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Best Location of Distributed Generation on Distribution Networks Using GA

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Abstract

In this paper we propose and develop a heuristic methodology based on genetic algorithms to obtain the optimal placement and size of distributed generation in order to minimize the technical aspects like energy losses, improvement of voltage levels. We use the IEEE 13 nodes test feeder and IEEE 37 nodes test feeder to validate the methodology. Analysis and simulations indicates that installation of DG results in active and reactive power loss reduction and voltage improvement.

Index Terms: *Distributed generation, distribution network, genetic algorithms, and optimal placement.*

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NOMENCLATURE

α,β	Voltage exponents of real and reactive loads
ILP,ILQ	Real and reactive power loss indices.
IC,IVD	MVA capacity and voltage profile indices
$CS_{(i,j)}$	MVA capacity of line
P_{0i},Q_{0i}	Real and reactive load of bus i at nominal Voltage
MVA_{SYS}	Total system MVA intake by DISCO.
P_D,Q_D	Total system real and reactive power demands.
P_L,Q_L	System real and reactive power losses without DG
$S_{(i,j)}$	MVA flow in the line connecting bus i and j
P_{LDG},Q_{LDG}	Real and reactive power losses with DG.
σ_1, $\sigma 2$, $\sigma 3$, $\sigma 4$	Weights of IMO components.
IMO	Multi Objective Index
V_i	Voltage magnitude at bus i
ΔV_{max}	Voltage drop limit between buses 1 and bus i.
V_{max},V_{min}	Maximum and minimum voltage limits of the buses

I. INTRODUCTION

A Smart Grid delivers electricity from suppliers to consumers using the support of digital technology to save energy, reduce cost and increase reliability and transparency. Such a modernized electricity network is being promoted by many governments as a way of addressing energy independence, global warming and emergency resilience issues.

Distributed energy resources (DER) are small sources of generation and/or storage that are connected to the Distribution System at load canters. For low levels of penetration (about 15% of peak demand or less), DER do not have a large effect on system design as long as they have proper protection at the point of interconnection. A Smart Grid has the potential to have large and flexible sources of DER.

Other design issues related to the ability of a Distribution System to operate as an Electrical Island, the ability of a Distribution System to relieve optimal Power Flow constraints, and the ability of DER to work in conjunction as a virtual Power Plant.

Power market is growing enormously and accelerated technical progresses have led to plant's size and unitary capacity cost reductions. These trends promote private participation in capacity expansion in a market-oriented industry organization. In addition, installation of small generators located close to the load centers, may give more flexibility to the power market. Installation of Dispersed Generation (DG) at non-optimal places can result in an increase in system losses, reconfiguration of protection scheme, voltage problems, etc...

The advantages by the introduction of DG units at optimal places Improves the voltage profile and reduces the losses, Back-up emergency power, Peak shaving, Grid support, acts as Premium power.

Different methodologies and tools have been developed to identify optimal places to install DG capacity and its size. These methodologies are based on analytical tools, optimization programs or heuristic techniques. Most of them find the optimal allocation and size of DG in order to reduce losses and improve voltage profiles. Others include the cost of energy not supplied and a few go deep in operating considerations [17].

Optimization techniques should be employed for deregulation of the power industry, allowing for the best allocation of the distributed generation (DG). The advancement in technology and a desire of the customers for cheap and reliable electric power has led to an increased interest in distributed generation. The issues related to reliability and maintenance has impeded the penetration of DG resources [18] and [19] in distribution systems.

There are many approaches for deciding the penetration level of distributed generation in distribution systems. Proposed method based on genetic algorithms (GA) to determine the network configuration. A genetic algorithm approach to the optimal multistage planning of the distribution networks. In this work a mathematical and algorithmic models are developed and experimented with real systems. The advantages of adopting this new approach are in planning context, in conjunction with adoption of multi criteria decision making methods. This optimization permits the best location of generators to be found so that power losses in an existing distribution network are minimized, and investments for electric grid upgrade, due to the growth of the energy demand of loads, can be deferred or reduced.

