A Heuristic Approach for Distributed Generation Sources Location and Capacity Evaluation in Distribution Systems

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Abstract—Distributed Generation (DG) sources are becoming more prominent in distribution systems due to increased demand for the electrical energy. The locations and capacities of DG sources will have an impact on system losses, voltage profile characteristics of distribution network. This paper presents a heuristic approach for selection of optimal location and determination of optimal capacity of DG sources. The technique adopts Genetic Algorithms and Optimal Power Flow to facilitate the decision making process. The developed technique is incorporated with the flexibility so that the network planner can choose the total number of DGs to be included, their constraints on maximum power outputs, non-feasible locations for DG insertion which are to be excluded from search. The proposed approach is tested for IEEE 69 bus system and the results have indicated the versatility of the technique.

***Index Terms*— Distributed Generation Sources, Genetic Algorithms, Maximum Power Output, Optimal Power Flow.**

I. Introduction

The planning of the electric distribution system with the presence of multiple DG sources requires the definition of several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem. Several technical, economic and environmental benefits can be attained by connecting distributed generation sources to distribution systems. Since the impacts of distributed generation units on system performance depend on system operating conditions and the characteristics of the distributed generation, it is necessary to use some solutions in planning and operation to attain the best performance.

From the planning viewpoint, distributed resources of appropriate sizes should be located at appropriate places. A number of solution algorithms for the siting and sizing of DG, based on classic or heuristic optimization methods, have been proposed to minimize various objective functions subjected to different constraints. The impact of distributed generation, reactive power and network-configuration as objective in distributed-generation-planning problem is considered in [1]. The Optimal sizing and siting decisions for DG capacity is obtained through a cost-benefit analysis approach based on optimization model aims to minimize the distribution company's investment and operating costs as well as payment toward loss compensation. Bus-wise cost-benefit analysis is carried out on an hourly basis for different forecasted peak demand and market price scenarios [2]. The integrated model for solving the distribution system planning problem by implementing distributed generation (DG) as an option in distribution utilities territories has been developed [3]. It introduced a novel framework for implementing DG capacity investment as an attractive option in distribution system planning to estimate the optimal DG capacity investment (sizing and siting) to serve peak demands. The optimization technique, aiming at minimization of generation costs has been implemented [4] [5].

Most of the techniques in the literature are aimed at optimize either location or capacity and to estimates the benefits resulting from that like voltage improvement, loss reduction, location marginal prices [6]. This paper proposes optimization of both location and capacity of multiple distributed generation sources by accounting technical, economical and geographical constraints using Genetic Algorithm and Optimal Power Flow techniques.

II. Proposed Methodology

The proposed methodology helps the distribution system planner to optimize both Capacity and Locations with main objective of maximizing the benefits from DG incorporation subject to the constraints specific to the concerned network.

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A. Proposed Heuristic Search Algorithm:

Step 1: Select number of buses (say N).
Number of DG units to be connected (say r)
Total search space (or combinations) = ${}_{N}C_{r}$
Generate these combinations by using Genetic Algorithm search procedure

Step 2: For each combination apply optimal power flow.

Step 3: Determine the maximum DG capacity available for that combination.

Step 4: Optimize the capacity allocation with objective function satisfying the constraints.

Step 5: Repeat the same for other combination

Step 6: Select the best combination (OPF acts as GA's Fitness Evaluation Function.)

B. Genetic algorithms

Genetic algorithms are a part of evolutionary computing, which is a rapidly growing area of artificial intelligence. Genetic algorithms are an optimization method that employs a search process imitated from the mechanism of biological selection and biological genetics. They combine survival of the fittest among those feasible solutions in the form of string structures (or genes: in binary form), and a randomized formation exchange to form a search algorithm. In every generation, a new set of string solutions is created from the fittest of the old string solutions set. While randomized, genetic algorithms are no simple random walk, they efficiently use historical information to speculate on new search points with expected improved performance.

The control variables have to be represented as strings. During the search procedure, initially, many solutions are randomized. Each solution string-fitness is computed. The higher fitness solution string has more probability to have more copies. This copying procedure is called "Reproduction". The "Crossover" is used for innovating the solution strings. Mutation can help the solution strings to have a wider area of feasible solutions. After these three genetic operations, namely, Reproduction, Crossover and Mutation, the new generation solution strings exist. These new generation solution strings start the genetic operations again and again till the feasible solution is satisfied.

