Economic Analysis by Optimal Placing of DGs in Distribution Networks by Particle Swarm Optimisation and Gravitational Search Optimisation Algorithm

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Abstract

The particle swarm optimisation and gravitational search optimisation algorithm (PSOGSA) is a hybrid algorithm which is used to determine size of optimal Distributed Generation (DG) in this paper. The PSOGSA integrates the social thinking ability (gbest) in PSO to capability of local search in GSA. The algorithm combines the searching capability of PSO and with enhanced exploration ability of GSA. Distributed generations are connected in distribution systems to consumers to reduce losses, enhance the voltage profile, reliability and economic benefits. DG optimal positioning and loss minimisation have a significant role for economic operation and overall reduction of energy costs. For evaluation of proposed algorithm, the test bus sets IEEE15, 33 and 69 are chosen. For considered objectives i.e., optimal DG

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sizing and economic analysis, this PSOGSA algorithm gives better results as compared to other methods and better outcomes has been achieved when DG unit of type III operates at power factor of 0.9 lag

Keywords: PSOGSA, method of PLI (power loss index), DG siting, radial network, reduction of losses.

1 Introduction

Now days due to continuous increase in utilisation of power, customers demand reliable and economic power. To increase the performance of existing distribution network the Distributed Generation (DG) offers a feasible solution for power loss mitigation and voltage profile enhancement. The distribution system is radial in structure and has unidirectional power flow. In order to reduce losses, Distributed Generations, Capacitors banks etc. are used. In order to minimise energy losses and has maximum benefits it is necessary to identify size and siting of Distributed generation. There are various techniques suggested for optimization of DG placement and power loss mitigation in Distribution networks. Different methods for DG siting were suggested in the literature.

It is crucial to find sizing and placement of DG for total losses minimisation. To yield maximum benefits, proper installation (or) location of DG is important. The analytical expression and methodology was proposed by the presenters (Zhaang et al., [26]; Aacharya et al., [2]; Waang and Nehrrir, [1]) for calculating the best sizing & siting of DG for total losses minimisation. The authors Singh and Parida, [26]; Aman et al., [11, 16] presented a new method called Voltage Stability Index approach (VSI) to improve minimisation of losses.

The Global criterion method was expounded by the authors Bhattacharya et al., [21] for various objectives like sizing and placement of DGs. Then K-means Clustering method was presented by Penang sang et al., [22] for power loss reduction by placing DGs in distributed systems. Mohammadi et al., [20] proposed a multi objective meta heuristic algorithm Bacterial Foraging optimisation [BFO]and Yammani et al., [26] presented Shuffled Bat algorithm to reduce power loss by optimal placing in distribution systems both the shunt capacitors and Distributed generations (DG).

The new MOF i.e., Multi objective function was developed using various performance assessment variables or indices like Reactive power loss and active power loss, voltage deviation etc was proposed by Bohhre et al., [17].

These authors Kalambe and Agnihotri [15] presented various methods for siting DG, Capacitor and reconfiguration of feeders for reduction of system losses.

For DG siting, Techno-Economic analysis plays a vital role. The concerns of DG planning was raised by some presenters in their papers and suggested various methods for the DG size optimization, siting to curb the overall investment and expense of DG. Mousavi and Proposed method for Techno-economic study of DG sizing and siting in a radial stabilised distribution network and cost benefit analysis method of placement of DG was presented by Mohammadi [7], Kansal et al., [13].

2 Problem Formulation

In distributed Generation(DG), because of R/X ratio high the power losses and fall in voltage is high. In distribution system, the predominant variable losses i.e., Copper losses are calculated as

$$P_{LOSS} = \sum_{i}^{n} I_i^2 R_i \tag{1}$$

Where the current is 'I_i', resistance is 'R_i'and 'n' is no. of buses. The constraints of voltage are between 0.9 to 1.05. Optimizing real power is also an objective here. The size limitations of DG are 60 to 3000, where the limits for DG Type I are in 'kW', DG Type II in 'kVAr' and DG Type III in 'kVA' respectively.

3 The Method of Power Loss Reduction

Depending on the power losses, loss reductions of systems the siting of Distributed Generation(DG) are found. In this power loss index method technique of Artificial intelligence is not used. Loss reductions are calculated at all buses. [0, 1] is the range for minimum and maximum values of loss reduction.