The paper is organized as follows: Section II presents a short review of the different methodologies and tools reported in the literature to find (or evaluate) places and sizes of DG in a distribution network. Section III presents the specific problem formulation and GA implementation. Section IV presents the simulation results and analysis. Section V concludes. Results show that installation of DG results in reduction of active and reactive power loss and voltage improvement (given the initial voltage profile in the IEEE system). Loss reduction is reached when DG is installed in remote bus bars.

II. METHODOLOGY FOR OPTIMAL PLACEMENT AND SIZE OF DG

As mentioned above, DG can be implemented either by the final users, by project developers, or by distribution utilities. The latter, in theory, cannot control where all DG is installed, but are interested in providing incentives to end users and project developers to undertake the installation of DG in strategic locations, that most agree with the company's objectives.

Different approaches have been proposed to solve DG placement in distribution systems and discuss the optimal planning and operation of the distributed generators. One of the approaches aims to site DG of discrete and pre-specified capacities at the best sites, requiring the use of intelligent techniques [3], such as multi objective evolutionary algorithms [4], [5], probabilistic optimization techniques [6], Genetic Algorithms (GA) [7] - [9], and Tabu Search (TS) [10], [11], able to handle discrete formulations. The second approach requires network locations of interest to be pre-specified with algorithms guiding capacity growth within network constraints. The methods tend to use continuous functions of capacity solved using methods like Optimal Power Flow (OPF) [12] or linear programming [13], which are repeatable. In [14], the authors present analytical methods to determine the optimal location to place a DG in radial as well as networked systems with respect to the power losses. In [15], Lagrangian based approaches are used to determine optimal locations for placing DG, considering economic limits and stability limits.

Proposed methodology is a multiobjective genetic algorithm (GA) is employed as an optimization tool for such problems. In recent years, it has been recognized that GA is particularly well suited for multiobjective optimization problems since they can simultaneously evolve an entire set of multiobjective solutions. In this way, instead of running an optimization algorithm [20] and [21].

There are various technical issues that need to be addressed when considering the presence of distributed generators in distribution systems. Ochoa *et al.* [22] computed several indices in order to describe the impacts on the distribution system due to presence of distributed generation during maximum power generation. The MVA_{sys} is the total MVA intake by the DISCO and is defined as

$$MVA_{sys} = [(P_{intake} + P_{DGi})^2 + (Q_{intake})^2]^{1/2}$$

In this work several indices will be computed in order to describe the effect of load models due to presence of DG. These indices are defined as follows.

1) Real and Reactive Power Loss Indices (ILP and ILQ): The real and reactive power loss indices are defined as

$$ILP = \frac{[P_{LDG}]}{[P_L]}$$

$$ILQ = \frac{[Q_{LDG}]}{[Q_L]}$$

where P_{LDG} and Q_{LDG} are the total real and reactive power losses of the distribution system after inclusion of DG. P_L and Q_L are the total real and reactive system losses without DG in the distribution system.

2) Voltage Profile Index (IVD): One of the advantage of proper location and size of the DG is the improvement in voltage profile. This index penalizes the size-location pair which gives higher voltage deviations from the nominal (V_1 = 1.03 p.u) In this way, closer the index to zero better is the network performance. The IVD can be defined as follows:

$$IVD = \max_{i=2}^{n} \frac{\left|(\overline{V_1} - \overline{V_i})\right|}{\overline{V_1}}$$

Normally, the voltage limits $(V_{\min} \le V_i \le V_{\max})$ at a particular bus is taken as technical constraint, and thus the value of IVD is normally small and within the permissible limits.