Evaluation Function

The evaluation function is the driving force behind the GA. The evaluation function is called from the GA to determine the fitness of each solution string generated during the search. It is unique to the optimization of the problem at hand. Therefore, for a different problem an evaluation function must be developed to determine the fitness of the individuals.

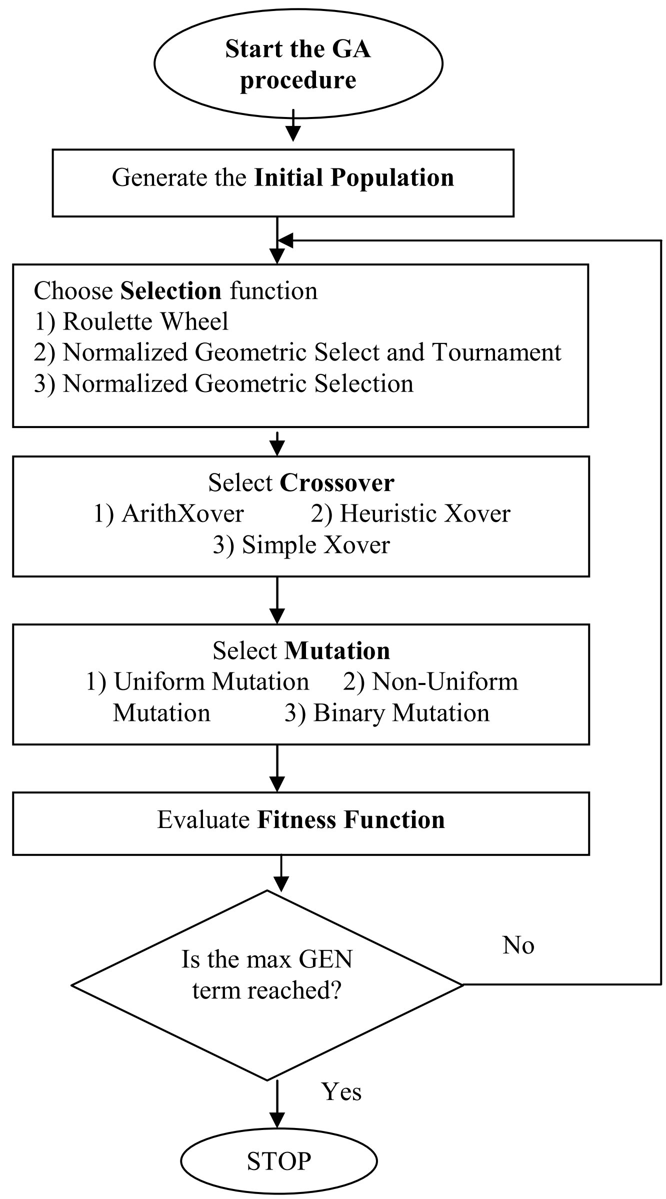


Fig. 1. Flow chart for GA Search Procedure

Operator Function

Operators provide the search mechanism of the GA. The operators are used to create new solutions based on existing solutions in the population. There are two basic types of operators, crossover and mutation. Crossover takes two individuals and produces two new individuals while mutation alters one individual to produce a single new solution. Selection Function The selection function determines which of the individuals will survive and continue on to the next generation. The GA function calls the selection function each generation after all the new children have been evaluated to create a new population from the old one.

Initialization and Termination Functions

Initialization of a population, to provide the GA starting point, is usually done by generating random strings within the search space, and this is the default behavior of the GA function. The termination function determines when to stop the simulated evolution and return the resulting population. The GA function calls the termination functions once every generation after the application of the entire operator functions and the evaluation functions for the resulting children.

C. Optimal Power Flow (OPF):

OPF has been developed extensively through power systems research to address problems ranging from economic dispatch to loss minimization and is a common feature in many power flow packages. As such, the use of OPF to maximize generation capacity appears to be a logical approach; OPF is the process of dispatching the electric power system variables in order to minimize an operation criterion while attending load and feasibility [9]. The complete concept of OPF is given in [2].

