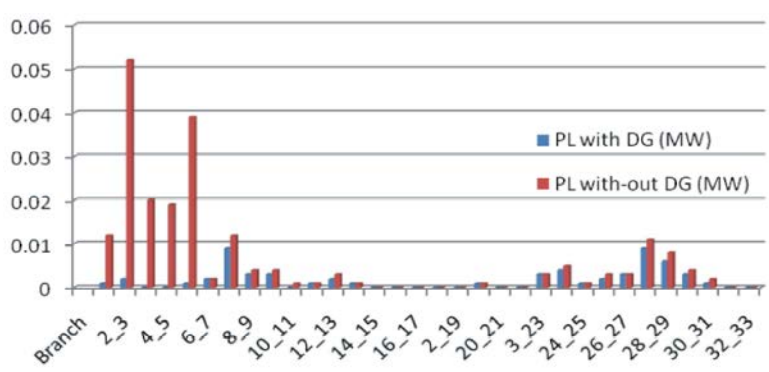

Fig. 7: The active power loss with and without DG for 33-bus radial system

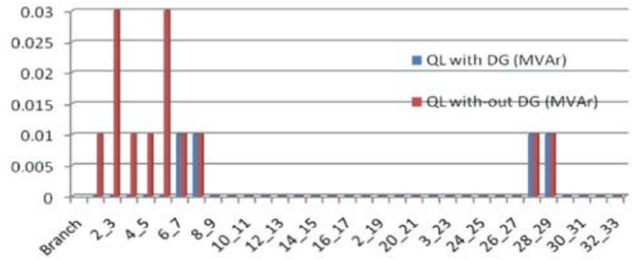

Fig. 8: The reactive power loss with and without DG for 33-bus radial system

Table 1: The value of multi-objective function (Fmo) and indices at buses for 33-bus radial system

Sr. No.	Obj. Fun. (Fmo)	Bus	CTI	PLI	QLI	VDI	LBI	SFI
1	0.828258	2	0.995723	0.943294	0.95626	0.082672	0.999999	1.001698
2	0.709413	3	0.98356	0.677595	0.750264	0.070124	0.999998	1.003874
3	0.666852	4	0.979025	0.584613	0.67688	0.062392	0.999998	1.003183
4	0.627795	5	0.974873	0.499172	0.609549	0.055349	0.999998	1.002769
5	0.531234	6	0.966572	0.326145	0.387892	0.038297	0.999987	1.002187
6	0.586995	7	0.967007	0.336722	0.422197	0.035233	1.330628	1.003076
7	0.57232	8	0.969885	0.399172	0.431803	0.043808	1.075292	1.002545
8	0.622694	9	0.971262	0.427196	0.445427	0.047165	1.35441	1.002791
9	0.622442	10	0.972254	0.446766	0.45574	0.049331	1.295075	1.003256
10	0.650894	11	0.972432	0.450247	0.456338	0.049494	1.490116	1.003303
11	0.675719	12	0.972824	0.457914	0.458986	0.05002	1.64778	1.002746
12	0.69002	13	0.974351	0.48822	0.487751	0.052793	1.643627	1.002917
13	0.737703	14	0.974921	0.499419	0.504564	0.05383	1.935542	1.003735
14	0.92033	15	0.975745	0.516	0.521916	0.054805	3.180074	1.003982
15	1.041304	16	0.976783	0.536922	0.540143	0.055868	3.974201	1.00397
16	1.223409	17	0.978579	0.57288	0.594834	0.057847	5.119796	1.005789
17	1.714027	18	0.979536	0.592186	0.61115	0.058659	8.560525	1.005821
18	1.250418	19	0.996924	0.970531	0.984679	0.083927	3.919186	0.999878
19	0.851865	20	0.998489	0.98665	0.98969	0.084643	1.032088	0.998108
20	0.951977	21	0.998601	0.987675	0.990643	0.084554	1.743525	0.998446
21	1.300903	22	0.998913	0.993109	0.999098	0.08454	4.213842	0.996793
22	0.821055	23	0.985902	0.736672	0.802345	0.073946	1.599887	1.001943
23	0.749759	24	0.987348	0.767495	0.819042	0.077327	0.999999	1.001984
24	0.904255	25	0.989227	0.803661	0.845484	0.079098	1.98988	1.001869
25	0.554119	26	0.966776	0.33161	0.390857	0.040337	1.145886	1.00206
26	0.553682	27	0.96704	0.338216	0.395157	0.042881	1.120374	1.001919
27	0.540418	28	0.967345	0.34555	0.396726	0.050221	1	1.002016
28	0.536839	29	0.967158	0.340914	0.382983	0.053392	1	1.001845
29	0.536746	30	0.967237	0.341939	0.38004	0.054687	0.999999	1.001772
30	0.786891	31	0.96977	0.393974	0.442394	0.059266	2.585774	1.002358
31	1.040336	32	0.970663	0.412316	0.467639	0.060804	4.32066	1.002597
32	3.284873	33	0.971942	0.43877	0.516593	0.063262	5.226097	1.002902

