Optimal Location and Sizing of Distributed Generation Unit Using Human Opinion Dynamics Optimization Technique

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ABSTRACT

The demand of electricity is soaring rapidly. Distributed generation (DG) is one of the most suitable alternatives to fulfill this swelling demand of energy. DG is a small scale generation which is directly installed in the distribution network or at load centre. Optimal allocation of DG is a vital factor in improving the voltage profile of the system and in reduction of total power losses. In this article, a detailed study of three different methods for DG allocation and sizing has been discussed. The first method is based on Newton Raphson load flow based technique to deduce the optimal location of DG in two different IEEE bus systems in MATLAB software. The next methodology is based on particle swarm optimization (PSO) technique where a multi-objective function is being minimized. The objective function has been modified and PSO has been implemented to attain optimal size and location of DG unit. The third method considered is based on human opinion dynamics evolutionary multi-objective optimization technique which is used to obtain the best possible size and location of DG unit in IEEE 14 and IEEE 30 bus systems. The human opinion dynamics method shows superiority in minimizing the size and location muti-objective function, over the other methods considered herein.

INTRODUCTION

Distributed generation, also referred to as dispersed generation is a small scale generation being used to meet the ever increasing demand of electricity. Distributed energy is generated by small grid connected generators known as distributed energy resources (DER). Conventional power plants such as thermal, nuclear, hydro power plants are centralized whereas distributed generation resources are decentralized, located near to the load centers. Distributed generation prominently uses renewable resources such as solar power, wind energy, biomass, small hydro and photovoltaic systems. Various other technologies may also be adopted in distributed generation such as fuel cells, battery, microturbines, small gas turbines and reciprocating engines [1-3]. Integration of DG in the distribution network has diverse technical merits.

Several researchers have worked in this area. An analytical technique based on exact loss formula is discussed in [4-5]. A loss sensitivity based method has been proposed in [6]. A multi-objective optimization approach for maximizing voltage profile in a deregulated electricity market has been discussed in [7]. A grid search algorithm to attain the optimal position and capacity of multiple DG units in the radial distributed system network is presented in [8]. An optimization technique based on weighting factor which stabilizes the cost and loss factors has been demonstrated in [9].

A genetic algorithm (GA) based methodology for optimal allocation and capacity of DG has been presented in [10]. A combination of particle swarm optimization (PSO) and clonal algorithm has been suggested in [11]. The placement of DG at non-optimal locations can elevate system losses, increase installation costs and lead to voltage drops.

In this article, three different types of methods are implemented to determine the optimal location and size of a single DG unit. Firstly, a load flow based approach is formulated to obtain the best possible location for DG deployment. Secondly, PSO based multi-objective optimization technique is formulated to determine the optimal location and size of DG unit for different weighting factors. Thirdly, human opinion dynamics (HOD) optimization technique based on social impact theory optimizer is proposed to evaluate the best location and size of DG unit to improve voltage profile of the system and for reduction of line losses. The methods are implemented on two bus systems i.e. IEEE 14 bus system and IEEE 30 bus system in a MATLAB environment. The data has been taken from [12]. This article shows that the newly proposed HOD optimization technique has been implemented for the first time to determine the optimal location and size of DG unit in test system. This method has never been used to find the ideal location and size of DG unit in earlier research work. The results conclude that the human opinion dynamics technique shows superiority over the other methods used in this article for optimal allocation and sizing of DG unit.

BACKGROUND LITERATURE

Load Flow Problem

Newton Raphson load flow study has been implemented in this article. For any typical bus system in the power system, the current entering bus i is given by equation (1). The power balance equations are given by (2) and (3).

$$\eta_{th} = 1 - \frac{T_l}{T_h} \tag{1}$$

$$P_i + jQ_i = V_i I_i^* \tag{2}$$

$$P_i + jQ_i = V_i I_i^* = V_i \left[\sum_{j=1}^{N} Y_{ij} V_j \right]^* \tag{3}$$

Equation (3) is separated into real components and imaginary components which form the following set of equations given by (4) and (5).

$$P_i = \sum_{j=1}^{N} |V_i||Y_{ij}||V_j| \cos\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{4}$$

$$Q_i = \sum_{j=1}^{N} |V_i||Y_{ij}||V_j| \sin\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{5}$$

Where,

N = Total buses in the system, V_i = Voltage magnitude at bus i, V_j = Voltage magnitude at bus j, δ_i = Voltage angle at bus i, δ_j = Voltage angle at bus j, Y_{ij} = Magnitude of Y_{ij} element in bus admittance matrix, θ_{ij} = Angle of Y_{ij} element in bus admittance matrix, P_i = Net real power injection in bus, Q_i = Net reactive power injection in bus i. The Newton Raphson load flow method is explained elaborately in [13].

