A Study of the Factors Influencing the Optimal Size and Site of Distributed Generations

Soma Biswas, S. K. Goswami, and A. Chatterjee

Abstract—**The paper solves a distributed generations placement problem considering loss and cost of DG as the main objectives while power quality issues like voltage magnitudes at different bus and harmonic distortion are maintained within some specified limits as per IEEE standards. To study the effect of several factors on DG placement the issues are considered individually first. Then the same problem is solved considering all the issues together. It has been shown that when all the issues are considered the harmonic distortion plays a vital role in deciding the DG locations and size. Again the harmonic distortions are more near to the harmonic generating loads. The shunt compensation is also included to improve the voltages to a specified limit.**

Index Terms—**Distributed generations, genetic algorithm, harmonic distortion, power quality, renewable energy.**

I. Introduction

Distributed generations (DG) are increasingly becoming important power resources for modern day power systems [1], [2]. DG technologies are mainly based on renewable energy sources. Hence it has similar advantages as obtained from renewable energy sources. Renewable energy facilities in DG generally require less maintenance than traditional generators. One remarkable advantage with renewable energy is that it produces little or no waste products such as carbon dioxide or other chemical pollutants, so has minimal impact on the environment. In spite of these the DG sources have several disadvantages compared to traditional fossil fuel generators. DGs have smaller generation capacity, less reliability of supply as renewable energy often relies on the weather for its source of power. Because of new technology and extremely large capital cost, current cost of generation from renewable sources is very high. The best solution to our energy and environment problems may be to have a balance between many different power sources hence to build diverse energy facilities. Instead of operating in isolated mode, the renewable energy sources are integrated with the grid system [3]. Problems, however, may arise while integrating the distributed generators with the power grid. Stability issue, complex protection requirements, power quality, long term reliability of the units, power flow control during interconnection and the islanded condition are some of the well known problems involving DG units. In recent years the placement of DGs has drawn significant interest of power system engineers. While placing a DG in the existing system what will be the size, where it is to be placed are big questions. Arbitrary placement of DGs may result in the deterioration of some technical as well as economical performances of the system. Some research works have already proved the fact that both the technical and economical benefits can be obtained by proper placement of DG [4]-[6].

In the present paper the DG placement problem is solved while improving bus voltages, reducing the system loss as well as harmonic distortion. The economical aspects in terms of cost of DG and cost of loss are minimized. To study the effect of harmonics a certain percentage of loads are assumed as harmonic generating loads. The optimal DG placement problem is solved and the impact of DG location on the various technical performance of the system has been studied.

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II. Problem Formulation and Solution Employing Genetic Algorithm

A. Problem Formulation

Due to advancement of modern power system use of semiconductor devices has been increased manifold. The use of such devices causes distortion in current and voltage waveform i.e. includes harmonics which may cause very bad impact on power system if it exceeds some specified limits. As discussed earlier one objective of optimal DG placement is to reduce the system loss. The use of capacitor, reconstruction of network etc are different means by which the loss can be reduced which in turn reduces the unsupplied energy [7], [8] and thereby saving energy. Now a day's many works have suggested the use of DG as a means of reduction of system loss by supplying energy locally and thereby avoiding transmission and distribution congestion. To include harmonics a certain percentage of loads is assumed as nonlinear loads i.e. harmonic generating loads. With proper modeling of the entire network and nonlinear loads [9] the harmonic power flow program is run and the voltage harmonic distortion of each bus is computed. To observe the effect of position of nonlinear loads on placement of DG the location of these loads are varied. The genetic algorithm (GA) optimization tool is used to solve the problem consisting some objectives and constraints. Energy loss and cost of DGs are considered as objectives whereas the voltage drop, power flow, DG capacity and harmonic limits are considered as constraints. Thus the problem can be expressed as follows:

Minimize f (location and size of DG) = cost of loss+cost of DG

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Subject to constraints:

1) power flow limits Smin<Ssys<Smax
2) Voltage limit $V_{min}<V_{sys}<V_{max}$
3) DG capacity $DG_{min}<DG_{sys}<DG_{max}$
4) Harmonic limits $THD_{min}<THD_{sys}<THD_{max}$

B. Solution Employing Genetic Algorithm

GA is search algorithm based on the mechanics of natural selection and natural genetics of living beings [10], [11]. It is a popular meta-heuristic, evolutionary optimization based algorithm. Searching method of GA is composed of three processes.