In k^{th} line, the real power loss is considered is given by [I_k^2] * [R_k]:

$$PL(j) = (P^2(j) + Q^2(j) * R_k)/(V(j)^2) \tag{2}$$

The Reactive power Loss in the k^{th} line is given by [I_k^2] * [X_k] :

$$QL(j) = (P^2(j) + Q^2(j) * X_k)/(V(j)^2) \tag{3}$$

Where

I_k – k^{th} line current
X_kR_k, – k^{th} line Reactance and Resistance
V(j) – 'j^{th}' busvoltage
Q[j] – Actual Reactive power provided further the 'j' bus
P[j] – Actual True power provided further the 'j' bus

The equation for calculation of factors of loss reduction is given by

$$\mathrm{PLI[b] = LR[b] - LR[min]/LR[max] - LR[min]} \tag{4}$$

Here,

'b' – The bus number
LR (b) – bus 'b' loss reduction
LR (max) – maximum value of loss reduction
LR (min) – minimum value of loss reduction

The system minimum loss reduction value and maximum loss reduction value of particular bus is represented by PLI method so that the maximum loss reduction DG can be predictable when positioned on high power loss index bus.

4 Optimal DG Siting for IEEE 15-Bus Test System

The proposed PLR method is implemented for the IEEE 15 – bus test system. Depending on the PLI values, find the locations of Distributed Generation (DG) optimal placement. Select the best siting of DGs based on values of PLI.

The best location for siting of DG for IEEE15-bus system is chosen as 15.

Table 1 IEEE 15-bus system PLI values

PLI Values	Bus No
1.0000	**15**
0.9865	11
0.9602	4
0.8353	7
0.8000	6
0.4611	12
0.4119	14
0.3266	8
0.3205	3

Table 2 IEEE 33-bus system PLI values

PLI Values	Bus No
1.0000	**30**
0.2176	32
0.1531	31
0.1371	29
0.1317	14
0.1283	8
0.1195	7

Table 3 IEEE 69-bus system PLI values

PLI Values	Bus No
1.0000	**61**
0.2669	64
0.1018	59
0.0736	65
0.0570	21
0.0547	12
0.0494	11

4.1 Optimal DG Siting for 33-Bus Test System

The proposed PLR method is implemented for the IEEE 33 – bus system. Depending on the PLI values, find the locations of Distributed Generation (DG) optimal placement. Select the best siting of DGs based values of PLI.

The best location for siting of DG for IEEE33-bus system is chosen as 30.

4.2 Optimal DG Siting for 69-Bus Test System

The proposed PLR method is implemented for the IEEE 69 – bus test system. Depending on the PLI values, find the locations of Distributed Generation (DG) optimal placement. Select the best siting of DGs based on values of PLI.

The best location for siting of DG for IEEE69-bus system is chosen as 61.

5 PSOGSA Algorithm

Standard Particle Swarm Optimisation (PSO)

Kennedy and Eberhart suggested the evolutionary PSO computation technique. The algorithm gets inspired by bird's flocking social behaviour. For determination of best solution in the search space, number of particles which fly are utilised as candidate solutions. It utilises a number of flying particles (candidate solutions) that move in the search space. In this process of searching, individual particles observes in their paths the best solution ie., the best particle. Alternatively candidate particles prefer their own best solutions that have found up until now. Every candidate in PSO should look at the present position, velocity, distance to $\mathrm{p_{best}}$ and change its position towards *best*.

Mathematically PSO was modelled as:

$$v_i^{t+1} = wv_i^t + c_1 \times rand \times [pbest_i - x_i^t] + c_2 \times rand \times [gbest - x_i^t] \quad (5)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (6)$$

Here 'v_i^t' is *i particle's Velocity* in the't^{th}' iter, '*w*' term a function of weighting, 'c_1' a factor of weighting, '*rand*' is a random number in range [0,1], x_i^t-'i^{th}' particle present location of 't^{th}' iter, '*pbest$_i$*' – agent 'i' *pbest* in the 't^{th}' iter and '*gbest*' is currently best solution.

The former starting component of Equation (5) 'wv_i^t' describes PSO's exploration capability. The later components of Equation (5) '$c_1 \times rand \times [pbest_i - x_i^t]$' and '$c_2 \times rand \times [gbest_i - x_i^t]$' represent local private thinking & collaboration among particles. The PSO begins by randomly placing candidates in problem area. The particles velocities are determined by using Equation (5) for individual *iter*. Following the calculation of Velocities, the masses locations are calculated using Equation (6) and positions are updated continuously till end criterion was met.