Particle Swarm Optimization

PSO is primarily an evolutionary computational technique and similar to genetic algorithm (GA). However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions called particles fly through the problem space by pursuing the current optimal particles. Each particle keeps track of its coordinates in the problem space which are correlated with the best solution it has attained so far. This value is referred to as pbest. Another best value that is tracked by the particle swarm optimizer is the best value, attained so far by any particle in the neighborhood of the particles. This location is referred to as lbest. When a particle takes all the population as its topological neighbor, the best value is known as global best or gbest [14-15].

The particle swarm optimization concept comprises of changing the velocity of each particle towards its pbest and lbest locations at each time step. Acceleration is weighted by a random term, with separate random numbers being generated for acceleration towards pbest and lbest locations.

Human Opinion Dynamics Algorithm (HOD)

The study of opinion dynamics and formations is an important area of social physics. Human opinion dynamics algorithm is complex to implement but effective. The four pillars of this algorithm are Social structure, Opinion space, Social influence and Update rule [16-17]

Social structure: Social structure lies between individuals or group of individuals. It portrays the way of interaction of individuals from other individuals in their neighborhood.

Opinion space: The second pillar of the algorithm is the opinion space. Each individual within a social graph has its own opinion space. Opinion space can be discrete or continuous, where discrete opinions can be as {0,1) whereas continuous opinions can take any real value.

Social influence: Social Influence plays a huge role in opinion dynamics. Decision making process is influenced by one's own considerations as well as social beliefs in the structure. Therefore, Social influence is formulated using the Social rank (SR) and the distance between the two nodes in the social graph. Social rank is determined from the fitness values which are the output from the objective function that is to be minimized. The social influence $W_{ij}(t)$ of individual j on individual i is given by equation (6).

$$W_{ij}(t) = \frac{SR_j(t)}{d_{ij}(t)} \tag{6}$$

Where,

d_{ij} = Euclidean distance between two individuals i and j.

Update rule: One of the important elements of any iterative optimization algorithm is its Updating rule which governs its dynamics in general. The update rule can be put according to equation (7).

$$\Delta o_i = \frac{\sum_{j=1}^{N} (o_j(t) - o_i(t)) W_{ij}(t)}{\sum_{j=1}^{N} W_{ij}(t)} + \xi_i(t), j \neq i \tag{7}$$

Where,

$o_j(t)$ is the opinion of neighbors of individual i, N is the number of neighbors, $W_{ij}(t)$ represents the social influence, $\xi_i(t)$ is a normally distributed random noise with mean zero and standard deviation $\sigma_i(t)$

$$\sigma_i(t) = S \sum_{j=1}^{N} e^{-f_{ij}(t)} \tag{8}$$

In equation (8), S denotes the strength of disintegrating forces in the society and $f_{ij}(t)$ denotes the modulus of difference in fitness values of individual i and individual j at time t.

PROBLEM FORMULATION

Computational Procedure for Load Flow Based Method

Step 1: Input line data, bus data of the test system.

Step 2: Run base case load flow to obtain the voltage profile of the system and the total real losses and reactive power losses of the system.

Step 3: The DG is placed at each bus and the load flow is run again to obtain the voltage profile after each installation. Total real losses and total reactive power losses are also obtained after each installation of DG.

Step 4: The percentage voltage improvement is obtained when DG is placed at each bus one by one. The bus with maximum percentage voltage change will be the optimal deployment position of DG unit.

Step 5: Then percentage real power reduction and percentage reactive power reduction are obtained. The graph is plotted.

Multi Objective Function Used in Formulation of PSO and HOD Techniques

The problem of optimum deployment of DG is formulated in the form of swarm optimization. A cost function considering the voltage and real power loss is obtained. The modified multi objective function is given in equation (9).

Minimize

$$f(x) = \sum_{i=1}^{N} W_1 * loss + \sum_{i=1}^{N} W_2 * (1 - V_i)^2 \tag{9}$$

$$W_1 + W_2 = 1 \tag{10}$$

W_1 is the weighting factor giving priority to reduction of real power losses and W_2 is the weighting factor giving priority to voltage profile improvement. The weighting factor values have been assigned as W_1= 0.1, 0.5 and 0.9 respectively. The values have been selected such that at W_1=0.1, best voltage profile is obtained whereas with W_1=0.5, same priority is given to both reduction of losses and voltage improvement whereby W_1=0.9 indicates maximum reduction of real losses.

