Optimal Location and Sizing of Distributed Generation Based on Gentic Algorithm

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Abstract—**This paper presents a methodology for optimal distributed generation (DG) location and sizing in distribution systems. The main objective of the added DG units is minimizing the total electrical network losses with acceptable voltage profile. Genetic Algorithm (GA) Technique is used as the optimization searching algorithm due to its advantages over the other optimization techniques in this application. The system losses and voltage profile evaluation is based on a power flow analysis for the distribution network with the representation of the distributed generators using MATPOWER software package. Cost Benefit Factor (CBF) is used to evaluate the benefits of the added DG units to the system performance. This factor combined the cost of adding new DG unit with the saving gained from total power losses reduction and reserved power generation. The optimization algorithm is applied to two different test distribution systems; 13-Bus radial system and actual 66 kV distribution network of Alexandria, EGYPT. The results indicated that if the DG units are placed at their optimal location and have optimal sizing, the total distribution system losses will be reduced.**

Keywords- Distributed Generation; Genetic Algorithm; optimization;Losses; CBF.

I. INTRODUCTION

The increasing need for more electrical power generation, progress in power system deregulation, and tight constraints over the construction of new transmission lines for long distance power transmission are the driving force for the increased interest in the development of Distributed Generation (DG) [1].

In the literature, there are many terms and definitions used in relation to distributed generation. For example; The Institute of Electrical and Electronic Engineers (IEEE) defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system [2]. The International Conference on Large High Voltage Electric Systems (CIGRE*)* defines DG as generation unites smaller than 50 – 100MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched [3]. The Electric Power Research Institute (EPRI) defines distributed generation as generation unites from a few kilowatts up to 50 MW [4].

DG technologies include small combustion turbine generators (including micro-turbines), internal combustion reciprocating engines and generators, photovoltaic panels, and fuel cells. Other renewable energy technologies including wind turbines, solar thermal conversion, and biomass conversion could be also utilized as DG sources.

Form the operational point of view; DGs have a positive impact on reduction of the distribution network power losses, improving voltage profile and enhancement of the system power quality. DGs also help in peak load shaving and load management programs, enhancing system continuity and reliability. In case of emergency and system outages, DGs can be used as on-site standby to supply electricity. Moreover, DGs maintain system stability, supply the spinning reserve required. They provide transmission capacity release [5].

The capacities of DG vary from micro to large size so they can be installed on medium and/or low voltage distribution network which give flexibility for sizing and sitting of DGs into the distribution network [6].

Conventionally, it is assumed that electric power in distribution systems always flows from substations to the end of feeders. However, introduction of distributed generators under de-regulated environment causes reverse power flow and complicated voltage profiles in the distribution systems. This type of complication in the systems depends on the strategic placement of DG. Therefore it is required to focus on optimal placement and sizing of distributed generation in the distribution systems [7].

It is crucially important to define the size and location of distributed generation to be placed. These definitions ensure maximizing DG benefits on the overall system losses with minimum size and cost.

The problem of sitting and sizing of DGs in a large radial distribution network is a very complex combinational optimization problem. Conventional techniques, like linear and non linear integer programming, will result in large computational time/effort and require sever modeling simplifications. Several different techniques have been proposed for the solution of the problem based on evolutionary computation.

The application of evolutionary computation to power system problems is growing research area. Evolutionary Computation techniques include Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search (TS) and Particle Swarm (PS). Genetic Algorithm (GA) is by far, the most used evolutionary computation technique in power system application [8].

II. GA FOR DG SITTING AND SIZING

Genetic algorithm is a search and optimization method simulating natural selection and genetics. It is the most popular and widely used of all evolutionary algorithms.

A simple genetic algorithm is an iterative procedure, which maintains a constant size population of candidate solutions. During each iteration step (generation) three genetic operators (reproduction, crossover, and mutation) are performing to generate new populations (offspring), and the chromosomes of the new populations are evaluated via the value of the fitness which is related to fitness function. Based on these genetic operators and the evaluations, the better new populations of candidate solution are formed.

With the above description, a simple genetic algorithm is given as follow [9]:

1. Generate randomly a population of binary string.
2. Calculate the fitness for each string in the population
3. Create offspring strings through reproduction, crossover and mutation operation.
4. Evaluate the new strings and calculate the fitness for each string (chromosome).
5. If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step (3).