1) Random creation of initial population
2) Evaluation of fitness function
3) Creation of new population utilizing different selection, crossover, and mutation

A candidate solution (or chromosome) designed in this paper for the problem of finding the optimal location and size of one DG unit is a two-component vector. First component represent the location of DG which may vary from 2 to *n* (where *n* is the number of bus). And the second component represents the size of DG which varies from a minimum value to a maximum value with a small step size. The chromosome encoding of the DG placement problem is shown in Fig. 1.

Position L_i (bus number), for i=1, n	Size P_{DG}. Size is varied from 500kW to 2500kW with a step size 100kW.

Fig. 1. Chromosome encoding for a single DG placement problem.

Thus the algorithm of DG placement problem has been described in various steps as following.

Step 1: Read network data and load data.

Step 2: Perform load flow and store results for base case such as loss, voltages at different buses and line flows etc without any DG.

Step 3: Perform harmonic power flow to calculate % THD. The following steps are followed.

3.1 Make the model of the non linear loads (converter type, DG source, fluorescent type etc.) as a harmonic source and prepare model of transmission lines, loads (including induction motor type), power factor correcting capacitor, grid etc. Find the Y_{BUS} for the system.

3.2 Solve harmonic voltages at different bus V_{hi} using Equation $[V_{hi}]=[Y_{hi}]^{-1}[I_{hi}]$,
where h=3,5,7,9,11,13,17,19...., i=1,2,3.....and then find voltage total harmonic distortion (THD).

Step 4: Generate a set of N_{indiv} location of DG keeping the size fixed.

Step 5: Compute the fitness of each individuals (locations of DGs)

Step 6: Sort the individual according to their fitness

Step 7: Perform genetic operators (selection, crossover and mutation) to produce a new generation of individuals. Go to step 5.

Step 8: Repeat until convergence criteria are satisfied.

Step 9: The individual with the best fitness is the final solution.

Step 10: Increase the size of DG with one step and repeat the same process again.

III. Simulation and Results Analysis

The above method has been implemented on a benchmark IEEE 69 bus radial distribution system [12] having 68 lines and 7 lateral branches as shown in Fig. 2. The line and load data have been given in [12].

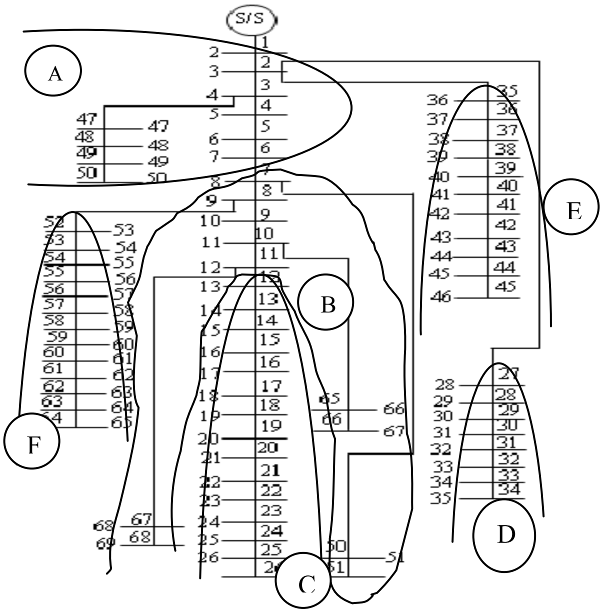


Fig. 2. 69 bus radial distribution system.

The system has a total load of 4.66 MVA out of which the active load is 3802.29kW and the reactive load is 2694.1kVAr. At full load the loss is 228.13kW and the minimum voltage is 0.905pu obtained at bus 65. In the following section the DG placement problem is solved considering various objectives; improvement of bus voltages, reduction of loss and harmonic distortions and cost of DG. In the present study first the problem is solved considering these objectives individually and then it is solved considering all the objectives together. A DG of Rs 450$ per kW and of life span 15 years is considered [13] for being placed in the distribution system.