Table 2: The DG size, generation cost and loss values at buses for 33-bus radial system

Bus	PDG Mw	QDG Mvar	CT-No-DG $/Mw/hr	CT-DG $/Mw/hr	PL-DG Mw	QL-DG Mvar
2	2.4308	2.5185	156.509379	155.8401	0.173971	0.119521
3	2.9955	2.273	156.509379	153.9364	0.124969	0.093774
4	2.8222	2.0505	156.509379	153.2266	0.10782	0.084602
5	2.6701	1.9115	156.509379	152.5768	0.092062	0.076187
6	2.4532	1.7452	156.509379	151.2776	0.060151	0.048482
7	2.314	1.6111	156.509379	151.3457	0.062102	0.05277
8	1.7342	1.0889	156.509379	151.7961	0.073619	0.05397
9	1.5196	0.9207	156.509379	152.0116	0.078788	0.055673
10	1.3604	0.8032	156.509379	152.1669	0.082397	0.056962

Table 2: Continued

11	1.3349	0.786	156.509379	152.1947	0.083039	0.057037
12	1.2975	0.7616	156.509379	152.2561	0.084453	0.057368
13	1.1457	0.6573	156.509379	152.4951	0.090042	0.060963
14	1.0906	0.618	156.509379	152.5842	0.092108	0.063065
15	1.0382	0.5826	156.509379	152.7133	0.095166	0.065233
16	0.9801	0.5463	156.509379	152.8757	0.099024	0.067512
17	0.8749	0.4781	156.509379	153.1568	0.105656	0.074347
18	0.8301	0.4525	156.509379	153.3066	0.109217	0.076387
19	1.7489	0.8552	156.509379	156.0279	0.178995	0.123073
20	0.5759	0.0943	156.509379	156.2729	0.181967	0.1237
21	0.5232	0.0565	156.509379	156.2905	0.182157	0.123819
22	0.5	-0.029	156.509379	156.3392	0.183159	0.124876
23	2.281	1.4572	156.509379	154.3029	0.135864	0.100284
24	1.6118	0.89	156.509379	154.5292	0.141549	0.102371
25	1.2415	0.6442	156.509379	154.8233	0.148219	0.105676
26	2.3305	1.6722	156.509379	151.3096	0.061159	0.048853
27	2.1817	1.587	156.509379	151.3508	0.062377	0.04939
28	1.7864	1.3674	156.509379	151.3986	0.06373	0.049586
29	1.5986	1.2688	156.509379	151.3693	0.062875	0.047868
30	1.4985	1.2183	156.509379	151.3817	0.063064	0.047501
31	1.3216	1.0489	156.509379	151.7781	0.072661	0.055294
32	1.2693	1.0022	156.509379	151.9178	0.076043	0.058449
33	1.2079	0.9519	156.509379	152.118	0.080922	0.064568

Table 3: The voltage, active and reactive power nodal price on buses with and without DG for 33-bus radial system

