DISTRIBUTED GENERATION PLANNING INCLUDING LOAD MODELS USING DIFFERENT OPTIMIZATION TECHNIQUES

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Abstract: *Today's requirement is to supply the sustainable and reliable power in power system. The reliability and sustainability of distribution system can be managed by well and optimal planned distributed generations. This paper presents and compares the optimal planning of distributed generations using Genetic Algorithm (GA), Standard or Conventional Particle Swarm Optimization (PSO) and Butterfly-PSO (BF-PSO). Also, the work reveals modeling of the mixed practical load models to analyze the actual system performance. The optimal planning of DG is considered so as to obtain the optimal location and size of the DG. The impacts of different load models on optimal sizing and location of DG can't be ignored throughout the system. The fitness evolution function is multi-objective function which is based on the active power loss index, reactive power loss index and voltage deviation index. The optimal solution is obtained by minimizing multi-objective fitness function (FMO) using GA, PSO and BF-PSO optimization technique. The proposed methodology has been tested on 15-bus and 33-bus radial distribution system. Result shows the performance; such as voltage profile improvement, reductions in loss are efficient. And the best optimization results are achieved by the BF-PSO technique.*

Key words: *Distributed Generations (DGs), Multi-objective fitness function, Load models, Indices, Location and size, Optimization technique.*

1. Introduction

The practical system consists of different type of load model not only constant loads. The percentage of constant loads in the actual practical system is very less or negligible. The energy consumption performance in the actual system is described by considering mixed load models. The real practical system loads include combinations of the industrial, residential and commercial loads. The different load models such as constant, industrial, residential, commercial and mixed load models are presented by [10-12, 14, 17-19]. Planning of distributed generation for expansion of the distributed system is reported in [21-22]. The index based multi-objective function to obtain optimal location and size of DG is reported in [11-12, 14, 2], and the network reconfiguration based concept is given in [13, 20, 23]. Several optimization techniques such as Genetic Algorithm (GA) [1-3], standard or conventional Particle Swarm Optimization (PSO) [4, 6-7] and Butterfly-particle swarm optimization (Butterfly-PSO or BF-PSO) [8-9] and [24-25] have been invented in the earlier research work. The NR-method based power flow is used in this algorithm and several power flow methodologies are described in [5, 10, 15-16].

This work reports the optimal sizing and location of distributed generation (DG) with the different type of load models. Then consider DG source as an active power and reactive power sources at the load bus. The optimal allocation and sizing of distributed generation (DG) with different objective indices such as Active Power Loss Index (PLI), Reactive Power Loss Index (QLI) and Voltage Deviation Index (VDI) based multi-objective function is evaluated as fitness function. The obtained results bestow impacts of the different load models on the overall system performance of distributed system. The optimization results for sizing and siting of DG have been compared with the different optimization techniques. It can be clearly inferred from the results that the better optimization results are obtained by the BF-PSO technique.

2. The Index Based Problem Formulation

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

$$FMO = t_1 \times PLI + t_2 \times QLI + t_3 \times VDI \quad (1)$$

Where, $\sum_{i=1}^{3} t_i = 1$, and the t_1, t_2 and t_3 are the indices weight factors. The detail concepts for selecting the weight factor of the indices are given in reference [11-12, 14]. All these weight factors are decided based on the individual impacts and the importance of the index while installing the DG. The main aim is to minimize the fitness functions to improve the overall performance of the system; hence the active power loss index gets the highest weight of the value 0.45. After that, second highest weight of 0.30 is given to the voltage deviation index (VDI) to maintain the power quality and voltage profile of the system. The reactive power loss index (QLI) gets a weight of 0.2, to maintain the reactive power losses in the system.

2.1 Active Power Loss Index (PLI)

The active power loss index (PLI) decides the performance of the active power loss of the whole system in the different cases. It can be expressed by considering PL_{DG} and PL_{No-DG} as the active power losses with DG and with-out DG of the system.

$$PLI = \frac{PL_{DG}}{PL_{No-DG}} \qquad (2)$$

2.2 Reactive Power Loss Index (QLI)

The total reactive power loss performance of the system is described by the reactive power loss index (QLI). It's given by considering QL_{DG} and QL_{No-DG} as the reactive power losses with DG and with-out DG of the system.

$$QLI = \frac{QL_{DG}}{QL_{No-DG}} \qquad (3)$$

2.3 Voltage Deviation Index (VDI)

The voltage profile performance throughout the system is given by the voltage deviation index (VDI). It can be given on basis of deviation of system voltage from the reference or rated value (Vreff). The minimum voltage deviation index denotes the better the system performance and improvement in voltage profile. This index can be given as:

$$VDI = \max_{j=2}^{n}\left(\frac{V_{reff} - V_{DGj}}{V_{reff}}\right) \qquad (4)$$

Where, n-is the total no. of buses. The V_{reff} and V_{DGj} are the reference voltage and the system voltage value in pu with DG respectively.

3. The Practical Load Models

The mathematical expression for practical and various type load models in the system is given by:

$$P_i = P_{oi}(a_1 V_i^{\alpha o} + b_1 V_i^{\alpha i} + c_1 V_i^{\alpha r} + d_1 V_i^{\alpha c})$$
$$Q_i = Q_{oi}(a_2 V_i^{\beta o} + b_2 V_i^{\beta i} + c_2 V_i^{\beta r} + d_2 V_i^{\beta c}) \qquad (5)$$

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 α and β are active and reactive power exponents for constant, industrial, residential, commercial load models with subscript *o*, *i*, *r*, and *c* respectively. The table-1 gives the exponents value of the load models. The value of the active power weight coefficients a_1, b_1, c_1, d_1 and the reactive power weight coefficient a_2, b_2, c_2, d_2 are selected on the basis of weightage of active and reactive power consumption of particular load or demand. The different type and mixed practical load model on the basis of equation (5) can be given as:

Load type-1: Constant load; $a_1 = 1$, $b_1 = 0$, $c_1 = 0$, $d_1 = 0$ and $a_2 = 1$, $b_2 = 0$, $c_2 = 0$, $d_2 = 0$.

Load type-2: Industrial load; $a_1 = 0$, $b_1 = 1$, $c_1 = 0$, $d_1 = 0$ and $a_2 = 0$, $b_2 = 1$, $c_2 = 0$, $d_2 = 0$.

Load type-3: Residential load; $a_1 = 0$, $b_1 = 0$, $c_1 = 1$, $d_1 = 0$ and $a_2 = 0$, $b_2 = 0$, $c_2 = 1$, $d_2 = 0$.