A. Impact of DG Location on the Bus Voltage Profile

Solving load flow problem for the distribution system the voltages at different buses during normal full load condition are obtained and has been shown graphically in Fig. 3.

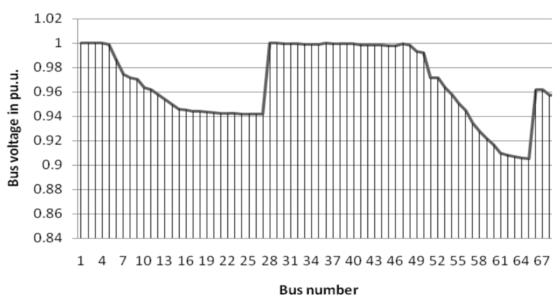


Fig. 3. Voltages at different buses in p.u. at full load condition.

The voltages for the system is attempted to keep within ±5% of the rated value as per IEEE standard. From Fig. 3 it is observed that the voltages at bus 14-27 and 56-65 remain below 0.95 p.u. The only objective is to improve the voltages to a specified value while a DG of varying size is placed in the system. Finally the locations and corresponding sizes are solved for which the voltages at all buses improve to specified value or higher.

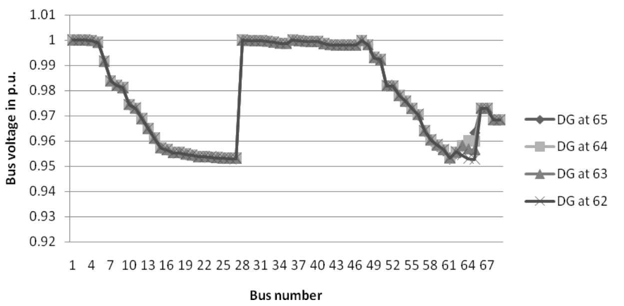


Fig. 4. Voltages at different bus for DG location 62, 63, 64 and 65.

Hence the optimum size of the DG is 1300kW, above this the system will be uneconomic as the cost of DG increases. The DG having size 1300kW is capable of reducing voltage below 0.95 p.u. only when this is placed at any of the buses 62, 63, 64 and 65. The bus voltage profile for those locations has been shown in Fig. 4. It is observed that the DG having size below 1300kW is unable to improve the voltage to specified value.

B. Impact of DG Location on the System Loss Reduction

In this section the DG placement problem will be solved considering only one objective which is loss. Under full load condition without any DG the system loss is 228.13 kW. The use of DG may reduce loss if properly placed. A graph showing the loss vs. DG location has been shown in Fig. 5.

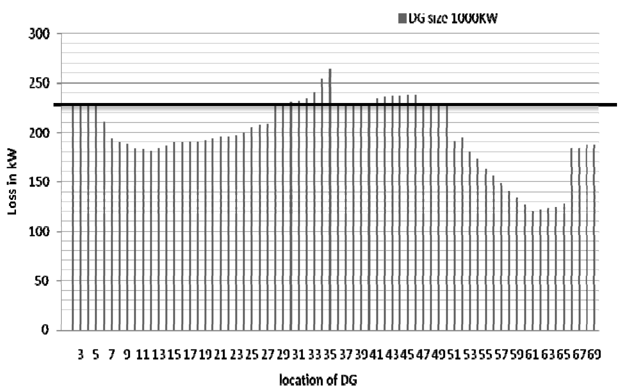


Fig. 5. Variation of loss with the location of DG.

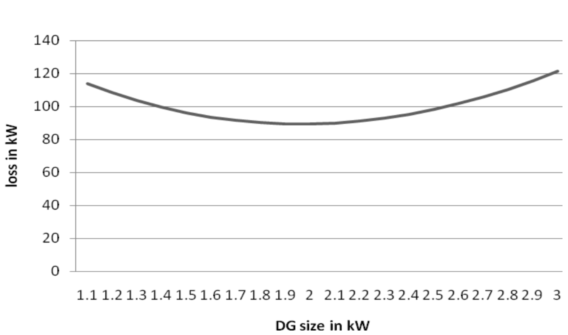


Fig. 6. Variation of loss with the size of DG.