RESULTS AND DISCUSSION

Load Flow Based Approach for Optimal Allocation of DG

IEEE 14 bus system: After formulating the load flow based algorithm, the best voltage profile is obtained when the DG unit is placed at bus 4. Table 1 shows the voltage profile of this bus system with and without DG deployment. Table 2 shows the results for IEEE 14 bus system.

The voltage profile of IEEE 14 bus system is shown in Figure 1 whereas Figure 2 shows the line graph depicting the real losses of the system with respect to the bus number when DG is placed at each bus of IEEE 14 bus system.

Table 1. Voltage profile of IEEE 14 bus system using load flow method

Bus No.	Voltage without DG (p.u.)	Voltage with DG at bus 4 (p.u.)	% Volt. Improve ment	Bus No.	Voltage without DG (p.u.)	Voltage with DG at bus 4 (p.u.)	% Volt. Improve ment
1	1.0600	1.0600	0	8	0.9005	1.0025	11.32
2	s0.9761	1.0175	4.24	9	0.8850	0.9879	11.62
3	0.8924	0.9683	8.50	10	0.8917	0.9842	9.25
4	0.9130	1.0100	10.62	11	0.8947	0.9942	11.12
5	0.9270	1.0038	8.28	12	0.8978	0.9952	10.84
6	0.9165	1.0120	10.4	13	0.8911	0.9898	11.07
7	0.9005	1.0025	11.32	14	0.8661	0.9695	11.93

Table 2. Optimal location of DG in IEEE 14 bus system using load flow method

System	IEEE 14 bus
Best voltage profile	DG at bus 4
Real loss without DG (MW)	0.20852
Min. MW losses	0.16552 at bus 4
% Real loss reduction	25.62
Optimal location	Bus 4

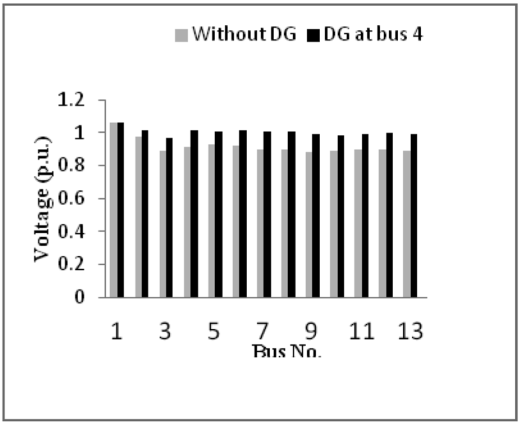

Figure 1. Voltage profile of IEEE 14 bus system

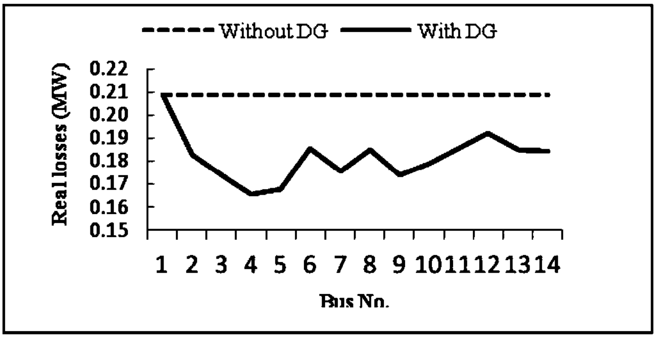

Figure 2. Real losses with and without DG for 14 bus system

IEEE 30 bus system: Table 3 shows the voltage profile of IEEE 30 bus system.

Table 4 shows the results for IEEE 30 bus system. The voltage profile of IEEE 30 bus system is shown in Figure 3 whereas Figure 4 shows the line graph depicting the real losses of the system with respect to the bus number when DG is placed at each bus of IEEE 30 bus system.