Load type-4: Commercial load; $a_1 = 0$, $b_1 = 0$, $c_1 = 0$, $d_1 = 1$ and $a_2 = 0$, $b_2 = 0$, $c_2 = 0$, $d_2 = 1$.

Load type-5: Mixed or practical load; $a_1 = t_{a1}$, $b_1 = t_{a2}$, $c_1 = t_{a3}$, $d_1 = t_{a4}$ and $a_2 = t_{r1}$, $b_2 = t_{r2}$, $c_2 = t_{r3}$, $d_2 = t_{r4}$. Also, for the practical mixed load models $t_{a1} + t_{a2} + t_{a3} + t_{a4} = 1$, and $t_{r1} + t_{r2} + t_{r3} + t_{r4} = 1$.

For mixed practical load models, this work assumes that the system consists of industrial, residential and commercial load models, with no constant loads. So a_1 and a_2 get weight equal to 0. The industrial load demands or consumes 20% active power and 30% reactive power of the total load demand hence b_1 and b_2 get weight equals to 0.2 and 0.3 respectively. The residential load demands 55% active power and 50% reactive power of the total load demand hence c_1 and c_2 get weight equals to 0.55 and 0.5 respectively. The commercial load demands 25% active power and 20% reactive power of the total load demand hence d_1 and d_2 get weight equals to 0.25 and 0.2 respectively.

Table-1: The exponent values for load models

Load type	Exponents	
Constant	αo	βo
	0	0
Industrial load	αi	βi
	0.18	6
Residential load	αr	βr
	0.92	4.04
Commercial load	αc	βc
	1.51	3.4

4. 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 [8]. 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) [9]. 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. Hence, the function of inertia weight, sensitivity and probability as a function of iterations can be given as [8-9]:

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

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

Where, $ITER_{max}$ = maximum number of iterations, and $ITER_k$ = k^{th} iteration count. And $FIT_{lbest,k}$ =Fitness of local best solutions with k^{th} iteration, $FIT_{gbest,k}$ = Fitness of global best solutions with k^{th} iteration.

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

$$v'_{(k+1)} = w * v_k + s_k (1 - p_k) c_1 r_1 (lbest_k - currentpop) + p_{kg} c_2 r_2 (gbest_k - currentpop) \quad (6)$$

$$x_{(k+1)} = x_k + v'_{k+1} \quad (7)$$

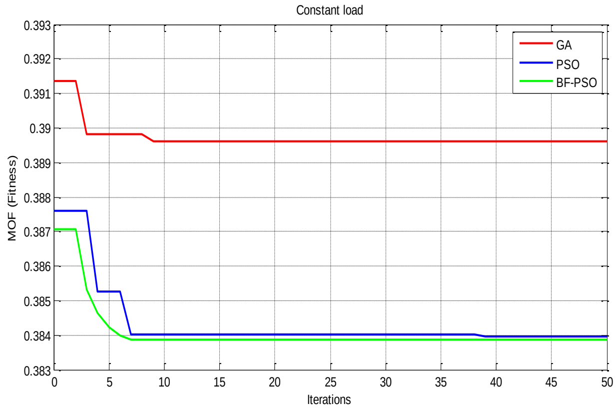
5. Results and Discussions

The proposed algorithm has been tested on 15-bus radial system [10] at 11 KV and the 33-bus radial system [20] at 12.66 KV with the base of 100 MVA. The range of DG size is 0.0 to maximum load (sum of all power demand) in the system. The DG is considered as a unity power factor. The loads are dependent on the voltage; i.e. real and reactive load demand depends on the voltage magnitude of the particular bus.

5.1 15-Bus Radial Test System

Results for the 15-bus radial distribution system are given from figure-1 to figure-4 and from table-2 to table-4. Figure-1 gives the results about convergence of multi-objective function (FMO) with iterations for the constant, industrial, residential commercial and mixed loads.

The convergence towards the optimal value of function varies with an optimization technique as shown for GA, PSO and BF-PSO. The comparative analysis indicates that convergence of BF-PSO technique is better and faster than GA and PSO. Hence the all system performance results are computed for the BF-PSO technique.



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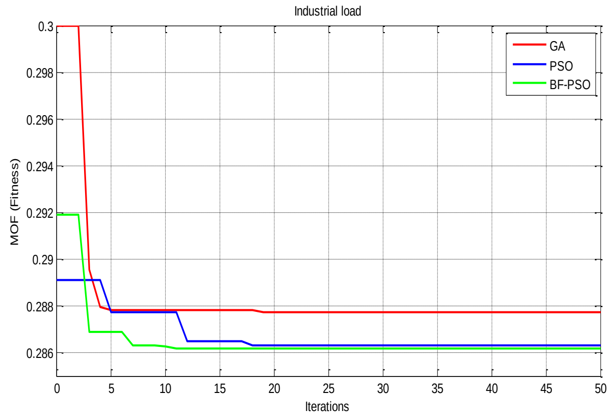

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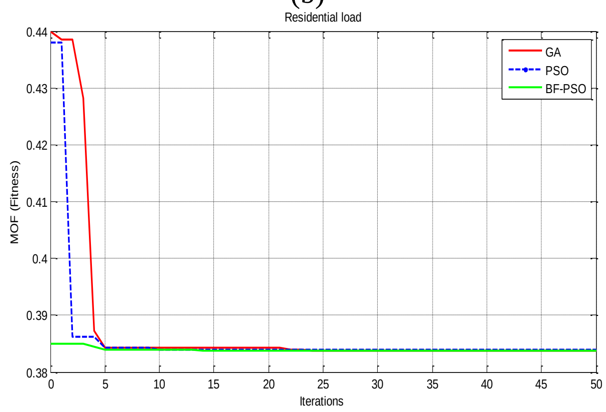

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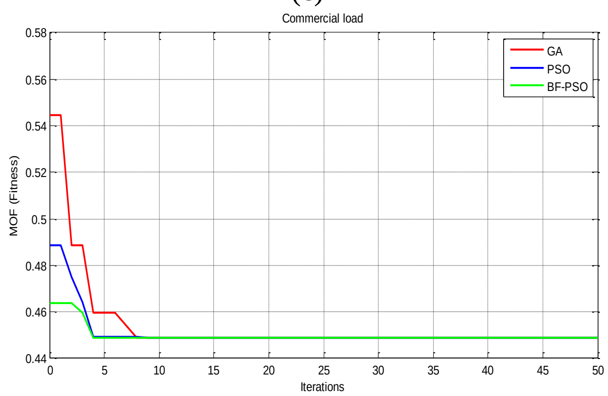