The DG size is kept fixed i.e. 1000 kW here. The horizontal farm line is drawn to compare the loss in two cases; with DG and without DG. Fig. 5 shows that at most of the DG locations the loss gets reduced for use of DG. At bus 61 the loss is minimum i.e. 120.4033kW. Hence the optimal location of DG is bus 61. Now to find the optimum size the loss is computed for different sizes of DG which is shown in Fig. 6. From this figure it is observed that the loss is minimum (i.e. 89.5602kW) when the DG size is 2000kW.

C. Impact of System Harmonic Distortion on the DG Location

To observe harmonic distortion phenomenon it is necessary to introduce some nonlinearity into the system to produce harmonic currents. This kind of load may be present in any amount at different places. So the magnitude and locations can be assumed arbitrarily. They can be present uniformly distributed over the system or concentrated. Thus for the purpose of harmonic analysis the whole system is subdivided into 6 zones namely A(2-7, 47-50), B(8-13, 51-52, 66-67, 68-69), C(14-27), D(28-35), E(36-46) and F(53-65) as shown in Fig. 2. The division of zones is done in an arbitrary basis where both distributed and concentrated placements of nonlinear loads are considered. The details of each section showing number of buses, the load connected at those buses and their percentage with respect to total load connected have been computed and is shown in Table I.

The harmonic generating loads are mainly made of semiconductor devices having 6pulse, 12pulse type converter. These loads produce harmonics of order np±1 (i.e. 5,7,11,13,17,19... for 6 pulse converter) where p is number of pulse and n varies for 1 to α [9]. Varying the location of such load the optimal placement problem is to be solved so that the harmonics distortions remain within permissible limits i.e. not greater than 5% as per IEEE standard. The load connected at any one section or a number of sections are assumed as harmonic generating loads while the loads at the remaining parts are assumed as linear. Thus the locations as well as the magnitudes of such loads vary automatically.

TABLE I: THE NUMBER OF BUS AND LOAD DISTRIBUTION OF DIFFERENT ZONES

Section	buses	Total load connected at each section			% of real load, reactive load and apparent power		
		P (kW)	Q(kW)	S(kVA)	P%	Q%	S%
A	2-7, 47-50	891.4	637.6	1096	23.44	23.67	23.52
B	8-13, 66 -69, 51-52	567.1	405	696.87	14.91	15.03	14.95
C	14-27	349.5	230.6	418.72	9.19	8.56	8.99
D	28-35	91.5	65.2	112.35	2.41	2.42	2.41
E	36-46	185.64	129	226.06	4.88	4.79	4.85
F	53-65	1717.2	1226.7	2110.3	45.16	45.43	45.29
ABC	2-27, 47 -52,66-69	1808	1273.2	2211.6	47.54	47.26	47.46
BCDE	8-46, 51 -52,66-69	1193.7	829.8	1454	31.39	30.8	31.2
ACDE	2-7,14-50	1518	1062.4	1853.2	39.92	39.44	39.77

From Table I it is observed that total nine set of locations are set for nonlinear loads. The harmonic distortion for all the cases has been shown in Fig. 7 and in Fig. 8. It is noted that for all the cases in Fig. 7 the buses have harmonic distortion below 5%. Whereas in Fig. 8 all cases but location ACDE violate this limit. As the intention is to show the effect of DG on harmonic distortion we will chose the locations F, ABC and BCDE where the distortion are beyond limits for solving DG placement problem.

The results of DG placement have been shown in Table II.

Some observations found from previous discussions have been listed below.

1) In case of section ACDE the %THD is less than in the case of BCDE, though the % load is higher as shown in Table I. This is probably because the distribution of load is more concentrated in BCDE as given in load data. For the same reason %THD is higher in case of section F than in case of ABC.

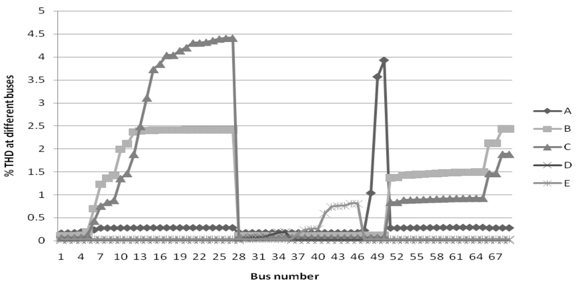


Fig. 7. Harmonic performances for section A, B, C, D and E.