Particle Swarm Optimization Technique

IEEE 14 bus system: Table 5 enlists the optimum location, optimum size, real losses before and after DG placement and percentage loss reduction in modified IEEE 14 bus system for different weighting factors i.e. $W_1 = 0.1$, 0.5 and 0.9 whereby $W_1 = 0.1$ means more priority is given

Table 3. Voltage profile of IEEE 30 bus system using load flow method

Bus No.	Voltage without DG (p.u.)	Voltage with DG at bus 28 (p.u.)	Bus No.	Voltage before DG (p.u.)	Voltage with DG at bus 28 (p.u.)
1	1.0600	1.0600	16	0.8195	0.9584
2	0.9446	0.9986	17	0.8062	0.9493
3	0.9063	0.9883	18	0.7959	0.9398
4	0.8708	0.9720	19	0.7902	0.9377
5	0.8273	0.9271	20	0.7942	0.9392
6	0.8439	0.9715	21	0.7934	0.9401
7	0.8271	0.9450	22	0.7997	0.9482
8	0.8267	0.9651	23	0.7939	0.9406
9	0.8270	0.9666	24	0.7852	0.9402
10	0.8103	0.9537	25	0.7982	0.9667
11	0.8270	0.9666	26	0.7754	0.9480
12	0.8422	0.9755	27	0.8174	0.9923
13	0.8422	0.9755	28	0.8343	1.010
14	0.8206	0.9585	29	0.7917	0.9718
15	0.8126	0.9528	30	0.7769	0.9599

Table 4. Optimal location of DG in IEEE 30 bus system using load flow method

System	IEEE 30 bus
Best voltage profile	DG at bus 28
Real loss without DG (MW)	0.33744
Min. MW losses	0.236 at bus 28
% Real loss reduction	35.87
Optimal location	Bus 28

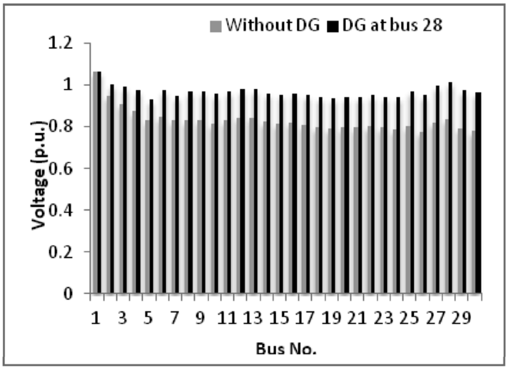

Figure 3. Voltage profile of IEEE 30 bus system

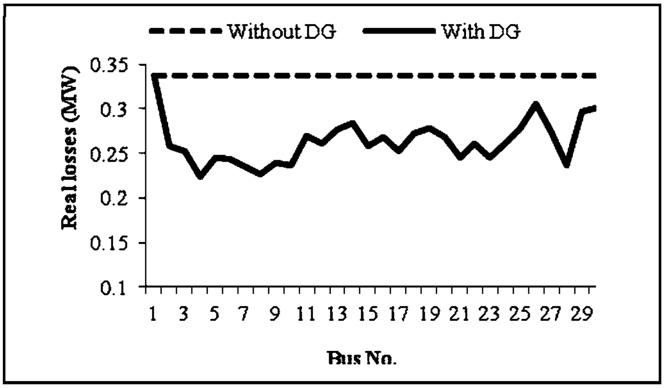

Figure 4. Real losses with and without DG for 30 bus system

to voltage profile improvement whereas when $W_1 = 0.5$ equal priority is given to both loss reduction and voltage profile improvement while when W_1=0.9, it implies that more priority is given to alleviation and minimization of losses. Figure 5 shows the voltage profile graph for IEEE 14 bus system.

Table 5. Optimal size and location of DG in IEEE 14 bus system using PSO

Weighting factor (W_1)	0.1	0.5	0.9
Optimum location	Bus 14	Bus 9	Bus 6
Optimum size (kW)	68.495	42.994	70.589
Real loss without DG (MW)	0.1758	0.1758	0.1758
Real loss with DG (MW)	0.0624	0.0598	0.0498
% Loss reduction	64.50	65.98	71.67