Generally, there are two major advantages of using genetic algorithms for optimization problems. First, GAs do not involve many mathematical assumptions about the problems to be solved. Due to their evolutionary nature, genetic algorithms will search for solutions without regard for the specific inner structure of the problem. GAs can handle any kind of objective functions and any kind of constraints, linear or nonlinear, defined on discrete, continuous, or mixed search spaces. Second, GA is a very effective tool to perform global search. The traditional approaches perform local search by a convergent stepwise procedure, which compares the values of nearby points and moves to the relative optimal points. Global optima can be found only if the problem possesses certain convexity properties that essentially guarantee that any local optimum is a global optimum [10].

Numerous papers have been published on the subject of optimal sitting and sizing of DG using GA, referring to either optimal sitting or optimal sizing or both. The objective functions used in GA as an efficient tool used to search for the optimum DG sitting and sizing could be classified into two main groups, one concern about the effect of DG in minimizing the total system power losses [11-13] and the other focus on the benefit of DG in the improvement of the voltage profile [14-15].

III. PROPOSED ALGORITHM

In this paper Cost Benefit Factor (CBF), is used to evaluate the achievement of multiple DG goals. This factor combined the cost of adding new DG unit with the saving gained from total power losses reduction and reserved power generation.

$$\mathbf{CBF} = \frac{\mathrm{Cost}(\Delta \mathrm{P}_{\mathrm{losses}}) + \mathrm{Cost}(\Delta \mathrm{P}_{\text{generated at slag bus}})}{\mathrm{Cost}\ (\mathrm{DG}_{\mathrm{added}})} \tag{1}$$

The flow chart of the optimization algorithm used in the paper is shown in Fig. 1. Genetic algorithm is the core of the algorithm and load flow analysis is used for power flow and total system losses calculation. The calculations are evaluated with the MATPOWER software package. Genetic algorithm searches to find the optimum place and size for installing DGs. This routine is programmed under MATLAB software. The solution methodology starts with reading the bus data and the line configuration and generator data required to calculates the fitness function which is the cost benefit factor (CBF). The application of GA takes place first by initial population and then applying crossover then compare with the result with constrains, when the new child is created mutation is applied to get out a new generation. If it reaches maximum CBF then final CBF value is displayed. The proposed algorithm has the option for total active power losses calculation as a traditional factor commonly used to evaluate the advantages of adding DGs units.

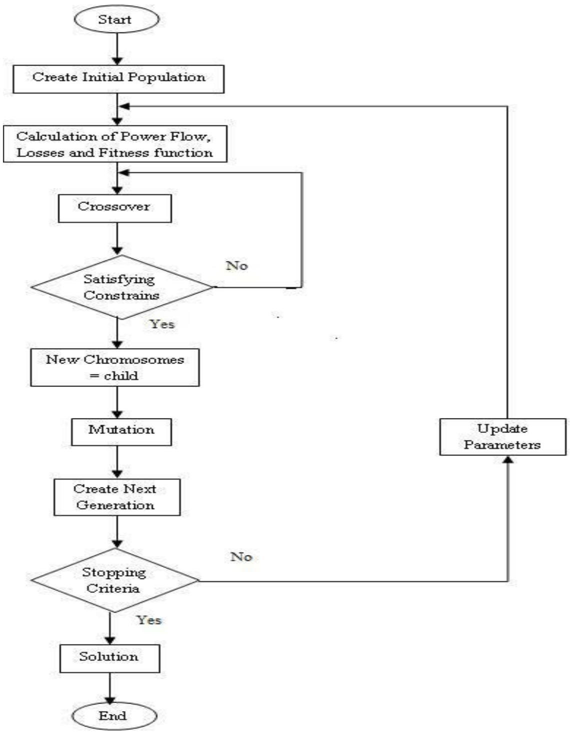

Fig.1: The flow chart of the optimization algorithm

The cost of generated power as base case electricity market price is assumed to be 70$/MWh and the DG is to be natural gas fired generator type with fixed cost of 0.5M$/MVA. The cost of unserved power or losses power is assumed to be 320$/MWh [16].

The main constraints in the optimization process in the proposed methodology are:

A. Total number of DG

The number of DGs (N_{DG}) must be less than or equal to the maximum number of DGs ($N_{DG/MAX}$) as:

$$N_{DG} \leqslant N_{DG/MAX} \quad (2)$$

Where

$$N_{DG/MAX} = \text{Number of Buses} \quad (3)$$

B. DG generation capacity constraints

The active power at each DG (Pg_d) is restricted by its minimum and maximum limits (Pg_d^{min} and Pg_d^{max}) as:

$$Pg_d^{min} \leqslant Pg_d \leqslant Pg_d^{max} \quad (4)$$

The maximum active power added by the DGs units Pg_d^{max} is set to be the total system active load.