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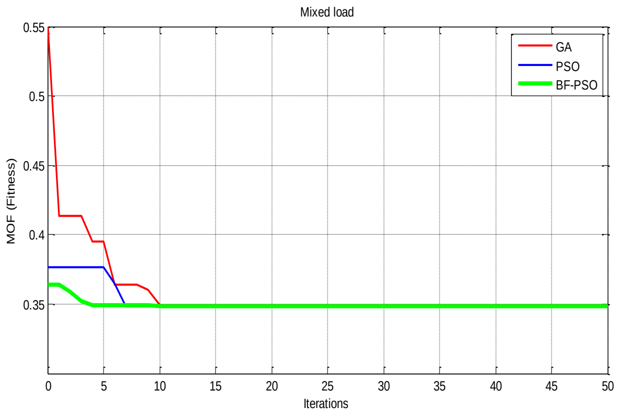

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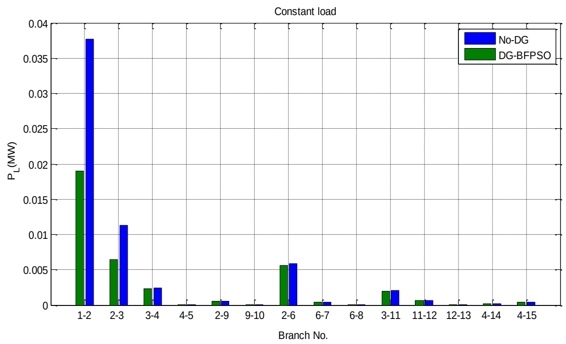
Figure-1: The convergence of multi-objective function (FMO) with iterations for 15-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



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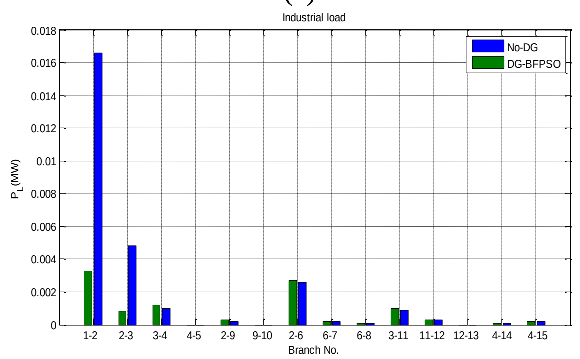

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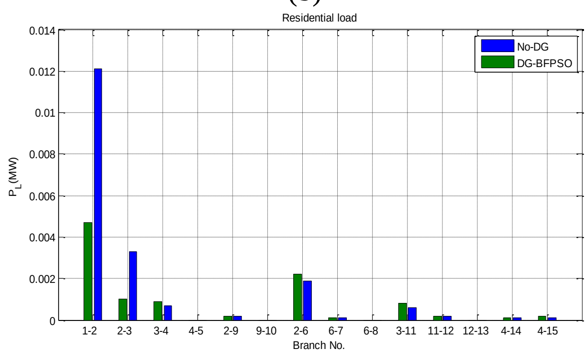

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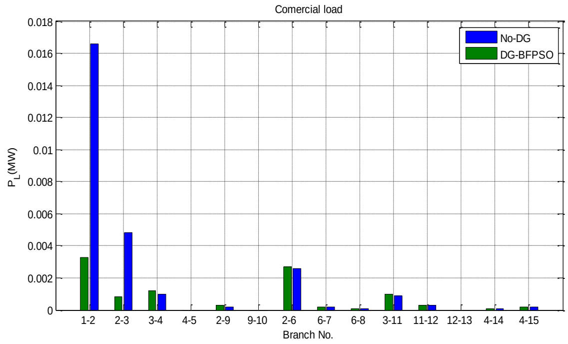

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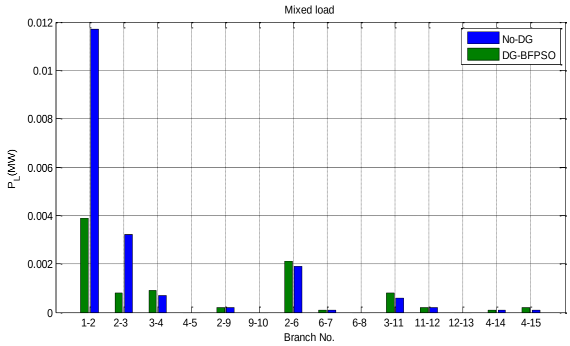

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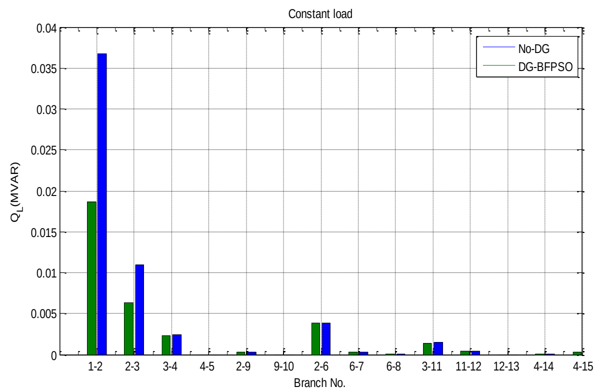
Figure-2: The active power loss of system for 15-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



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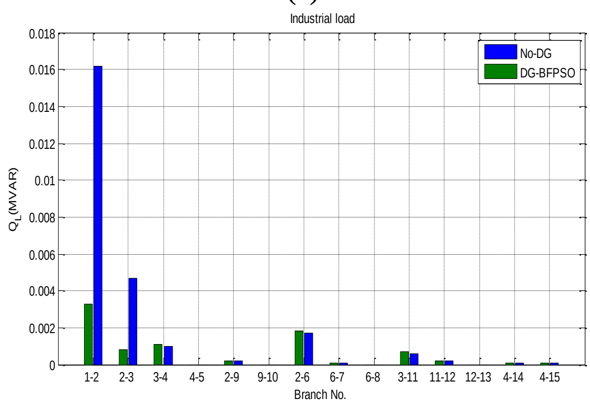