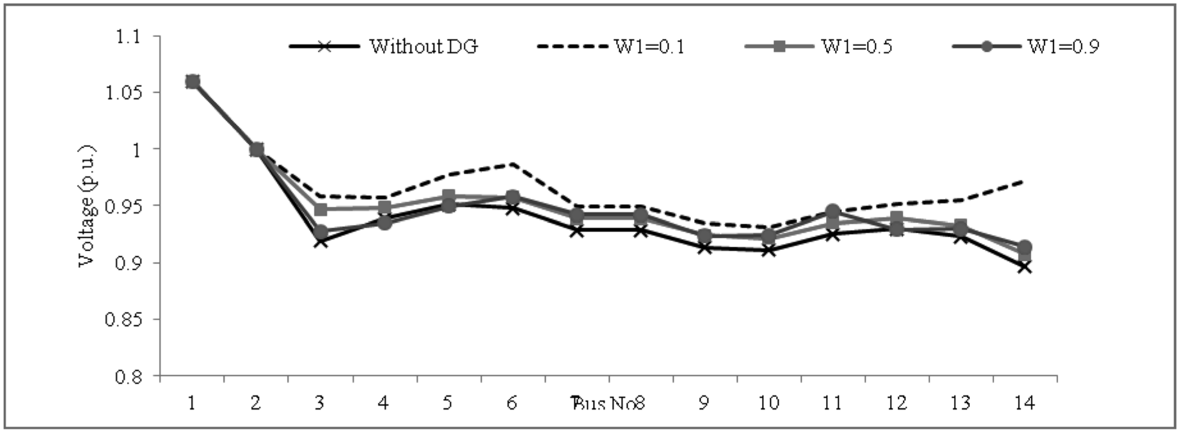

Figure 5. Voltage comparison for 14 bus system for different W_1

IEEE 30 bus system: Table 6 enlists the optimum location, optimum size, real losses before and after DG placement and percentage loss reduction in modified IEEE 14 bus system for different weighting factors i.e. W_1 = 0.1, 0.5 and 0.9. Figure 6 shows the voltage profile of IEEE 14 bus system for different W_1.

Table 6. Optimal size and location of DG in IEEE 30 bus system using PSO

Weighting factor (W_1)	**0.1**	**0.5**	**0.9**
Optimum location	Bus 5	Bus 11	Bus 5
Optimum size (kW)	57.058	79.554	86.485
Real loss without DG (MW)	0.2919	0.2919	0.2919
Real loss with DG (MW)	0.0493	0.0477	0.0385
% Loss reduction	83.11	84.80	86.73

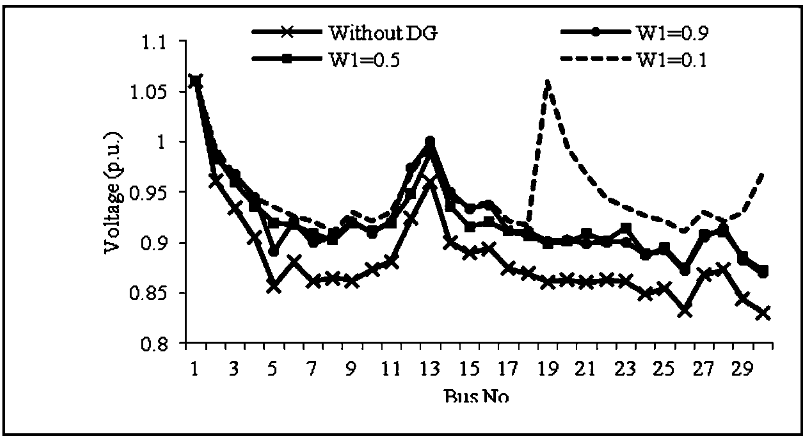

Figure 6. Voltage comparison for 30 bus system for different W_1

Human Opinion Dynamics Algorithm

IEEE 14 bus system: Table 7 enlists the optimum location, optimum size, real losses before and after DG placement and percentage loss reduction in modified IEEE 14 bus system for different weighting factors.

Figure 7 demonstrates the convergence of particle 1 which determines the location of DG unit for W_1=0.1. Figure 8 displays the convergence characteristics of particle 2 which shows the DG size for W_1=0.1. Figure 9 shows the optimal DG location for W_1=0.5. Figure 10 displays

Table 7. Optimal size and location of DG in IEEE 14 bus system using HOD

Weighting factor (W_1)	0.1	0.5	0.9
Optimum location	Bus 3	Bus 2	Bus 5
Optimum size (kW)	52.6236	58.238	46.8081
Real loss without DG (MW)	0.1758	0.1758	0.1758
Real loss with DG (MW)	0.04118	0.0356	0.0215
% Loss reduction	76.57	79.74	87.77

the optimal DG size for W_1=0.5 using HOD. Similarly, Figure 11 shows the optimal DG location for W_1=0.9. Figure 12 displays the optimal DG size for W_1=0.9 using HOD for IEEE 14 bus system.

IEEE 30 bus system: Table 8 enlists the optimum location, optimum size, real losses before and after DG placement and percentage loss reduction in modified IEEE 30 bus system for different weighting factors.

Figure 13 shows the optimal DG location for W_1=0.1. Figure 14 displays the optimal DG size for W_1=0.1 using HOD. Similarly, Figure 15 shows the optimal DG location for W_1=0.5. Figure 16 displays the optimal DG size for W_1=0.5 using HOD for IEEE 30 bus system. Figure 17 displays the optimal DG location for W_1=0.9. Figure 18 displays the optimal DG size for W_1=0.9 using HOD. Table 9 shows the comparison of all the methods used for optimal placement and sizing of DG unit in IEEE 14 and 30 bus systems respectively.