Standard Gravitational Search Algorithm [GSA]

E. Rashedi et al., in 2009 discusses the new GSA heuristic optimisation approach. The basis of GSA is Newton's basic physical theory that each particle of the universe attracts every other particle of universe with an energy that is directly proportional to the masses and inversely proportional to their distance square. The collection of candidates in GSA algorithm has fitness function value proportional to their masses. All masses are drawn by the gravity forces in the course of generations. The attraction forces will be more for heavier masses. The heavier masses and potentially closer to the global optimum thus draw the masses of other candidates according to their distances.

The GSA is mathematically modelled as: With respect to the 'N' agents scheme, all candidates in the search field will be arbitrarily located. In all times, the gravitational forces of agent '*j*' on agent '*i*' at a certain time '*t*' is described as below equation:

$$F_{ij}^{d}[t] = G[t]\frac{M_{pi}[t] \times M_{aj}[t]}{R_{ij}[t] + \varepsilon}[x_j^d[t] - x_i^d[t]] \quad (7)$$

$M_{aj}[t]$ – active candidate (or) agent '*j*' gravitational mass
$M_{pi}[t]$ – the passive candidate '*i*' gravitational mass
$G[t]$ – The gravity constant time 't'
ε – small constant
R_{ij} [t] – two agents '*i*' and '*j*' Euclidian distance

$G[t]$ Calculation is:

$$G[t] = G_0 \times \exp[-\alpha \times iter/Max\ iter] \quad (8)$$

Where α = descending coefficient and G_0 = initial value correspondingly.

iter = the present Iteration, and *Max iter* = max. no. of Iterations.

For problem areas with 'd' dimension, the cumulative force on 'i' agent is determined as follows:

$$F_i^d(t) \sum_{j=1, j\neq 1}^{N} rand_j F_{ij}^d(t) \quad (9)$$

$rand_j$ is a randomised number in the interval range [0,1]. As per the motion law, the acceleration of agent is relative to the resulting force and is reverse of its mass. Then the acceleration of all agents is measured as:

$$ac_i^d[t] = \frac{F_i^d[t]}{M_{ii}[t]} \quad (10)$$

Given, Specific time is 't' and M_{ii} is 'M' object mass.

The agents velocity and locations are calculated from the below equation:

$$vel_i^d[t+1] = vel_i^d[t] + ac_i^d[t] \quad (11)$$

$$x_i^d[t+1] = x_i^d[t] + vel_i^d[t+1] \quad (12)$$

All masses are randomly valued initialized first in GSA. The candidate solution is individual mass. The velocity of all masses after the initialization phase is defined by Equation (7). In between the time, Gravity constant, total forces and accelerations parameters are measured respectively as (8), (9), and (10). The location position is determined with the aid (12). Ultimately, GSA would be stopped by meeting the final requirement.

The Hybrid PSOGSA Algorithm

The PSO hybridization with GSA uses the low level heterogeneous hybrid to optimize functions (Mirjalili and Hashim, 2010). Due to combination of functionality of both algorithms, the hybrid is of low level. Since the two algorithms aren't used one by one, they 're both run parallel. To produce final results, two different algorithms are involved so it also can be stated as heterogeneous.

The PSOGSA blends the social thinking potential (*gbest*) of PSO with the GSA local search potential. The new velocity equation incorporates this two algorithms by:

$$v_t[t+1] = w \times v_i[t] + c_1 \times rand \times ac_i[t] + c_2 \times rand \times [gbest - x_{i[t]}] \tag{13}$$

$v_i[t]$ is agent 'i' velocity of iter *t*, *rand* is a random number in the range [0,1] weighting factor – c_j, w – weighting function, $ac_i[t]$ is acceleration of agent '*i*' at 't^{th}' iteration, and gbest is the best solution until now. In each iteration, the updated particle locations is given by

$$\mathrm{X_i[t+1] = X_i[t] + v_i[t+1]} \tag{14}$$

In the algorithm PSOGSA, first process is random initialisation of all agents. Every individual agent is considered as solution of the candidate. Later the process of initialisation, the parameters gravitational forces, gravitational constant, resulting forces between the candidates are calculated using Equations (8), (9), and (10). Next, the particles accelerations are defined by Equation (10). In every iteration, update the so far obtained best solution. After estimation of the accelerations, all agent speeds are determined in equation with the best solution revised so far by Equation (13). Ultimately, the positions (or) locations of agents are represented by Equation (14). The velocities and positions updating process terminates when an end criterion is achieved.