Formulation of OPF

The objective function is the total cost of real and /or active generation. The costs may be defined as polynomials or as piecewise-linear functions of generator output. The problem can be formulated schematically as :

Min (cost of generation)

Subject to

Active power balance equations

Reactive power balance equations

Apparent power flow limit of line, from and to side bus voltage limits

Active and reactive power generation limits

III. DG Placement with Heuristic Search Algorithm

In this method the planner has the flexibility to define the number of DG units to be connected rather than constraining the locations or unit size of generators. The Genetic Algorithm generates and optimizes combinations of locations from those possible for the network. For each combination of locations, an optimal power flow is used to estimate the capacity available for this combination. OPF acts as the GA's fitness function. This information is fed back to the GA which searches for the optimal connectable capacity. As such, this combination method should deliver the best locations as well as the capacities available for a user-specified number of DG.

A. DG Capacity Allocation

With the help of the OPF, the maximum DG capacity available for the each combination can be determined by modeling DG as negative load [8]. By minimizing the negative cost of all the generators and benefit resulting from this (DG capacity) is maximized. In this process economic constraints will be accounted which will limit the maximum possible power output from DG sources which are realizable in a practical situation. The objective function is to maximize the DG capacity and is formulated in linear form as

$$f_{OPF} = \sum_{i=1}^{n} c_i . P_{gi} \quad (1)$$

where C_i is incentive factor, subject to the following technical constraints :

i. *DG capacity*

As DG capacity is inherently limited by the energy resource at any given location it is necessary to constrain capacity between maximum and minimum levels.

$$Pg_{\min} \le Pg \le Pg_{\max} \quad (2)$$

ii. *Voltage limits*

The generator voltage will be the load/bus voltage plus some value related to the impedance of the line and the power flows along that line. It is evident that the larger the impedance and power flow, the larger the voltage rise. The increased active power flows on the distribution network have a large impact on the voltage level because the resistive element of the lines on distribution networks is higher than other lines. This leads to an X/R ratio of approximately 1 rather than a more typical value of 5 on transmission networks. The voltage must be kept within standard limits at each bus [7] [9].

$$V_{\min} \le V \le V_{\max} \quad (3)$$

iii. *Thermal limits*

This is a stand-alone constraint; simply put, the rated current of the lines must not be exceeded.

$$I_i < I_{iRated} ....i \forall n \quad (4)$$

Where I_i is the current flowing from generator i to bus i, and I_{iRated}. is the maximum rated current for the line between each generator and its corresponding bus. Under standard voltage and power factor conditions, the rated current of the line can be translated directly into a rated active power for that line. Besides to the constraints mentioned above, the other constraint of maintaining power factor is also considered.

Geographical Constraints

The Distributed Generation Sources need to be located only at feasible nodes from the installation and operation point of view. The mode or technology of generation, the demography of the location, the environmental factors put restriction on the location as well as the capacity of the DG source. The proposed approach incorporates the feature of embedding these heuristic rules in the algorithm in order to arrive at the optimal solution.

IV. Case Studies And Results:

Simulations were carried out on an 11-kV distribution system having two substations, four feeders, 69 nodes and 67 branches [10]. The network diagram and data is given in the Appendix. The system operates within voltages limits of ±6% of nominal and thermal limits of 3 MVA for all lines. The minimum aggregate active and reactive loadings are 4.47 MW and 3.06 MVAR, respectively.

Genetic Algorithm Application

Step l: Representation

The representation scheme determines how the problem is structured in the GA and also determines the genetic operators that are used. Between the two different representations, a float and a binary genetic algorithm, a float genetic algorithm (FGA) is employed to generate the combination of bus numbers for better solutions.

Step 2: Initialize Population

The GA must be provided with an initial population matrix of random numbers with the number of rows equal to the population size. For each member of the population Fitness is evaluated by using OPF (as OPF acts fitness function for this algorithm). An initial population of size 60 is selected (normal range 50 to 100).

Step 3: Selection

Among the three implemented selection functions, which are Roulette Wheel, Normalized Geometric Select and Tournament Normalized Geometric Select is chosen with ratio of 0.8 is selected for testing.

Step 4: Reproduction

To produce the new solutions two operators, Crossover and Mutation are required. For this test system Simple Cross Over [0.06] , [60% to 95% range] and Binary Mutation of ratio [0.05], [.5% to 1% range] is used

Step 5: Fitness Evaluation

The total power generated from distributed generation sources are aimed to be maximum and is selected for fitness evaluation.