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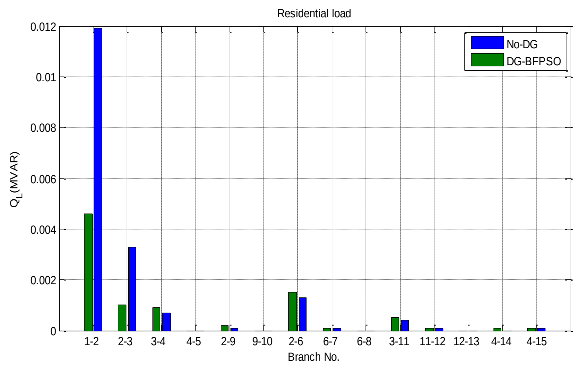

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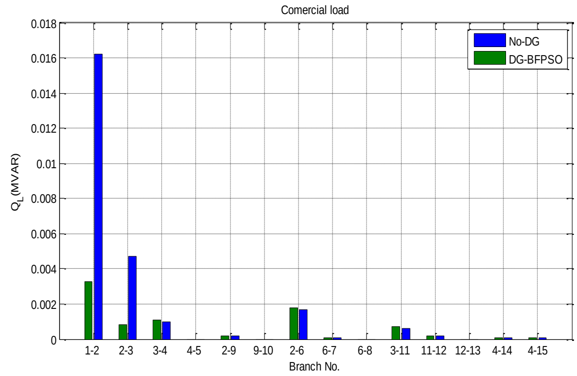

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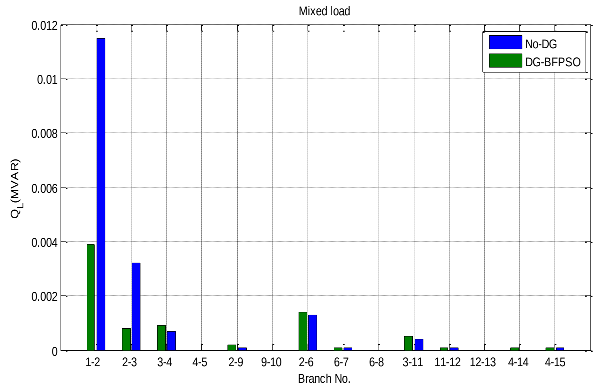

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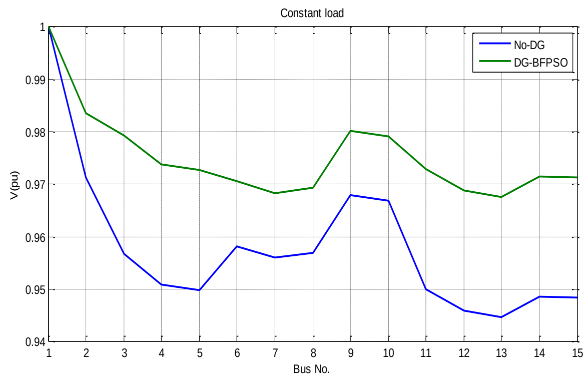
Figure-3: The reactive power loss of system for 15-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



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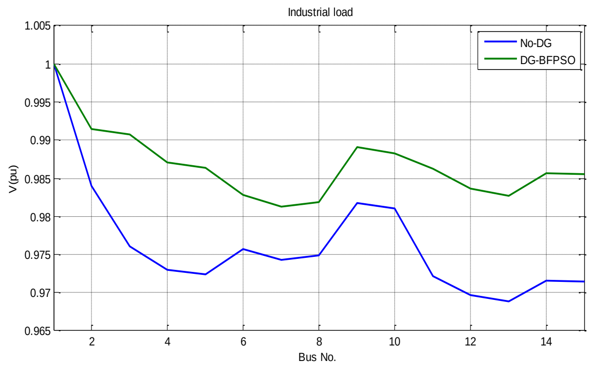

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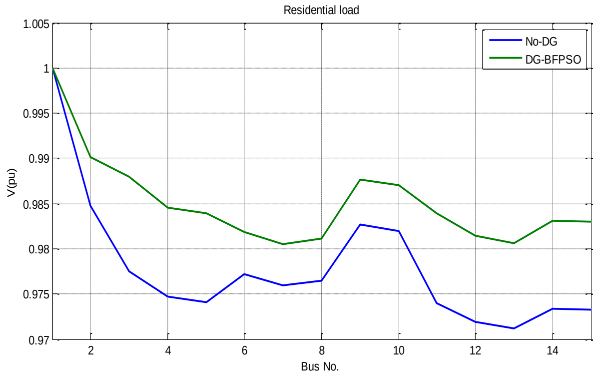

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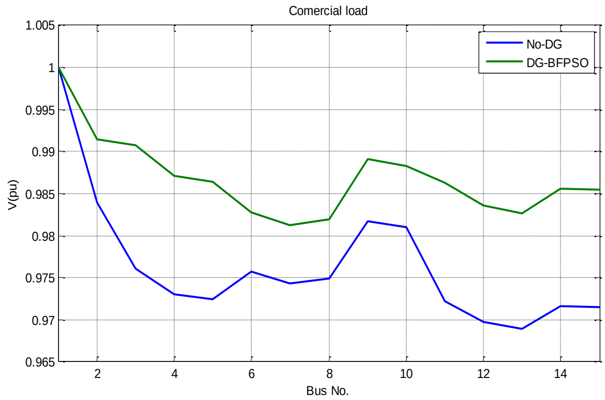

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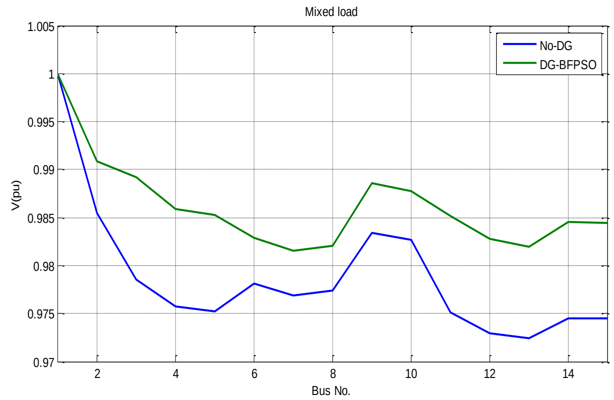

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Figure-4: The voltage profile of system for 15-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.