3) MVA Capacity Index (IC): As a consequence of supplying power near to loads, MVA flows may diminish in some sections of the network, thus releasing more capacity, but in other sections they may also increase to levels beyond distribution line limits (if line limits are not taken as constraints). The index (IC) gives important information about the level of MVA flow/currents through the network regarding the maximum capacity of conductors. This gives the information about need of system line upgrades. Values higher than unity (calculated MVA flow values higher than the MVA capacity) of the index give the amount of capacity violation in term of line flows, whereas the lower values indicate the capacity available

$$IC = \max_{i=2}^{n} \frac{\left|\overline{S_{ij}}\right|}{\overline{CS_{ij}}}$$

The benefit of placing DG in a system in context of line capacity released is measured by finding the difference in IC between system with and without DG. The avoidance of flow near to the flow limit is an important criterion as it indicates that how earlier the system needs to be upgraded and thus adding to the cost. The use of IC index may not be applicable in the context available transmission capacity (ATC) improvement in transmission systems. Normally, the limits $(S_{ij} \le S_{ij\max})$ at a particular line is taken as a strict constraint, and thus the value of IC is always positive.

III. PROBLEM FORMULATION AND GA IMPLEMENTATION

In this paper, a GA optimization technique developed in a previous work of [2],[4] and [9] has been used for finding the best solutions of the IMO optimization algorithm. The first important aspect of correct GA implementation is the examination of potential solution. If the network structure is fixed, all the branches between buses are known, and the evaluation of the objective functions depend only on location and size of DG. For this reason each solution is examined for proper location and corresponding size of DG unit.

The implemented GA starts by random generating an initial population of the possible solutions. For each solution a size of DG and a location (bus) is generated by the planner with economical and technical justifications. A number of size-location pairs are randomly chosen until the total power loss of the system is optimal (or near optimal) for DG penetration level. At this point objective function is evaluated for verifying all technical constraints. If one of them is violating, such solution is rejected.

Once population cycle is initialized, the genetic operators are repeatedly applied in order to produce new solution. By applying crossover and mutation operators new population is generated. If one of the technical constraints is violated or the DG size and /or location exceed the limit, new solution is rejected. Finally, according to the GA theory, the new population is formed comparing old and new solutions and choosing the best among them. The algorithm stops when the maximum number of generation is reached or difference between objective function value of the best and worst individuals becomes smaller than specified value.

The multiobjective index for the performance calculation of distribution systems forDG size and location planning with load model considers all previously mentioned indices by strategically giving a weight. This can be performed since all impact indices were normalized (values between 0 and 1) [23]. Indices Weights are ILP=0.4, ILQ=0.2, IC=0.25, IC=0.15.

The GA-based multiobjective performance index (IMO) is given by

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$$IMO = (\sigma_1 ILP + \sigma_2 ILQ + \sigma_3 IC + \sigma_4 IVD)$$

Where

$$\sum_{p=1}^{4} \sigma_p = 1.0 \wedge \sigma_p \in [0,1].$$

The multiobjective function (IMO) is minimized subject to various operational constraints to satisfy the electrical requirements for distribution network. These constraints are discussed as follows.

1) *Power-Conservation Limits*: The algebraic sum of all incoming and outgoing power including line losses over whole distribution network and power generated from DG unit should be equal to zero

$$P_{ss}(i,V) = \sum_{i=2}^{n} (P_D(i,V) + \sum_{n=1}^{NOL} P_{loss}(V) - P_{DGi}$$

NOL = no. of lines, P_D = power demand (MW)

2) *Distribution Line Capacity Limits*: Power flow through any distribution feeder must comply with the thermal capacity of the line

$$S_{(i,j)} \le S_{(i,j)\max}$$

3) *Voltage Drop Limits*: The voltage drop limits depend on the voltage regulation limits provided by the disco

$$|V_1 - V_j| \le \Delta V_{\max}$$

If voltage and MVA limits are satisfied in system buses for a particular size-location pair, accept that pair for next generation population. Else reject the size-location pair which does not satisfy voltage and MVA limits in the next generation. Obtain the size-location pair for minimum IMO. All possible generations are tested with operational constraints, the size and location corresponding to minimal IMO is the optimum-size location pair.

IV. SIMULATION, RESULTS AND ANALYSIS

The test systems are the IEEE 13 nodes and IEEE 37 nodes test feeders [24], whose one line diagram shown in Fig. I and Fig-III.