To observe PSOGSA efficiency some observations are noted as below.

1. In the updating procedure, the qualities of fitness (solutions) are to be considered.
2. The other candidates (or) agents that are exploring in search space try to get attracted to the candidates which are nearer to best solutions.
3. All the candidates which are closer to best solutions move very gently (slowly).

Here, the gbest supports the candidates to exploit the global best. The PSOGSA in order to save the best solution utilises the memory which is gbest that was found until now. So that it ia available at all times. Every candidate can look at the solution obtained so far which is the best and lean toward it. The capabilities of local search and global search can be adjusted for balancing using c_1 and c_2 variables.

6 Simulation Results

The paper presents the PSOGSA algorithm for obtaining the sizing of DG and cost-benefit analysis. Assessed the test bus systems IEEE 15, 33 and 69 bus by means of Matlab. Following are the parameters taken in PSOGSA algorithm are pop size = 50, Maxgen = 60. $C_1 = 0.5$, $C_2 = 1.5$, $G_0 = 1$, $a = 20$, 'w' is reduced from 0.9 to 0.2 linearly;

Cost-Effective (Economic) Analysis

The various parameters like minimum voltage level, total losses of energy, power loss and power attainment of the Distributed Generations (DG) are compared for test systems IEEE 15,33 and 69 bus at lagging 0.9 power factor and power factor of unity. The mathematical model of cost factors of energy losses and DG power component denoted as

Energy Losses Cost Component (CL)

The author [Murthy & Kumar (2013)] [9] gave the annual cost component of loss of energy as

Energy losses cost component

$$CL = [[TLP] \times K_p + K_e \times LSF \times 8760]\$ \tag{15}$$

Where,

TRPL – Total Losses of Real power
K_p – power loss (\$/kW) demand price per annum
K_e – the energy loss price (\$/kWh) per annum
LSF – loss factor component [LF] w.r.t the Load Factor [Lf], LF is determined

$$\text{LSf} = \text{A x Lf} + [1 - \text{A}] \text{ x Lf}^{\wedge 2} \tag{16}$$

The coefficient values in the estimation of the loss factor are:

$A = 0.2$, $Lf = 0.47$, $k_p = 57.6923$ \$/kW, $k_e = 0.00961538$ \$/kwh.

Cost Factor for Real and Reactive Power of DG

The Reactive and active component factor of cost for DG is

$$C[pdg] = a \times pdg^2 + b \times pdg + c \,\$MWh \tag{17}$$

a,b,c are co-efficients whose values are $a = 0$, $b = 20$, $c = 0.25$.

The Maximum complex power provided by DG is considered, the reactive power cost component by DG is given to be:

$$\mathrm{C}\{\mathrm{Q_{dg}}\} = \{\mathrm{Cost[Sgmax]} - \mathrm{Cost}\sqrt{[\mathrm{sgmax}^2 - \mathrm{Q_g^2}]}\} \times \mathrm{k} \tag{18}$$

$$\mathrm{Sgmax} = \frac{\mathrm{Pg\,max}}{\cos\phi} \tag{19}$$

Pgmax is given as $1.1 \times$ pg. Assessed the analysis at 0.9 pf lag and upf. The range of $k = 0.05$–0.1. Here take k as 0.1.

IEEE 15-Bus System Results

The IEEE 15-bus SLD [29] is given as below

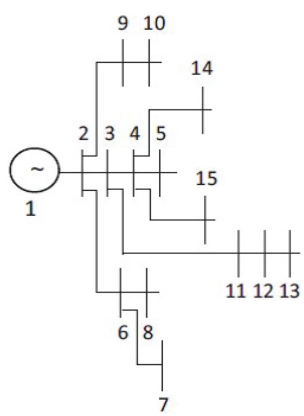

Figure 1 IEEE 15 bus.