The BF-PSO results of 15-bus radial system for the active power loss of system with constant, industrial, residential commercial and mixed load are shown in figure-2. This result indicates that the active power loss for the system with-DG is reduced and fulfils the effective sustainable power requirement as compared to without-DG. And also, size and optimal location are varied with the different load models and the active power losses are different with-DG. The reactive power loss without and with-DG using BF-PSO technique for load models are given in figure-3. 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 improvement in the voltage profile with DG-BFPSO 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. Table-3 represents the active and reactive power losses of the system for load models using GA, PSO and BF-PSO with-DG. The active and reactive powers losses value including mixed load model for without-DG case are 0.0189 MW and 0.0175 MVAR; with-DG using BF-PSO are 0.0095 MW and 0.0082 MVAR; with-DG using PSO are 0.0096 MW and 0.0082 MVAR; and with-DG using GA are 0.0097 MW and 0.0083 MVAR.

The values of the multi-objective function (FMO), size of DG (PDG) and optimal bus location of DG are given in table-4 for 15-bus radial system. The 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 0.3487; PDG is 0.689 and optimal bus location is 3 using BF-PSO for the mixed load model. The value of FMO is 0.349; PDG is 0.6708 and optimal bus location is 3 using PSO for the mixed load model. The value of FMO is 0.3542; PDG is 0.6043 and optimal bus location is 3 using GA for the mixed load model.

Similarly, the impacts of industrial, residential, commercial and mixed load models on the multi-objective function (FMO), size of DG (PDG) and optimal bus location of DG can be analyzed. The results of 15-bus radial system show that the reduction in losses and improved voltage profile because of that the sustainability and reliability of the power and energy supplied to the customers is enhanced.

Table-2: The objective indices with different load models using GA, PSO and BF-PSO for 15-bus radial system

Load Type	PLI	QLI	VDI	Method
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
Mixed load	0.5039	0.4658	0.0185	BF-PSO
	0.5041	0.4663	0.0186	PSO
	0.5107	0.4745	0.0191	GA

Table-3: The active and reactive power loss for different load models using GA, PSO and BF-PSO with-DG for 15-bus radial system

Methods	Constant Load		Industrial Load		Residential Load		Commercial Load		Mix Load	
	PL	QL	PL	QL	PL	QL	PL	QL	PL	QL
No-DG	0.0617	0.0572	0.027	0.025	0.0195	0.0181	0.016	0.0149	0.0189	0.0175
DG-BFPSO	0.0378	0.0339	0.0102	0.0085	0.0106	0.0092	0.0106	0.0093	0.0095	0.0082
DG-PSO	0.038	0.034	0.0108	0.0092	0.011	0.0096	0.0108	0.0095	0.0096	0.0082
DG-GA	0.0382	0.0343	0.0135	0.0112	0.0126	0.0109	0.0118	0.0105	0.0097	0.0083

Table-4: The Multi-objective function and DG size at optimal bus location with different load models using GA, PSO and BF-PSO for 15-bus radial system

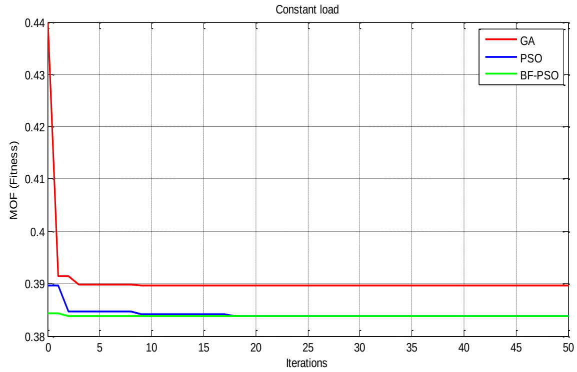
Load Type	Fitness funct. (FMO)	PDG	Bus	Method
Constant load	0.4335	1.0355	3	BF-PSO
	0.4346	0.9703	3	PSO
	0.4375	1.1596	3	GA
Industrial load	0.2609	0.8549	3	BF-PSO
	0.2785	0.7232	4	PSO
	0.3439	0.5862	15	GA
Residential load	0.3786	0.672	3	BF-PSO
	0.3926	0.5697	4	PSO
	0.4467	0.4502	15	GA
Commercial load	0.4602	0.5505	3	BF-PSO
	0.4673	0.644	3	PSO
	0.5151	0.363	15	GA
Mixed load	0.3487	0.689	3	BF-PSO
	0.349	0.6708	3	PSO
	0.3542	0.6043	3	GA

5.2 33-Bus Radial Test System

Results of the 33- bus systems with practical load models for the optimal planning of the DG are given from figure-5 to figure-8 and from table-5 to table-7 using BF-PSO algorithm. The figure-5 shows the convergence of multi-objective fitness function (FMO) with iterations for the different practical load models. These results illustrate that the best convergence and speed to find the optimal solution of the multi-objective function is obtained using BF-PSO technique. Hence the results of the 33- bus system with load models are presented for the BF-PSO technique.

The figure-6 shows the active power loss of the 33-bus system, which is reduced with-DG as compared to without-DG condition. Due to reduction in losses, the availability of power supply is increased and because of which the sustainability and reliability of the power and energy supplied to the customers is improved. The active power losses of the system with various load models are shown in figure-7 using BF-PSO. The reactive power losses of the system with-DG are less as compared to no-DG case. Due to this reduction, the reactive power injection into the system is enhanced and the support of sustainable reactive power and energy is maintained throughout the system.

The impact of load models on size and location of DG and also on the reactive power losses are different with-DG. The voltage profile improvement with and without-DG case with load models is shown in figure-8. The installation of DG in the distribution system increases the voltage profile throughout the system, so that with-DG condition in the system will manage the sustainability of the voltage profile with different load models.