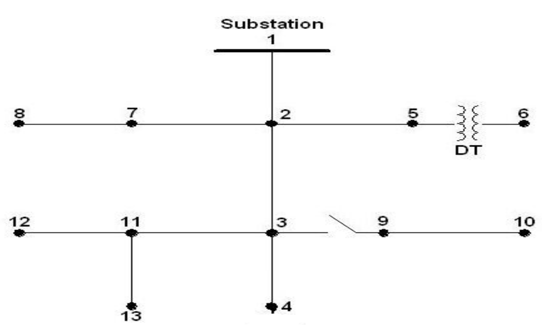

Fig – I IEEE 13 nodes test feeder one line diagram

Table – I

Results of IEEE 13-Nodes test feeder without and with DG

Load model	constant
Optimal location	10
Optimal size (kva)	62.4771
Ploss without DG (kw)	36.0593
Ploss with DG (kw)	20.8851
Qloss without DG (kvar)	110.2412
Qloss with DG (kvar)	64.0712

Table – II

Comparison of Voltage Profiles for IEEE 13-Nodes test feeder without and with DG for one phase of three phases

Bus	Voltage (p.u) without DG	Voltage (p.u) with DG
1	1	1
2	0.99784	1.00414
3	0.99715	1.00577
4	0.99715	1.00577
5	0.99751	1.00447
6	0.99681	1.00516
7	0.99784	1.00414
8	0.99784	1.00414
9	0.99679	1.00638
10	0.99598	1.00779
11	0.99494	1.00797
12	0.99494	1.00797
13	0.99406	1.00884

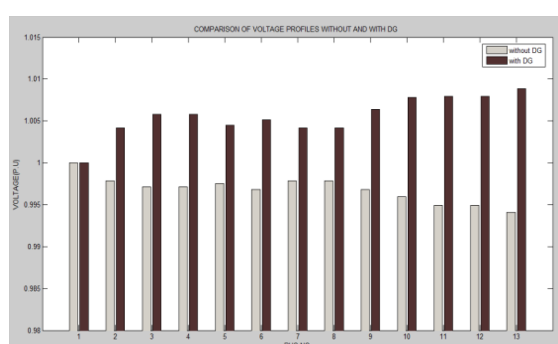

Fig – II Comparison of Voltage Profiles for IEEE 13-Nodes test feeder without and with DG for one phase of three phases

Table-I summarizes the optimal DG size-location pairs for IEEE 13-nodes test feeder, IMO along with its components constant load model. From Table I, the optimal size-location pair (0.6247 p.u.- bus 10) for constant load model and reduction in active and reactive power loss with DG are observed.

Table-II summarizes the voltage profile improvement of one phase of three phases after placing the DG at optimal location.