Step 6: Termination

The algorithm stops if the number of generations reaches 300, each simulation is a fairly lengthy process, but given that this process is a strategic one, the duration is reasonable.

This algorithm gives the best combination of sites for multiple DG sources placement with optimal capacities. The algorithm has been implemented in MATLAB environment with the help some of the features of the approaches used in MATPOWER [6]. Simulations are carried out in four cases with the objective to maximize the total power generated from DG units i.e. 2-DG, 3-DG, 4-DG and 5-DG. In each case it is subdivided based on DG capacity limits. The constraint on Power Output from DG sources have been set as 1 MW, 1.5 MW and 2 MW for different trial cases which is represented by Pgmax .

Analysis

In the network data and line diagram, the optimal DG locations obtained from the algorithm are at near to junction feeder points, junction feeder points and end of the branch lines. The amount of DG capacity added from 2-DG to 5-DG is increased, which in turn the cost benefit derived is also increased. There is a possibility for similar locations to be favoured in many of the cases depending on the network characteristics. The following tables give DG Location and their capacity and total generation capacity added in the distribution network by way of incorporation of DG sources.

TABLE I
Optimal Placement and Sizing of 2-DG units

Pgmax=1 MW		Pgmax=1.5 MW		Pgmax= 2 MW	
Bus no	Pg[MW]	Bus no	Pg[MW]	Bus no	Pg[MW]
37	1.00	46	1.48	29	1.21
62	1.00	53	1.50	58	2.00
Total	2.00	Total	2.98	Total	3.21

TABLE II
Optimal Placement and Sizing of 3-DG units

Pgmax=1 MW		Pgmax=1.5 MW		Pgmax=2 MW	
Bus no	Pg[MW]	Bus no	Pg[MW]	Bus no	Pg[MW]
4	1.00	13	1.27	5	2.00
55	1.00	31	1.50	56	0.70
60	1.00	60	1.50	58	2.00
Total	3.00	Total	4.27	Total	4.70

TABLE III
Optimal Placement and Sizing of 4-DG units

Pgmax= 1MW		Pgmax=1.5 MW		Pgmax=2 MW	
Bus no	Pg[MW]	Bus no	Pg[MW]	Bus no	Pg[MW]
4	1.00	16	1.50	29	1.47
34	1.00	27	0.18	43	1.64
45	1.00	36	1.50	50	0.09
59	1.00	54	1.50	67	1.71
Total	4.00	Total	4.68	Total	4.90

TABLE IV
OPTIMAL PLACEMENT AND SIZING OF 5-DG UNITS

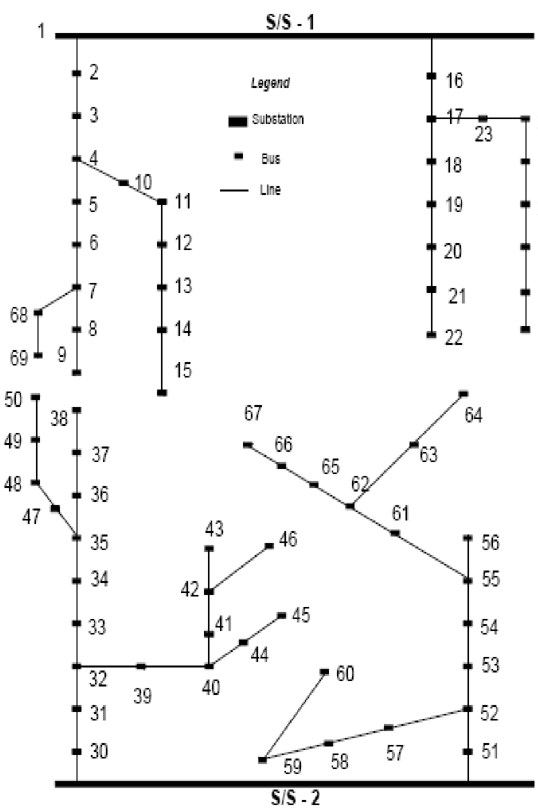
Pgmax=1MW		Pgmax=1.5 MW		Pgmax=2 MW	
Bus no	Pg[MW]	Bus no	Pg[MW]	Bus no	Pg[MW]
49	1.00	11	1.50	26	2.00
54	1.00	30	0.29	29	0.38
60	1.00	37	1.50	38	2.00
63	0.64	64	1.50	65	0.23
67	0.42	69	0.01	68	0.33
Total	4.75	Total	4.80	Total	4.94