For the test system IEEE 15 Bus, without placing or installing the DG the real (or) active power loss and the reactive Power loss are 61.7933 KW, 57.2969 KVAR respectively. Correspondingly, with placing (or) installing

Table 4 IEEE 15 bus system results

	Without DG	With DG at 0.9 pf lag [28]	Proposed Method at 0.9 pf lag	With DG at UPF [28]	Proposed Method at UPF
Location of DG	–	*6*	15	6	15
Size of DG(KVA)	–	907.785	910.5	675.248	673.8651
TLP (KW)	61.7933	33.385	28.05	45.8035	42.8186
TLR (KVAR)	57.2969	29.89	22.94	41.88	39.99
Vmin [p.u]	0.9445	0.959	0.971	0.9527	0.9596
Energy losses Cost($)	4970.3	2865.31	2256	3684.18	3444.1
PDG cost ($/MWh)	–	16.5404	16.598	13.754	13.73
QDG cost ($/MVARh)	–	1.8656	1.872		

Table 5 IEEE 33 bus system results at UPF

	Without DG	Method [9]	Method [28]	Proposed Method at UPF
Location of DG	–	16	6	30
Size of DG (KVA)	–	1000	2590.2	1542.7
TLP (KW)	211	136.7533	111.0338	125.2
TLR (KVAR)	143	92.6599	81.6859	89.3
Vmin [p.u]	0.904	0.9318	0.9424	0.9272
Energy losses Cost ($)	16982.6	11007.9	8930.65	10067.3
PDG cost ($/MWh)	–	20.25	52.05	31.1

Table 6 IEEE 33 bus system results at 0.9 pf

	Method [9]	Method [28]	Proposed Method at 0.9 pf
Location of DG	16	6	30
Size of DG (KVA)	1200	3073.5	1940.4
TLP (KW)	112.7864	70.8652	78.4
TLR (KVAR)	77.449	56.7703	58.97
Vmin [p.u]	0.9378	0.9566	0.9386
Energy losses Cost ($)	9078.7686	5700.01	6308.8
PDG cost ($/MWh)	21.85	55.5	35.138
QDG cost ($/MVARh)	2.1207	6.2	3.932

the DG at UPF the active (or) real power loss and the reactive power loss are 42.8 KW, 39.99 kVAR. With placing of DG operative at lagging 0.9 power factor the active or real power loss and reactive power loss 28.05 kW, 22.94 kVAR respectively. In Table 4, the evaluation of results is shown. The best location for siting of DG for IEEE15-bus system is chosen as 15. The DG type III functioning at lagging 0.9 power factor had minimum voltage high and low losses on comparison with DG functioning at UPF because both

Table 7 IEEE 69 bus system results at UPF

	Without DG	Method [9]	Method [28]	Proposed Method at UPF
Location of DG	–	65	61	61
Size of DG (KVA)	–	1450	1872.7	1872.8
TLP (KW)	225	112.0217	83.22	83.23
TLR (KVAR)	102.1091	55.1172	40.57	40.54
Vmin [p.u]	0.909253	0.96606	0.9685	0.9683
Energy losses Cost ($)	18101.7621	9017.2139	6694.4	6694.4
PDG cost ($/MWh)	–	29.25	37.7	37.7

Table 8 IEEE 69 bus system results at 0.9 pf

	Method [9]	Method [28]	Proposed Method at 0.9 pf
Location of DG	65	61	61
Size of DG (KVA)	1750	2217.3	2217.4
TLP (KW)	65.4502	27.9636	27.96
TLR (KVAR)	35.625	16.4979	16.46
Vmin [p.u]	0.969302	0.9728	0.9724
Energy losses Cost ($)	5628.4297	2249.2	2249.3
PDG cost ($/MWh)	31.75	40.1	40.0916
QDG cost ($/MVARh)	3.083	4.48	4.4824

active power and reactive power are provided by DG at lagging 0.9 pf but not provided when functioning at UPF. Hence, the losses are higher at DG functioning at UPF than at 0.9 pflag. The cost components are presented in the Table 4. By comparison the energy losses cost decreased from 4970.3 $ to 2256 $(DG at 0.9 pf) and to 3444 $ (DG operating at UPF). The cost of losses of energy is least when DG is functioning at lagging 0.9 power factor.

IEEE 33-Bus System Results

The IEEE 33-bus single Line diagram [SLD] [29] is given as below

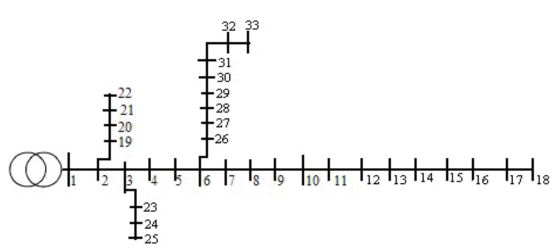

Figure 2 IEEE 33 bus.