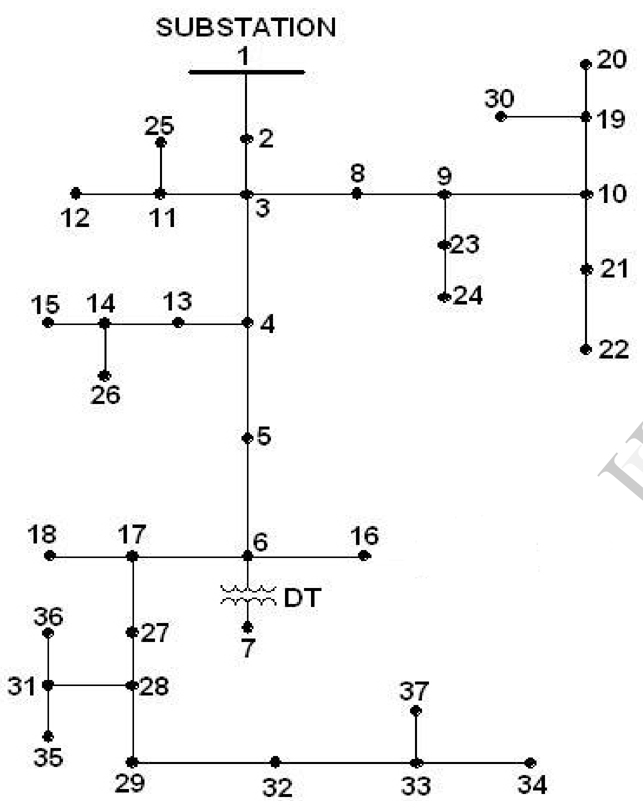

Fig – III IEEE 37 nodes test feeder one line diagram

Table – III

Results of IEEE 37-Nodes test feeder without and with DG

Load model	constant
Optimal location	30
Optimal size (kva)	60.4468
Ploss without DG (kw)	48.9932
Ploss withDG (kw)	12.4190
Qloss without DG (kvar)	26.9017
Qloss with DG (kvar)	6.1496

Table – IV

Comparison of Voltage Profiles for IEEE 37-Nodes test feeder without and with DG for one phase of three phases

Bus	Voltage (p.u) Without DG	Voltage (p.u) with DG
1	1	1
2	0.99862	1.00137
3	0.99857	1.0015
4	0.99855	1.00153
5	0.99851	1.00163
6	0.99841	1.0024
7	0.99842	1.00243
8	0.99861	1.00137
9	0.99859	1.00137
10	0.99842	1.0013
11	0.9982	1.00141
12	0.9982	1.00141
13	0.99849	1.00162
14	0.99849	1.00162
15	0.99849	1.00181
16	0.99841	1.0024
17	0.99831	1.00266
18	0.99826	1.00266
19	0.99831	1.00108
20	0.99831	1.00108
21	0.99842	1.0013
22	0.99842	1.0013
23	0.99859	1.00139
24	0.99859	1.00192
25	0.99807	1.00141
26	0.99845	1.00166
27	0.99817	1.00322
28	0.99767	1.00502
29	0.99809	1.00715
30	0.99825	1.00093
31	0.99745	1.00502
32	0.99772	1.00752
33	0.99671	1.00752

34	0.99659	1.00752
35	0.99745	1.00502
36	0.9972	1.00502
37	0.99604	1.00752

Table-III summarizes the optimal DG size-location pairs for IEEE 37-nodes test feeder with constant load model. From Table III, the optimal size-location pair (0.6044 p.u.- bus 30) for constant load model and reduction in active and reactive power loss with DG are observed.

Table-IV summarizes the voltage profile improvement of one phase of three phases after placing the DG at optimal location.

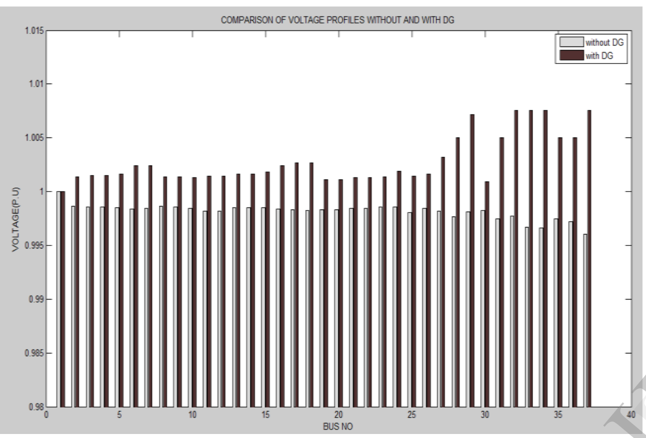

Fig – IV Comparison of Voltage Profiles for IEEE 37-Nodes test feeder without and with DG for one phase of three phases

V. CONCLUSION

The exhaustive analysis for size-location planning of distributed generation in multiobjective optimization in distribution systems is presented. The multiobjective criteria based on system performance indices of ILP and ILQ, related to real and reactive power losses, and IC and IVD, related to system MVA capacity enhancement and voltage profile improvement, is utilized in the present work.

The application of GA for DG size-location planning has been tested by comparing the results with exhaustive enumeration. It was observed that when GA was run multiple numbers of times.

The results show improvement in voltage profiles and reduction in active and reactive power loss after including DG at optimal place.

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