C. Power balance constraint

The total power generated by the initial generation sources and the added DG units must cover the total load demand (P_d) and the total active power losses (P_{LL}).

$$\sum_{g=1}^{N_G} Pg_{gw/DG} + \sum_{d=1}^{N_{DG}} Pg_d = P_d + P_{LL} \quad (5)$$

D. Bus-voltage constraints

The bus voltage (V_i) at any bus i is restricted by its minimum and maximum limits (V_i^{min} and V_i^{max}) as:

$$V_i^{min} \leqslant V_i \leqslant V_i^{max} \quad (6)$$

Where

$V_i^{max} = 1.1$ p.u.
$V_i^{min} = 0.9$ p.u.

The Fitness function, with the used constrains and goals is determined as following:

$$P_{loss} = \sum_{line\,(i,j)=1}^{m} P_{line\,(i,j)} \quad (7)$$

$$P_{line\,(i,j)} = P_i - P_j \quad (8)$$

$$\text{CBF} = \frac{\text{Cost}\,(\Delta P_{\text{losses}}) + \text{Cost}\,(\Delta P_{\text{generated at slag bus}})}{\text{Cost}\,(\text{DG}_{\text{added}})} \quad (9)$$

IV. SIMULATION RESULTS

A. 13-Bus Radial System

The first application for the proposed optimization algorithm is the 13-Bus Radial system shown in Fig.2 [17]. Three different load distribution forms; uniformly distributed loading, centrally distributed loading, and increasing distributed loading are used. The test system data are introduced in appendix A.

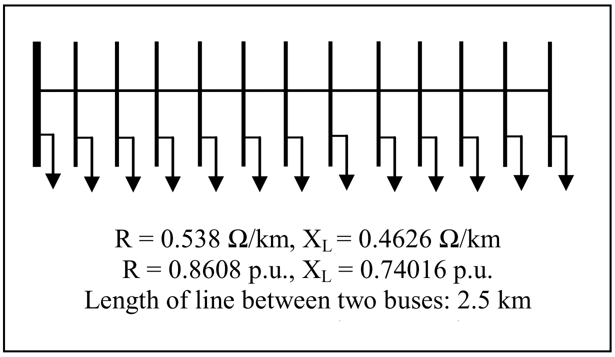

Fig. 2: the 13-Bus radial system.

Table I represents the optimization algorithm results for the optimal distribution of the DG units in the system for each loading distribution form for minimum total active power losses. It can be seen that the size of the DGs units required to be added to the system to satisfy minimum total power losses depends on the loading distribution forms.

Table I: GA results for the Radial systems DG units

DG Location (Bus No.)	Uniformly Dist. System Added DG (MW)	Centrally Dist. System Added DG (MW)	Increasing Dist System Added DG (MW)
2	0.249	0.004	0.344
3	0.378	0.333	0.02
4	0.273	0.109	0.02
5	0.248	0.356	0.277
6	0.23	0.375	0.342
7	0.498	0.443	0.338
8	0.09	0.157	0.096
9	0.428	0.375	0.468
10	0.314	0.107	0.233
11	0.151	0.148	0.52
12	0.431	0.0	0.464
13	0.25	0.443	0.356
Total power losses (MW)	0.000277	0.00245	0.00072
Total DGs Power (MW)	3.54	2.85	3.478

Two options for DGs integration in the system are investigated in the study; single DG unit and multiple DGs units.

The load flow simulations were executed without DGs units, with single DG unit optimized for minimum total power losses, with single DG unit optimized for maximum CBF, and finally with optimum multi-location DG units.

Table II summarizes the optimization algorithm results for all such cases. It is clear from table II that the DG required for single optimum location option (2.623 or 2.055 MW) is less than that required in multi-location option (3.595MW). Also it is shown in the table that maximum CBF option required the least DG unit to be added to the system (2.055 MW)

Table.II: Summary of optimization results for uniformly loaded system

Cases	Optimal Single DG for min losses	Optimal Single DG for max CBF	Optimal multiple DGs for max CBF
Total Power Losses (MW)	0.0515	0.106	0.000123
Added DG (MW)	2.623	**2.055**	3.595
Bus No.	9	13	Buses from 2 to 13
CBF	297.36	313.77	276.48

B. *Case Study*

In this case study the actual 66 kV distribution network of Alexandria, EGYPT is used to apply the GA optimization algorithm. The simplified power network is shown in Fig. 3, while its load data are presented in Appendix B.