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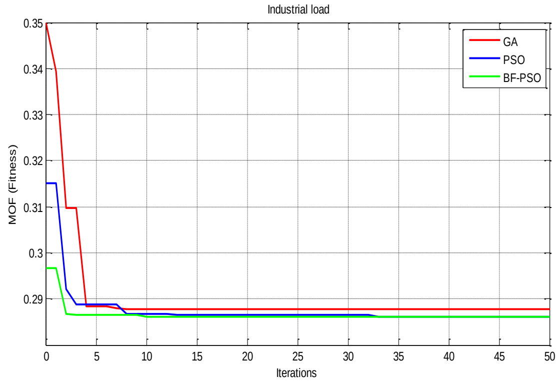

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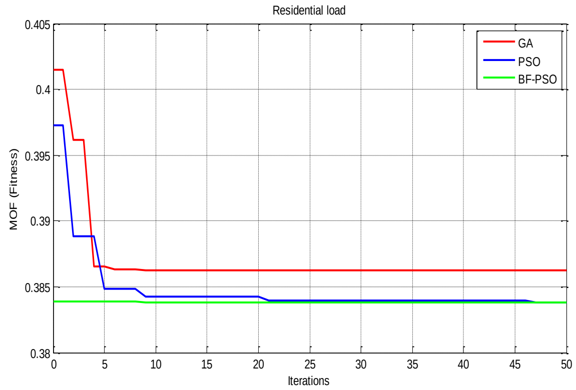

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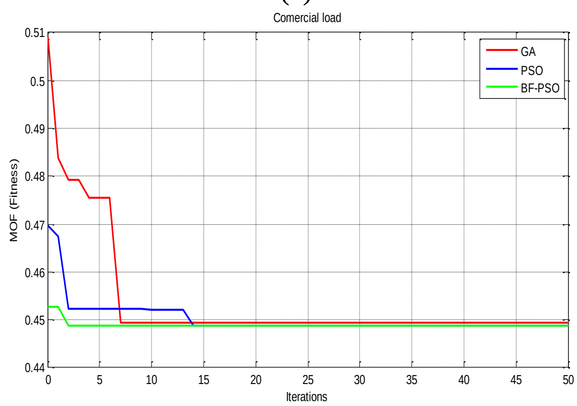

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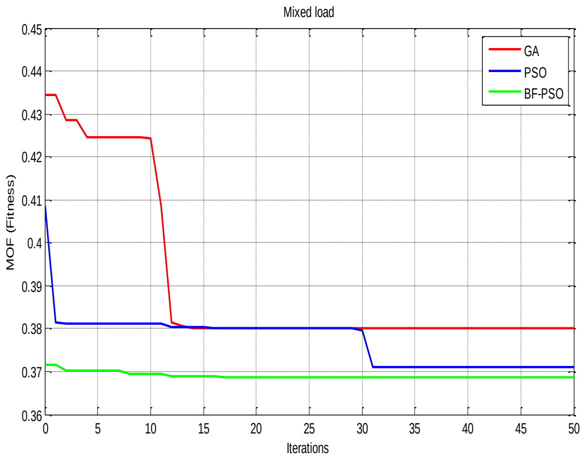

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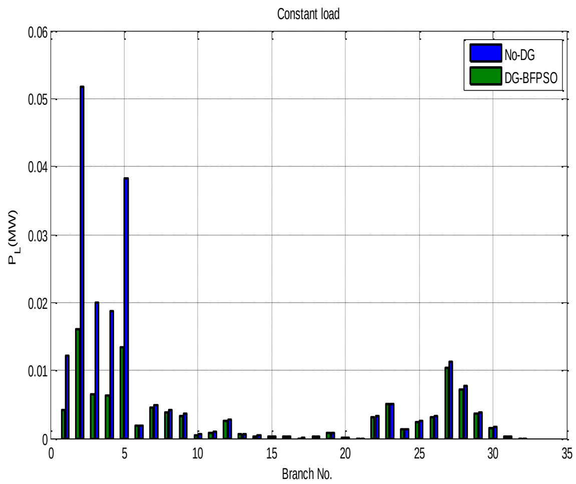
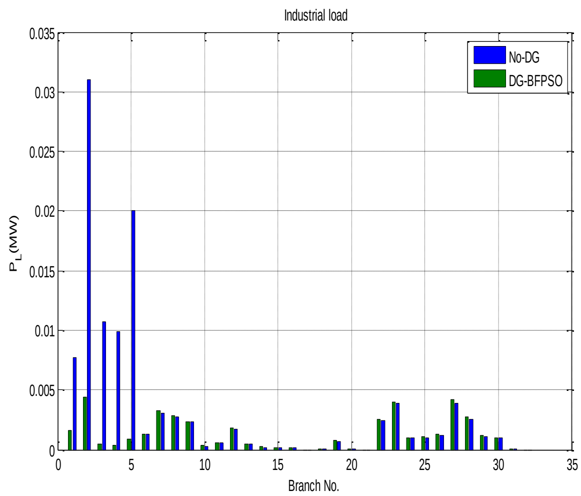
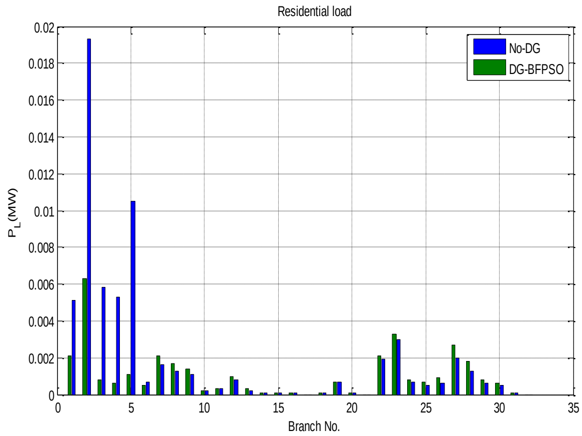
Figure-5: The convergence of multi-objective function (FMO) with iterations for 33-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



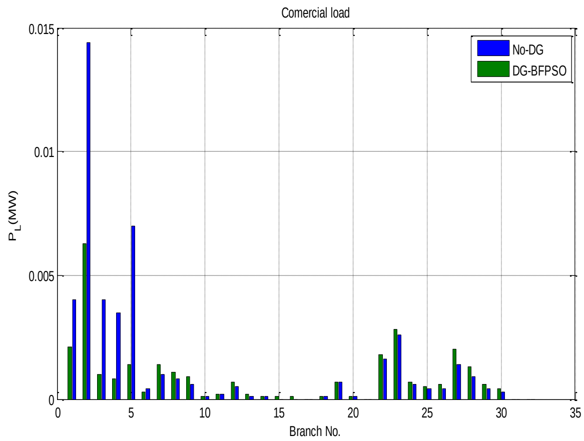
(a)



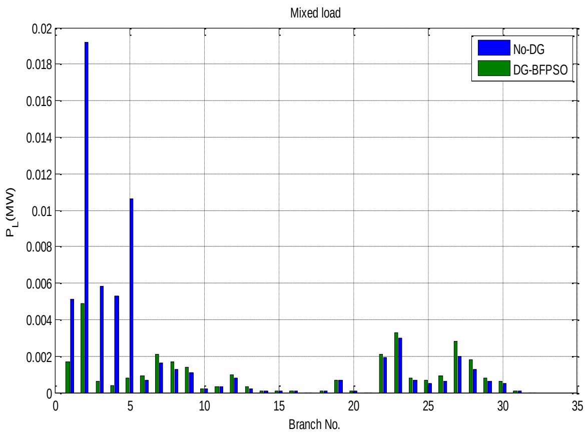
(b)