For the test system IEEE 33 bus, without placing (or) installing the DG the real (or) active power loss and the reactive power loss are 211 kW and 143 kVAR. Correspondingly, with placing (or) installing the DG at UPF the reactive power loss and the active (or) real power loss are 89.3 kVAR and 125.2 kW. With placing of DG operative at 0.9 power factor lag the reactive power loss and active loss 58.97 kVAR and 78.4 kW respectively. In Tables 5 & 6, the evaluation of results is shown. The best location for siting of DG for IEEE15-bus system is chosen as 30. The DG type III operating at 0.9 pf has the minimum voltage more and low losses on comparison with DG functioning at UPF because both reactive power and active power are provided by DG at 0.9 pf lag but not provided when functioning at UPF. Hence, the losses are higher at DG functioning at UPF than during lagging power factor of 0.9. The cost components are presented in the Table 4. By comparison the energy losses cost decreased from $16982.57 to the value $6308.8 (DG functioning at lagging 0.9 pf) and to the value of $10067.3 (DG functioning at Unity Power Factor).

The cost of losses of energy is least when the Distributed Generation is functioning during lagging 0.9 power factor.

IEEE 69-Bus System Results

The IEEE 69-bus single Line diagram [29] is given as below

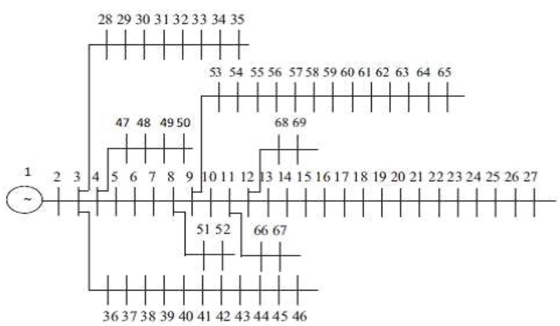

Figure 3 IEEE 69 bus.

For test system IEEE 69 bus, without placing (or) installing the DG the values for the reactive power loss and the real (or) active power loss obtained is 102.10 kVAr and 225 kiloWatts. Correspondingly, placing (or) installing Distributed Generation at UPF the reactive power loss and the active (or)

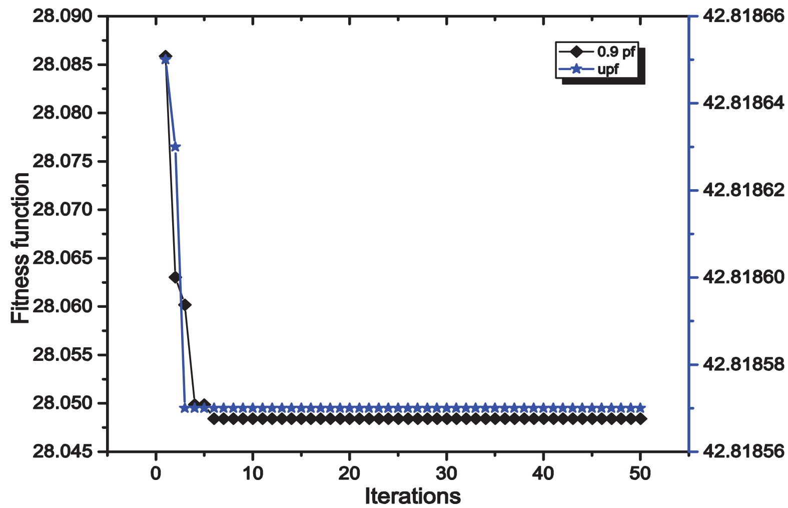

Figure 4 Convergence characteristics of IEEE 15 bus (0.9 pf and UPF).