The optimization algorithm simulation results for multi-location DG units that results in minimum active power losses applied for the practical case study are shown in table III. The total active power losses are 1.625 MW with 504.426 MW added DG units.

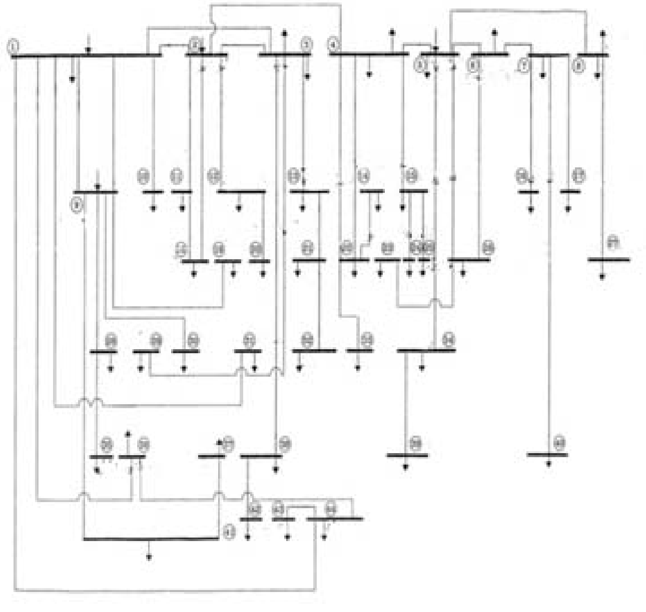

Figure 3: Simplified 66kV distribution network of Alexandria, EGYPT

Table.III: Summary of results of Alexandria, EGYPT 66 kV distribution network

DG Location	DG Added (MW)	DG Location	DG Added (MW)
1	13.971	24	9.067
4	15.206	25	12.718
5	8.692	26	10.063
6	9.149	27	11.602
7	13.441	28	11.863
8	8.013	29	12.486
10	6.181	30	5.619
11	9.464	31	16.253
12	14.466	32	20.137
13	14.995	33	17.825
14	10.379	34	16.884
15	10.561	35	10.101
16	16.633	36	11.658
17	14.992	37	7.595
18	11.272	38	14.374
19	10.979	39	14.824
20	12.204	40	5.833
21	17.917	41	8.975
22	11.289	42	18.986
23	7.691	43	13.058
		44	17.01
Total Power Losses (MW)	1.6249		
Total DGs (MW)	504.426		

Table IV show the summary optimization algorithm simulation results for different DGs integration options and goals. The results show that the optimum size of the DG unit required for maximum CBF is 34.14 MW, while it is increased to 43.89 MW if minimum total losses is required without significant difference in the total losses (2.972MW-2.895MW i.e. 0.077 MW only). The total losses could be reduced to 1.625MW with the multi-DG location option but with 504.426MW added DG units (the details of the last case were shown in table III). The results shown in the table IV, indicates that the CBF is more powerful factor for measuring the effectiveness of adding DGs units than the active power losses, with respect to the sensitivity of the cost added by the DGs units with regard to the saving from the power losses reduction.

V. CONCLUSION

This paper discusses the simulation approach for the optimal size and placement of a DG. The applications of GA in DG location and sizing have been discussed and performed using MATLAB simulations. The objectives of the optimum location and sizing of DG are to reduce the total power losses and/or maximize the CBF. Two test systems were studied 13-bus radial system with three different load distribution systems, the uniformly distributed system, centrally distributed system and increasing distributed system in addition to a practical case study of the 66 kV distribution network in Alexandria, Egypt.

The optimization algorithm simulation results prove the effectiveness of the applications of GA in solving the discussed optimization problem and result in the optimum size and location of the DG units that satisfy the objective functions under the specified system constrains. Also, it was shown that the use of CBF in the assessment of the DGs benefits is more accurate, with respect to the economical evaluation, than the used of active power losses.