(c)

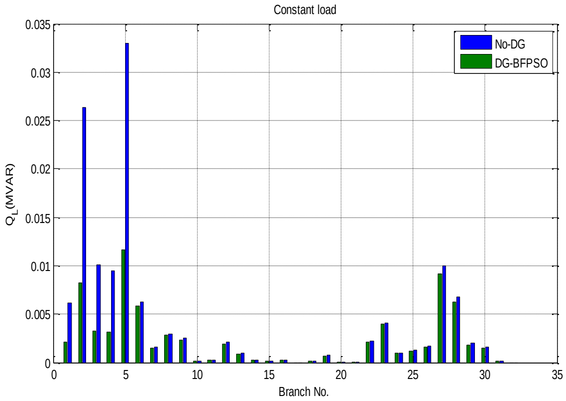


(d)

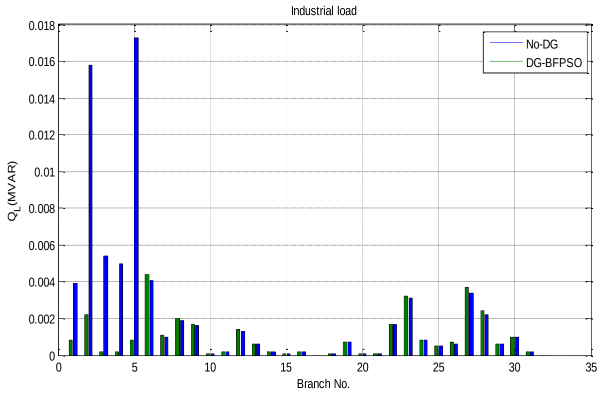


(e)

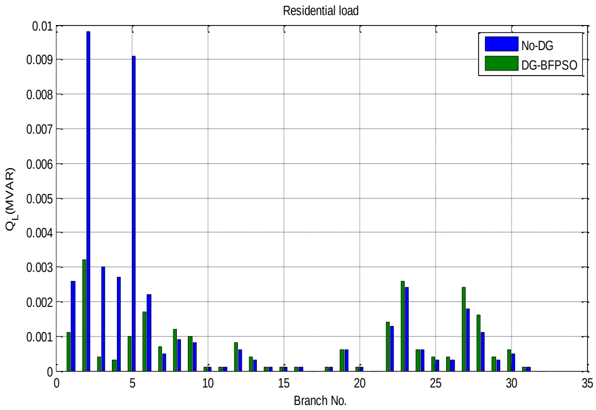
Figure-6: The active power loss of system for 33-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



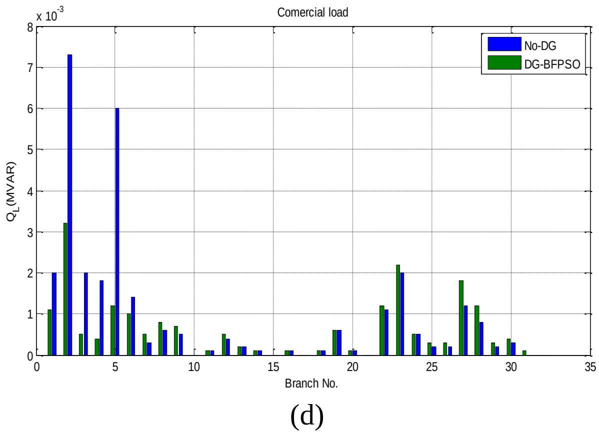
(a)



(b)



(c)



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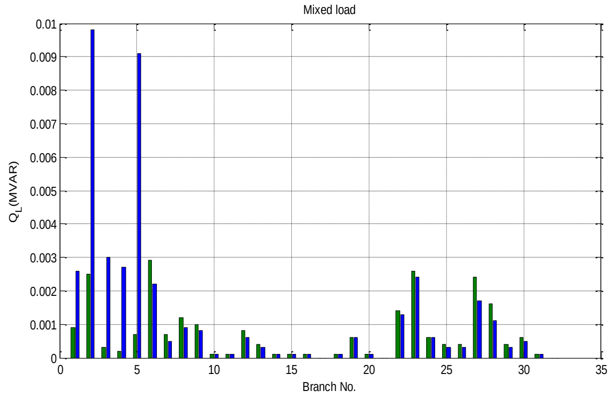
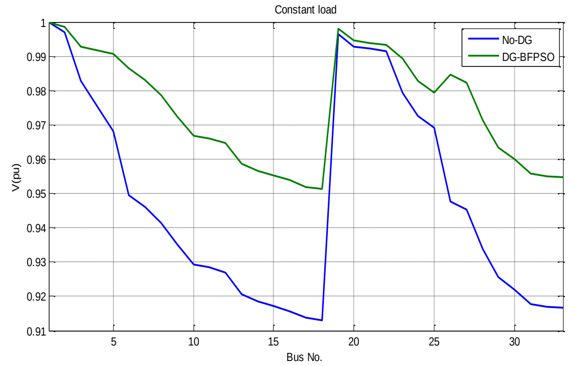
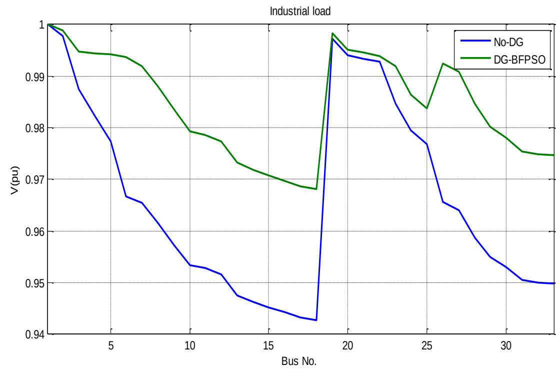


(e)

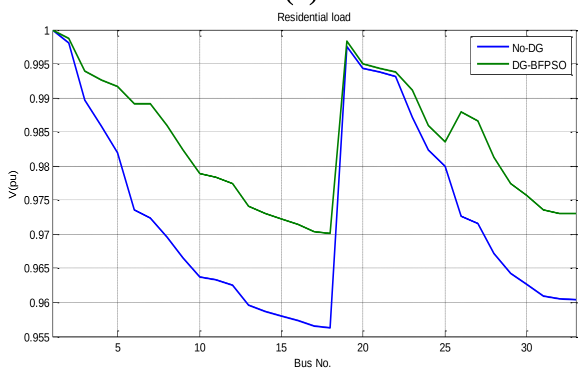
Figure-7: The reactive power loss of system for 33-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.