Bus No.	Voltage with-DG pu	Voltage No-DG pu	Nodal price of P with-DG $/Mw/hr	Nodal price of P No-DG $/Mw/hr	Nodal price of Q with-DG $/Mvar/hr	Nodal price of Q No-DG $/Mvar/hr
1	1.06	1.06	40.074	40.304	0	0
2	1.059	1.057	40.13	40.474	0.026	0.105
3	1.056	1.044	40.331	41.293	0.116	0.625
4	1.057	1.037	40.309	41.729	0.101	0.932
5	1.057	1.03	40.266	42.166	0.071	1.242
6	1.06	1.013	40.151	43.113	0	1.932
7	1.057	1.009	40.244	43.24	0.05	2.001
8	1.045	0.997	40.959	44.115	0.392	2.419
9	1.039	0.991	41.3	44.533	0.551	2.615
10	1.034	0.985	41.618	44.922	0.702	2.801
11	1.033	0.985	41.672	44.988	0.729	2.833
12	1.032	0.983	41.767	45.103	0.774	2.887
13	1.026	0.977	42.102	45.517	0.928	3.078
14	1.024	0.975	42.212	45.655	0.976	3.138
15	1.023	0.974	42.294	45.757	1.004	3.173
16	1.022	0.973	42.375	45.857	1.035	3.211
17	1.02	0.971	42.477	45.986	1.076	3.263
18	1.019	0.97	42.511	46.028	1.091	3.282
19	1.059	1.057	40.157	40.501	0.038	0.117
20	1.055	1.053	40.34	40.687	0.12	0.2
21	1.055	1.053	40.374	40.721	0.135	0.215
22	1.054	1.052	40.403	40.751	0.148	0.228
23	1.053	1.041	40.525	41.497	0.211	0.725
24	1.046	1.034	40.877	41.871	0.379	0.904
25	1.043	1.031	41.055	42.059	0.464	0.994
26	1.058	1.011	40.238	43.219	0.089	2.04
27	1.056	1.009	40.354	43.359	0.211	2.188
28	1.046	0.998	40.761	43.861	0.665	2.746
29	1.038	0.99	41.052	44.219	1.008	3.169
30	1.035	0.987	41.206	44.406	1.208	3.412
31	1.032	0.983	41.41	44.66	1.311	3.539
32	1.031	0.982	41.452	44.713	1.333	3.567
33	1.031	0.982	41.463	44.726	1.34	3.576

Table 4: The Comparative analysis of 33-bus radial system

Cases		Parameter			
		Active power loss (kw)	Active power loss reduction (%)	Reactive power loss (kvar)	Reactive power loss reduction (%)
With-out-DG (Base case)		211.7	---	143.1	---
With-DG	Existing	96.76 [3]	52.26 %	NA	NA
		67.95 [9]	67.79 %	54.79	61.69 %
		139.53 [12]	33.87 %	NA	NA
		100.4 [13]	52.42 %	NA	NA
	Proposed (DG at bus 6) PDG(2.4532 Mw) QDG(1.7452Mvar)	60.151	71.49 %	48.482	66.12 %

without DG are 40.151 and 43.113 \$/Mw/hr. The reactive power nodal price with and without DG are 0 and 1.932 \$/Mvar/hr. Also, the Table 4 shows comparative results analysis between the proposed methodology and the existing one.

CONCLUSION

The optimal allocation and sizing of the distributed generation (DG) with multi-objective function based on the indices using the Butterfly-PSO/BF-PSO optimization technique has been suggested. The results analysis of the 33-bus radial system clarifies that the advised method is the efficient method for the decrease of power losses, the betterment of the voltage profile, increase the load balancing capacity. The comparative analysis of the results of the proposed and existing methodology is given in table-4 for the 33-bus radial system. This comparative analysis of the 33-bus radial system shows the active power loss reduction is 67.79 % [9] with the existing method and the active power loss reduction is 71.49 % with the proposed method which is better than the existing method. And the reactive power loss reduction with the existing method is 61.69 % [9] and the reactive power loss reduction with the proposed method is 66.12 % which are superior results than the existing method.

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