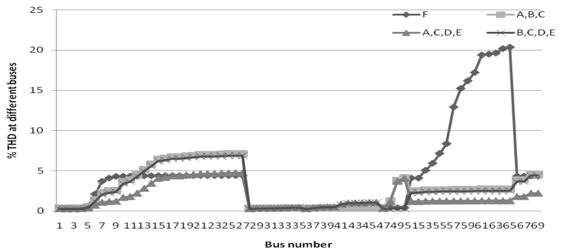


Fig. 8. Harmonic performances for F, ABC, ACDE and BCDE.

TABLE II: THE RESULTS OF DG PLACEMENT PROBLEM CONSIDERING HARMONICS ONLY

Section	Bus content	% Non linearity (approx)	Maximum THD		Bus locations where %THD >5%	DG locations where % THD <5%
			Magnitude	Location (bus)		
F	53-65	45	20.3451	65	53-65	59-64
ABC	2-27, 47 -52,66-69	47	7.1027	27	13-27	8-27
BCDE	8-46, 51 -52,66-69	31	6.8801	27	14-26	8-27

2) Harmonics are more distorted near the harmonic generating loads as shown in Table II and also in Fig. 7 and Fig. 8. Though section ABC contains buses 2-27, 47-52, 66-69 maximum %THD occurs at bus 27. From load data [12] it can be seen that among 47% of harmonic producing load most are located near first subsection of three i.e. 2-27. i.e. why %THD is maximum at bus 27. Same thing happen for section BCDE also.

3) To reduce the harmonic distortion below specified limits the DG is also need to place near the harmonic generating loads.

4) The harmonic distortion less depends on the size of DG.

D. *Optimum* DG placement considering all the objectives

Now the problem is to place DG optimally so as to reduce loss and cost of DG while keeping the harmonics and line voltages within specified limits. The cost of system loss is considered as 0.08$/kWhr. In this case an uncompensated system is considered i.e. no compensating devices are considered. The results are shown in Table III. Following are several observations found.

1) In case of section F the optimal size is 1300kW and location is bus 62. The DG having capacity 1300kW when placed at bus 62 satisfy two constraints namely voltage limit and harmonic distortions. Remaining two objectives are loss and cost of DG. The loss is minimum when DG size is 2000kW. But in this problem optimum size is 1300kW as cost of DG becomes high for higher size of DG. Fig. 9 shows the variation of cost of operation with the size of DG.

TABLE III: OPTIMUM SIZE, LOCATION OF DG AND CORRESPONDING LOSS AND COST OF OPERATION

Sections	Results of optimal placement			
	DG size (in kW)	Optimum locations (bus)	Cost of operation (million $)	Loss in kW
F	1300	62	1.6614	103.82

2) In case of section ABC and BCDE it is observed that only the locations where %THD becomes below permissible limits are 8-27 (Table II). Other than these locations %THD cannot be below specified value. Again voltages can be improved beyond permissible limits only when a DG of minimum 1300kW is placed any of these four locations 62-65 as discussed in case A. The DG at other locations having any capacity is not suitable for improving voltage at all buses to the specified value. Hence any optimum solution cannot be found for these two cases which satisfy all constraints.

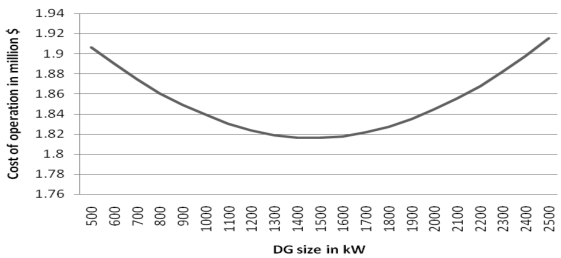


Fig. 9. DG size versus optimum cost of operation for nonlinearity at F, the location of DG at bus 61.

Hence there are two alternatives. Either the locations of harmonic generating loads can be changed an external device can be introduced to improve the voltages. The locations of harmonic generating loads are decided by the customer mainly. So these cannot be changed. Shunt capacitors can be used to improve the voltages thus satisfying voltage constraints. Hence to improve voltages three fixed capacitors rated 500kVAr (total 1500kVAr and 32% of total load) are included at bus 61, 63 and 65 respectively. Table IV shows the results of DG placement problem. The optimal size and locations are 1000kW and bus 12 respectively. The shunt capacitors not only improve the voltages but also reduce loss.