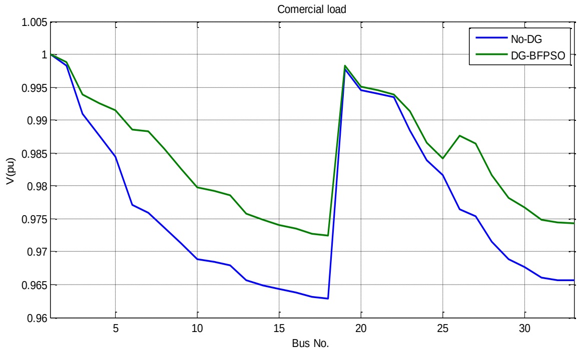
(a)



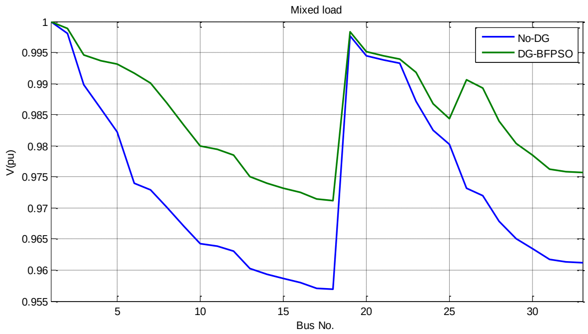
(b)



(c)



(d)



(e)

Figure-8: The voltage profile of system for 33-bus radial system with (a) Constant load, (b) Industrial load, (c) Residential load, (d) Commercial load, (e) Mixed load.

The values of system indices using different methods for each load model with-DG conditions are given in table-5. These values are the optimal solution values of the optimization technique. The active and reactive power losses for different load models using GA, PSO and BF-PSO with-DG of the 33-bus radial system are given in table-6. The mixed load models active and reactive power losses value for the without-DG case are 0.0644 MW and 0.0423 MVAR; with-DG using BF-PSO are 0.0317 MW and 0.0237 MVAR; with-DG using PSO are 0.0318 MW and 0.0237 MVAR; and with-DG using GA are 0.0327 MW and 0.0242 MVAR. The values of the multi-objective function (FMO), size of DG (PDG) and optimal bus location of DG are given in table-7. The minimum value of the fitness function (FMO) is obtained using BF-PSO method for all load models; hence all system results are evaluated for BF-PSO method. The mixed load models value for FMO, PDG and optimal bus location respectively are 0.3702, 1.6611, 6 using BF-PSO; 0.3709, 1.5843, 6 using PSO; and 0.3801, 1.5648, 26 using GA. Similarly, the analysis for constant, industrial, residential and commercial load models can be given using different methods and load models for the 33-bus test system.

Table-5: The objective indices with different load models using GA, PSO and BF-PSO for 33-bus radial system

Load Type	PLI	QLI	VDI	Method
Constant load	0.513	0.5537	0.0487	BF-PSO
	0.5133	0.5544	0.048	PSO
	0.519	0.5646	0.0497	GA
Industrial load	0.3734	0.4343	0.0318	BF-PSO
	0.3743	0.4337	0.0326	PSO
	0.3794	0.4297	0.0318	GA
Residential load	0.5212	0.5612	0.0299	BF-PSO
	0.5199	0.5653	0.0296	PSO
	0.515	0.582	0.0301	GA
Commercial load	0.6179	0.6497	0.0276	BF-PSO
	0.6169	0.6522	0.0274	PSO
	0.6211	0.6459	0.0281	GA
Mixed load	0.4919	0.5608	0.0288	BF-PSO
	0.4937	0.5597	0.0294	PSO
	0.5072	0.5716	0.0298	GA

Table-6: The active and reactive power loss for different load models using GA, PSO and BF-PSO with-DG for 33-bus radial system

Methods	Constant Load		Industrial Load		Residential Load		Commercial Load		Mix Load	
	PL	QL	PL	QL	PL	QL	PL	QL	PL	QL
No-DG	0.2027	0.1352	0.1116	0.074	0.0646	0.0424	0.0462	0.0301	0.0644	0.0423
DG-BFPSO	0.104	0.0749	0.0417	0.0322	0.0336	0.0238	0.0285	0.0196	0.0317	0.0237
DG-PSO	0.1041	0.075	0.0418	0.0322	0.0336	0.024	0.0286	0.0196	0.0318	0.0237
DG-GA	0.1052	0.0763	0.0423	0.0318	0.0332	0.0247	0.0287	0.0195	0.0327	0.0242

Table-7: The Multi-objective function and DG size at optimal bus location with different load models using GA, PSO and BF-PSO for 33-bus radial system

Load Type	Fitness funct. (FMO)	PDG	Bus	Method
Constant load	0.3839	2.5968	6	BF-PSO
	0.384	2.6454	6	PSO
	0.3896	2.3233	7	GA
Industrial load	0.2862	2.2019	6	BF-PSO
	0.2866	2.1294	6	PSO
	0.2877	2.0047	7	GA
Residential load	0.3838	1.4755	7	BF-PSO
	0.3841	1.5204	7	PSO
	0.3863	1.6196	6	GA
Commercial load	0.4487	1.1576	7	BF-PSO
	0.4489	1.1854	7	PSO
	0.4494	1.0984	7	GA
Mixed load	0.3702	1.6611	6	BF-PSO
	0.3709	1.5843	6	PSO
	0.3801	1.5648	26	GA

5. CONCLUSIONS

The performance of the system has improved with-DG as compared to without-DG condition using GA, PSO and BF-PSO optimization technique. This performance includes reduction in losses and increased in voltages, etc.; hence the overall reliability and sustainability of the system with-DG has improved. The modeling and analysis of the mixed practical load models is presented and results are compared for this using different optimization technique. These results prove that the performances throughout the system are improved. The effect of different types of load on the system is considerable when dealing with the optimal sizing and siting problem of DG within the system. Also, the size and location of DG vary with different load models for GA, PSO and BF-PSO technique.

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