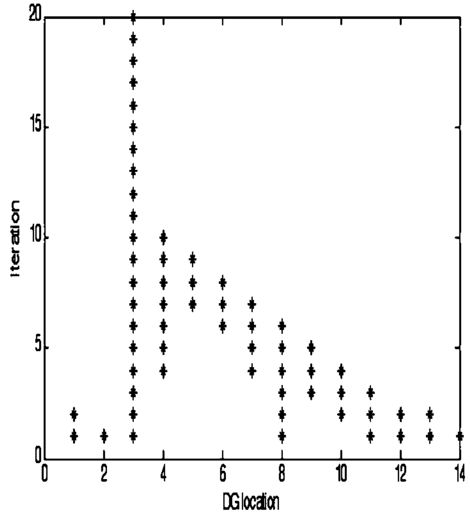

Figure 7. DG location for W_1= 0.1

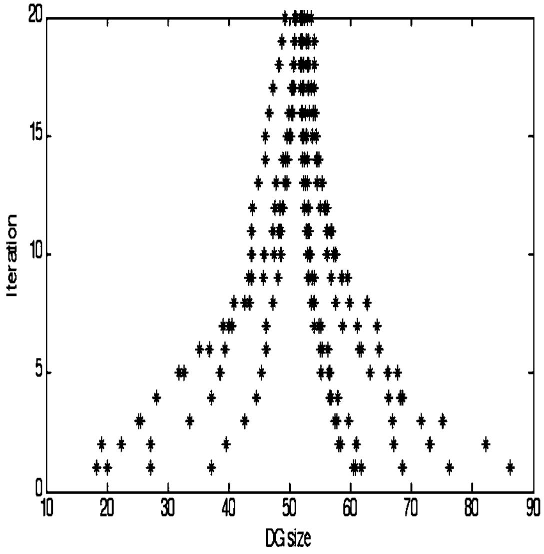

Figure 8. DG size for W_1= 0.1

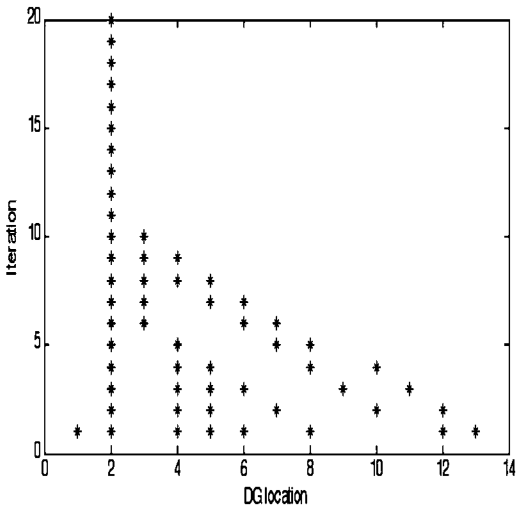

Figure 9. DG location for W_1= 0.5

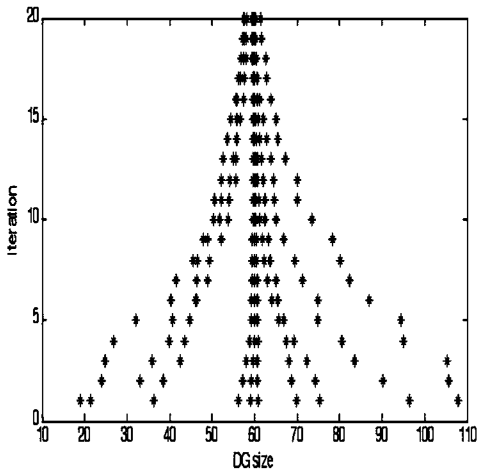

Figure 10. DG size for W_1= 0.5

Table 8. Optimal size and location of DG in IEEE 30 bus system using HOD

Weighting factor (W_1)	0.1	0.5	0.9
Optimum location	Bus 5	Bus 11	Bus 5
Optimum size (kW)	56.6236	78.64	61.2248
Real loss without DG (MW)	0.2919	0.2919	0.2919
Real loss with DG (MW)	0.04118	0.0405	0.0377
% Loss reduction	85.89	86.12	87.09