TABLE IV: RESULTS OF OPTIMUM DG PLACEMENT WITH COMPENSATION

Sections	Results of optimal placement			
	DG size (in kW)	Optimum locations (bus)	Cost of operation (million $)	Loss in kW
ABC	1000	12	1.6529	116.0171
BCDE	1000	12	1.6529	116.0171

Due to presence of compensatory devices the DG capacity is also reduced to improve the voltages. Hence the total cost of operation is also reduced. The optimum location which is bus 12 is mainly influenced by the location of harmonic generating loads. Due to the presence of capacitors the variation of % THD is not so remarkable this is shown in Fig. 10.

Fig. 11 shows the voltage profile of different buses in a compensated distribution system having DG of 1000kW at bus 12 for section ABC. Fig. 12 shows the harmonic performance for two cases with DG and without DG for different locations of nonlinear loads.

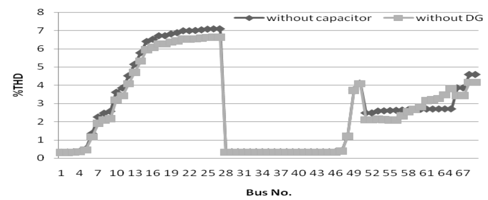


Fig. 10. %THD at different buses for two cases with capacitor and without capacitor when section BCDE is considered to have non linear loads.

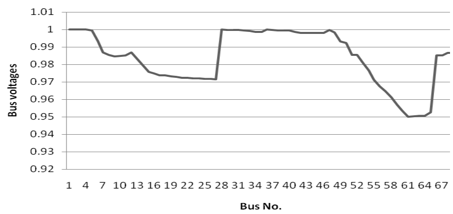
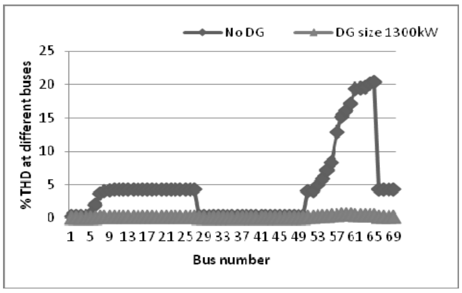
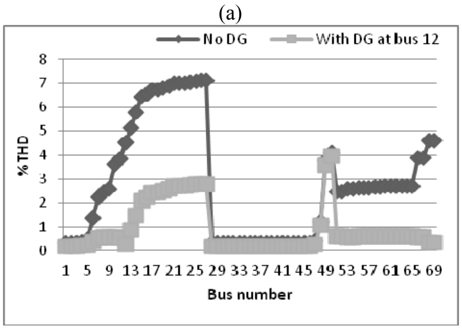


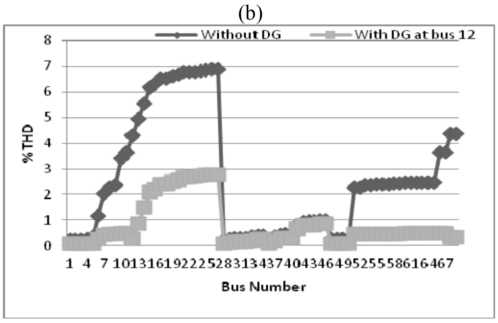
Fig. 11. Voltage at different bus of the distribution system with capacitor having DG size 1000kW and placed at bus 12.



(a)



(b)



(c)

Fig. 12. %THD at different buses at optimal condition in case of section (a) F, (b) ABC (c) BCDE.

IV. Conclusion

In this paper the optimal placement problem of DG is solved and the factors that can affect the results are analyzed. A single DG is considered to be placed in the 69 bus radial distribution system such that the effect of DG placement on the various issues may be analyzed in a focused way. The DG placement problem is solved considering the objectives individually as well as considering all the objectives together. The optimum location and size of DG is solved for different position of nonlinear loads. To minimize THD below some specified limits the optimum placement problem of DG is solved and it is observed that for all the cases the location is near the harmonic generating loads.

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