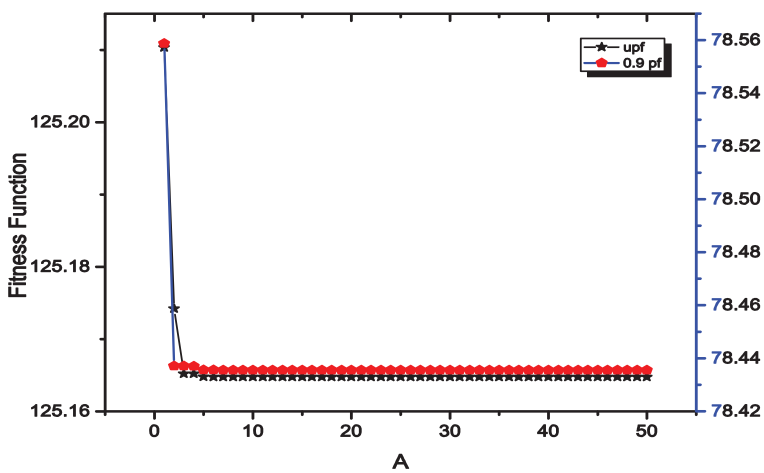

Figure 5 Convergence characteristics of IEEE 33 bus (0.9 pf and UPF).

real power loss 40.54 kVAr are and 83.23 kW. Reactive power loss and Active or real power loss obtained is 16.46 kVAr and 27.9 kilowatts when DG operative at 0.9 power factor lag. In Tables 7, 8, the evaluations of results are shown. The best location for siting of DG for IEEE15-bus system is chosen as 61. The DG of type III functioning at lagging power factor of 0.9 has high minimum voltage and low losses on comparison with DG functioning at

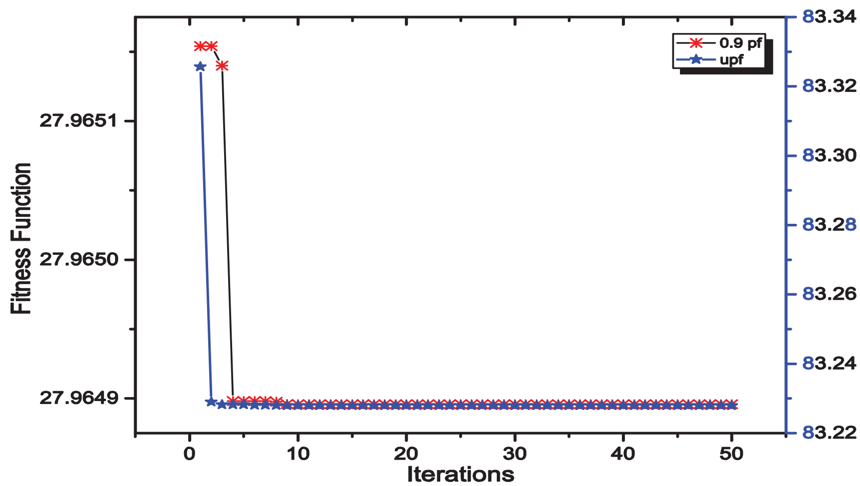

Figure 6 Convergence characteristics of IEEE 69 bus (0.9 pf and UPF).

UPF because both active (or) real power and reactive power are provided by DG at 0.9 pf lag but not provided when functioning at UPF. Hence, the losses are higher at DG functioning at UPF than at 0.9 pf lag. The cost components are presented in the Table 4. By comparison the energy losses cost mitigated from 18,100.7$ to 2,249.3$ (DG at 0.9 pf) and to 6,694.4$. (DG operating at UPF). The low cost of energy loss is obtained while DG is functioning on 0.9 power factor lag.

7 Conclusion

PSOGSA is a new hybrid algorithm presented to find the optimal DG units sizing. PSOGSA was developed on the basis that the social thinking ability (gbest) in (PSO) is combined with local Search ability of gravitational search algorithm. An another objective considered is Economic analysis with loss reductions. The IEEE 15, 33, 69 buses with DGs of two types are considered for study in this paper. By comparison the proposed method decreases the energy losses cost from 4970.3$ to 2256$ (DG at 0.9 pf) and to 3444$ (DG operating at UPF) for IEEE 15 bus, from $16982.57 to the value $6308.8 (DG functioning at lagging 0.9 pf) and to the value of $10067.3 (DG functioning at Unity Power Factor) for IEEE 33 bus system, from 18,100.7$ to 2,249.3$ (DG at 0.9 pf) and to 6,694.4$. (DG operating at UPF) for 69 bus system. It can be concluded that the DG functioning at lagging power factor of 0.9 reduces more power losses like real and reactive power losses, voltage profile improvement than when functioning at UPF due to supplement of reactive power to system. From the result values, on evaluation with other algorithms over all better desirable results was attained with power Loss Index method combined with PSOGSA algorithm.

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