Table IV: Optimization algorithm simulation results for the Alex 66 kV network with multi DG units

Cases	Optimal Single DG for min losses	Optimal Single DG for max CBF	Optimal multiple DGs for max CBF
Total Power Losses (MW)	2.895	2.972	1.625
Added DG (MW)	43.89	34.14	504.426
Bus No.	41	37	Buses from 1 to 44 except 2,3,9
CBF	202.36	202.71	201.2

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Appendix A

Table.A1: 13 Bus radial system load data

Bus No		Uniformly Dist. Load (MW)	Centrally Dist. Load (MW)	Increasing Dist. Load (MW)
1	Load at each Bus	0.3	0.06	0.09
2		0.3	0.12	0.12
3		0.3	0.18	0.15
4		0.3	0.24	0.18
5		0.3	0.3	0.21
6		0.3	0.36	0.24
7		0.3	0.42	0.27
8		0.3	0.36	0.3
9		0.3	0.3	0.33
10		0.3	0.24	0.36
11		0.3	0.18	0.39
12		0.3	0.12	0.42
13		0.3	0.06	0.45
Total-Load (MW)		3.9 MW	2.94 MW	3.51 MW

Appendix B

Table B.1: Line Data for Alex 66 kV Network

Bus Code	Resistance (p.u.)	Inductance (p.u.)
1-2	0.0004	0.003
1-3	0.0017	0.0085
1-9	0.009	0.026
1-10	0.052	0.064
1-31	0.006	0.01
1-36	0.01	0.014
1-44	0.021	0.07
2-3	0.0006	0.004
2-4	0.0002	0.0014
2-11	0.015	0.042
2-12	0.01	0.022
2-18	0.027	0.071
3-13	0.002	0.006
3-29	0.004	0.006

3-38	0.0004	0.001
4-5	0.0004	0.00212
4-15	0.003	0.005
4-22	0.002	0.004
4-33	0.01	0.022
5-6	0.0017	0.00912
5-8	0.0004	0.00212
5-26	0.016	0.038
5-34	0.007	0.014
6-7	0.0017	0.00912
6-26	0.003	0.014
7-16	0.006	0.025
7-17	0.006	0.026
7-40	0.046	0.131
8-27	0.002	0.004
9-19	0.014	0.024
9-28	0.008	0.019
9-30	0.003	0.006
9-41	0.005	0.008
11-18	0.009	0.026
12-20	0.006	0.014
13-21	0.004	0.009
14-22	0.004	0.006
15-24	0.002	0.005
15-25	0.001	0.002
21-32	0.003	0.007
23-26	0.009	0.016
28-35	0.002	0.003
34-39	0.005	0.02
36-44	0.01	0.014
37-41	0.006	0.008
38-42	0.01	0.015
43-44	0.007	0.009

Table B.2: Bus Data for Alex 66 kV Network

Bus	Generation		Load	
	P (p.u)	Q (p.u.)	P (p.u)	Q (p.u.)
1	0.46	0.4	0.1	0.008
2	5.31	3.98	0	0
3	0	0	0.33	0.25
4	0	0	1.43	1.07
5	2.18	1.64	0.12	0.09
6	0	0	0.26	0.12
7	0	0	0.02	0.015
8	0	0	1.05	0.79
9	1.04	0.79	0	0
10	0	0	0.02	0.015
11	0	0	0.01	0.008
12	0	0	0.02	0.015
13	0	0	0.235	0.176
14	0	0	0.015	0.0113
15	0	0	0.08	0.06
16	0	0	0.3	0.225
17	0	0	0.1	0.075
18	0	0	0.1	0.075
19	0	0	0.232	0.174
20	0	0	0.272	0.204
21	0	0	0.16	0.12
22	0	0	0.065	0.049
23	0	0	0.06	0.045
24	0	0	0.01	0.075
25	0	0	0.12	0.09
26	0	0	0.19	0.143
27	0	0	0.01	0.008
28	0	0	0.27	0.203
29	0	0	0.14	0.105
30	0	0	0.215	0.161
31	0	0	0.31	0.23
32	0	0	0.21	0.158
33	0	0	0.28	0.21
34	0	0	0.19	0.143
35	0	0	0.12	0.09
36	0	0	0.01	0.008
37	0	0	0.1	0.075
38	0	0	0.5	0.375
39	0	0	0.19	0.143
40	0	0	0.02	0.015
41	0	0	0.51	0.383
42	0	0	0.245	0.184
43	0	0	0.08	0.06
44	0	0	0.35	0.263