V. CONCLUSION

The determination of location and sizing of multiple distributed generation sources in a distribution system requires consideration of several constraints and arriving at an optimal solution is a challenging task. A heuristic approach which is the combination of OPF and Genetic Algorithm search meeting the technical, economical and geographical constraints has been presented in this paper. The developed technique is tested on IEEE 69 bus system and simulation results demonstrates the flexibility available to the planner in determination of number of DGs, their feasible locations and capacity of DG sources with the constraints specific to the distribution network.

APPENDIX

Network Diagram and Data:



n.line	s-bus	r-bus	R (Ω)	X (Ω)	P (r-bus) (kW)	Q (r-bus) (kVAr)
1	1	2	1.0970	1.0740	100	90
2	2	3	1.4630	1.4320	60	40
3	3	4	0.7310	0.7160	150	130
4	4	5	0.3660	0.3580	75	50
5	5	6	1.8280	1.7900	15	9
6	6	7	1.0970	1.0740	18	14
7	7	8	0.7310	0.7160	13	10
8	8	9	0.7310	0.7160	16	11
9	4	10	1.0800	0.7340	20	10
10	10	11	1.6200	1.1010	16	9
11	11	12	1.0800	0.7340	50	40
12	12	13	1.3500	0.9170	105	90
13	13	14	0.8100	0.5500	25	15
14	14	15	1.9440	1.3210	40	25
15	7	68	1.0800	0.7340	100	60
16	68	69	1.6200	1.1010	40	30
17	1	16	1.0970	1.0740	60	30
18	16	17	0.3660	0.3580	40	25
19	17	18	1.4630	1.4320	15	9
20	18	19	0.9140	0.8950	13	7
21	19	20	0.8040	0.7870	30	20
22	20	21	1.1330	1.1100	90	50
23	21	22	0.4750	0.4650	50	30
24	17	23	2.2140	1.5050	60	40
25	23	24	1.6200	1.1100	100	80
26	24	25	1.0800	0.7340	80	65
27	25	26	0.5400	0.3670	100	60
28	26	27	0.5400	0.3670	100	55
29	27	28	1.0800	0.7340	120	70
30	28	29	1.0800	0.7340	105	70
31	1	30	0.3660	0.3580	80	50
32	30	31	0.7310	0.7160	60	40
33	31	32	0.7310	0.7160	13	8
34	32	33	0.8040	0.7870	16	9
35	33	34	1.1700	1.1450	50	30
36	34	35	0.7680	0.7520	40	28
37	35	36	0.7310	0.7160	60	40
38	36	37	1.0970	1.0740	40	30
39	37	38	1.4630	1.4320	30	25
40	32	39	1.0800	0.7340	150	100
41	39	40	0.5400	0.3670	60	35
42	40	41	1.0800	0.7340	120	70
43	41	42	1.8360	1.2480	90	60
44	42	43	1.2960	0.8810	18	10
45	40	44	1.1880	0.8070	16	10
46	44	45	0.5400	0.3670	100	50
47	42	46	1.0800	0.7340	60	40
48	35	47	0.5400	0.3670	90	70
49	47	48	1.0800	0.7340	85	55
50	48	49	1.0800	0.7340	100	70
51	49	50	1.0800	0.7340	140	90
52	1	51	0.3660	0.3580	60	40
53	51	52	1.4630	1.4320	20	11
54	52	53	1.4630	1.4320	40	30
55	53	54	0.9140	0.8950	36	24
56	54	55	1.0970	1.0740	30	20
57	55	56	1.0970	1.0740	43	30
58	52	57	0.2700	0.1830	80	50
59	57	58	0.2700	0.1830	240	120
60	58	59	0.8100	0.5500	125	110
61	59	60	1.2960	0.8810	25	10
62	55	61	1.1880	0.8070	10	5
63	61	62	1.1880	0.8070	150	130
64	62	63	0.8100	0.5500	50	30
65	63	64	1.6200	1.1010	30	20
66	62	65	1.0800	0.7340	130	120
67	65	66	0.5400	0.3670	150	130
68	66	67	1.0800	0.7340	25	15

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