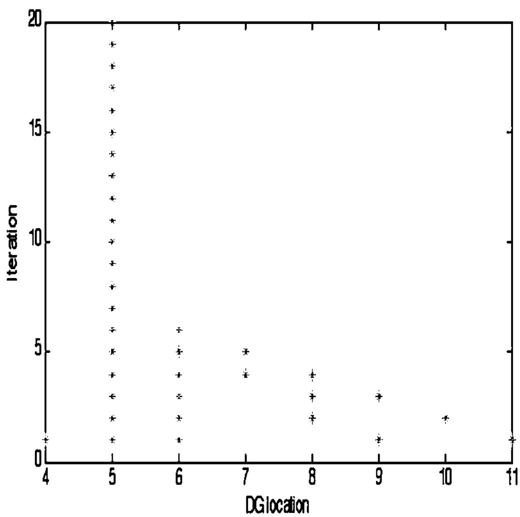

Figure 11. DG location for W_1= 0.9

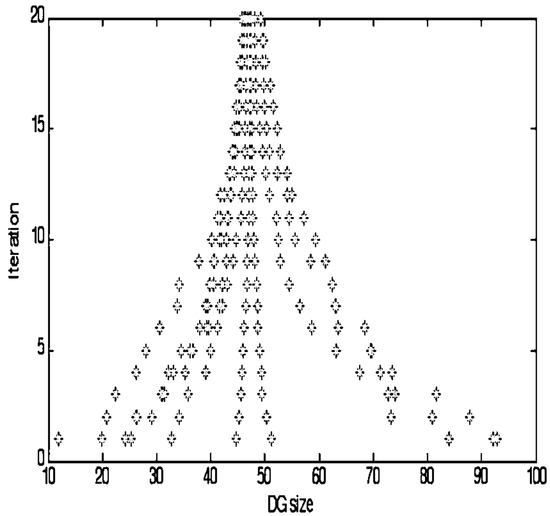

Figure 12. DG size for W_1= 0.9

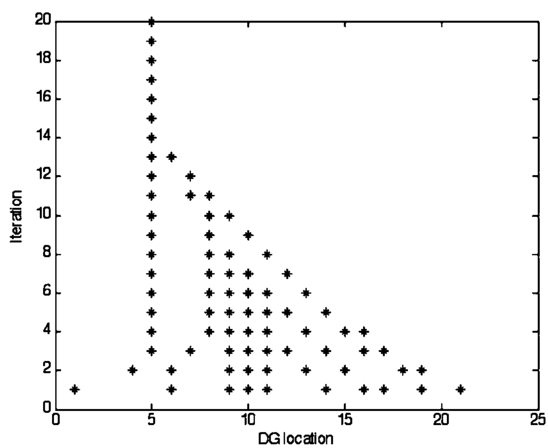

Figure 13. DG location for W_1= 0.1

CONCLUSION

In this article, three different methods are implemented to determine the optimal location and size of single DG unit for voltage profile improvement and minimization of losses. The convergence characteristics obtained in the case of human opinion dynamics method are better than retrieved from the PSO method. The minimum value of objective

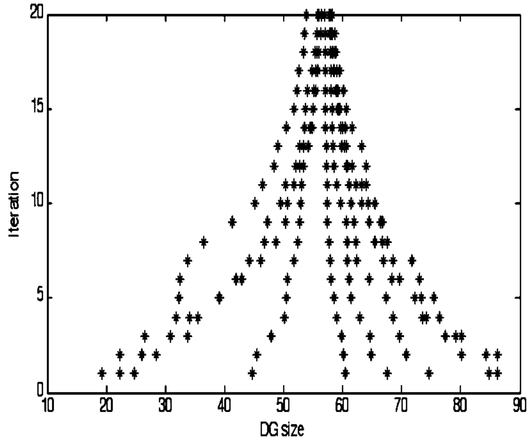

Figure 14. DG size for W_1= 0.1

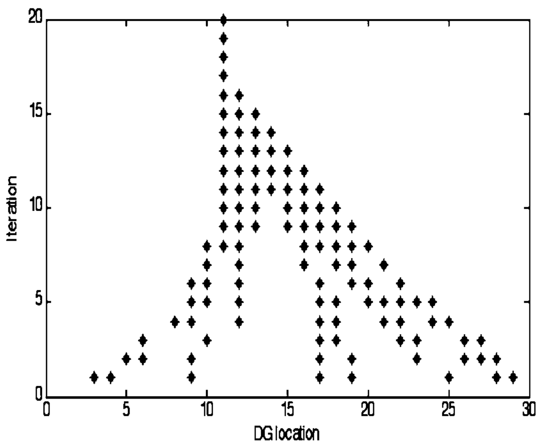

Figure 15. DG location for W_1= 0.5

function obtained is least for human opinion dynamics optimization as compared to other methods. The time of convergence of particles/ opinions is also less in human opinion dynamics optimization technique as compared to PSO. The load flow approach for allocation of DG unit is insufficient in evaluating the exact size of DG unit to be installed. The work can be further extended for integration of multiple DG units using the new proposed human opinion dynamics algorithm. Based on minimizing a loss objective function given by equations 11 and 12, the results

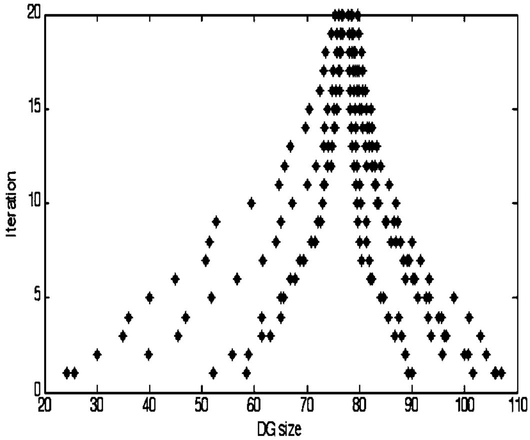

Figure 16. DG size for W_1= 0.5

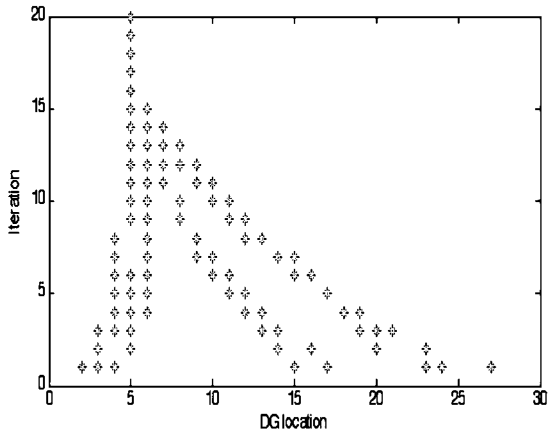

Figure 17. DG location for W_1= 0.9

conclude that the human opinion dynamics technique shows superiority over the other methods used in this article for optimal allocation and sizing of DG.

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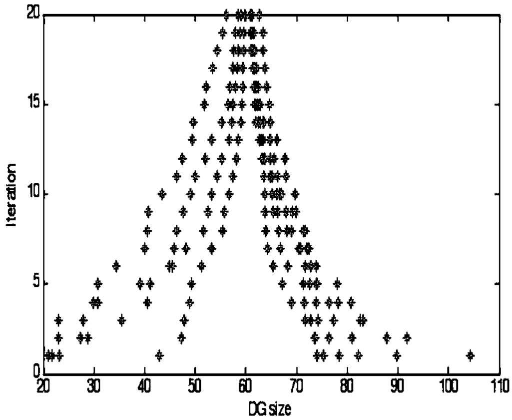

Figure 18. DG size for W_1= 0.9

Table 9. Comparison of methods used for optimal DG location and sizing

IEEE bus system	Method	Weighting factor (W_1)	DG Location	DG size (KW)	Real loss after DG placement (MW)	Time taken (Sec)	Min value of objective function
14	Load flow approach	-	Bus 4	-	0.1655	-	-
	Particle swarm optimization	0.1	Bus 3	97.863	0.0524	32.559	0.0910
		0.5	Bus 3	76.941	0.0398	35.140	0.0900
		0.9	Bus 4	46.908	0.0298	39.434	0.0630
	Human opinion dynamics	0.1	Bus 3	52.6236	0.0411	25.064	0.0231
		0.5	Bus 2	58.238	0.0356	19.310	0.0246
		0.9	Bus 5	46.8081	0.0215	25.128	0.0200
30	Load flow approach	-	Bus 28	-	0.236	-	-
	Particle swarm optimization	0.1	Bus 5	57.058	0.0493	85.293	0.0724
		0.5	Bus 11	79.554	0.0477	85.204	0.0771
		0.9	Bus 5	86.485	0.0385	86.343	0.0908
	Human opinion dynamics	0.1	Bus 5	56.623	0.0411	65.312	0.0532
		0.5	Bus 11	78.640	0.0405	66.782	0.0453
		0.9	Bus 5	61.224	0.0377	66.033	0.0566

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