Application of Genetic Algorithm to Distribution Network Expansion Planning with Distributed Generation

MAJID GANDOMKAR
Department of Electrical Engineering
Islamic Azad University, Saveh Branch, Saveh
IRAN

Abstract: - This paper proposes a Genetic Algorithm (GA) based method for distribution network expansion including Distributed Generation (DG). It may be introduced as a combinatorial optimization method that determines the location and capacity of feeders and substations while minimizing the network loss and installation cost. In this paper, DGs are considered in the network expansion planning due to their importance in regulated distribution network. This paper also proposes a new objective function considering the installation cost of equipments (feeders, substations and DGs), cost of losses and cost of DGs operation. The proposed method is successfully applied to planning a real distribution network.

Key-Words: - Genetic Algorithm, Distribution Network Expansion Planning, Distributed Generation

1. Introduction
Distribution network planners continually endeavor to develop new planning strategies for their network in order to serve the load growth and provide their customers with a reliable electricity supply. Traditional planning studies for serving the forecasted load demand in distribution systems were carried out by considering addition of new substations, or expanding the existing substation capacity and associated new feeder requirements. Competitive electricity market forces the distribution network planners to investigate the economical and technical feasibility of new expansion alternatives such as distributed generations (DG) [1].

Distributed Generations scheme includes a set of small generators, scattered throughout a power system, to satisfy the electric energy consumption of electrical customers. DG scheme often offers a set of valuable alternatives in addition to the traditional sources of electric power generation for industrial, commercial and residential consumers. DG scheme employs the latest modern generation technologies in an extensive form and it can be efficient, reliable, and simple to own and operate comparing with other electrical power systems. In some cases DGs provide significantly lower cost and higher reliability versus those which can be obtained from the electrical grid. In others, it can augment the grid so that the combination of grid and DG provide higher performance than either could alone. However it offers an alternative that utility planners should explore it for the best solution problems [2-3].

Distribution network planning involves identification of the best equipment, along with its location, and schedule of deployment. The solutions of the problem are the set of all feasible combinations of sites and sizes realizing the schedule of deployment of equipments (substations, feeders, DGs) in distribution network. However, the large number of the possible solutions makes it difficult to extract the optimum solution.

Since cost is an important attribute in distribution network planning, almost invariably one of the planner’s chief goals is to minimize overall cost [2,4]. In this paper, the important task of planning the optimal number and position of DGs has been faced. This optimization permits selection of the best location of generators to minimize total cost including investments for electric grid upgrade and cost of power losses, along the planning duration. For this optimization a software, based on genetic algorithm, is developed and tested on a typical distribution network.

2. Distributed Generation
Due to rapid increase, there have been numerous increases in electric consumption growth rates and high load densities. This growth and need for more flexible electric systems, changing regulatory and economic scenarios, energy savings, environmental impact and the need to protect sensitive loads against network disturbances are providing impetus
to the development of distributed generation and storage systems based on variety of technologies. In particular, the term DG implies the use of any modular technology that is sited throughout a utility service area to lower the cost of services. DG can comprise diesel and internal combustion engines, small gas turbines, fuel cells and photovoltaic. The purpose of these plants is to cope with the growing demand of electricity in certain areas and render certain activities self-sufficient in terms of power production thus achieving energy savings [1-3]. The main reasons for the increasingly widespread use of distributed generation can be summed up as follows [3]:

1. DG units are closer to customer so that transmission and distribution costs are reduced.
2. The latest technology has made available plants ranging in capacity from 10 kW to 15 MW.
3. It is easier to find sites for small generators.
4. Usually DG plants require shorter installation times and the investment risk is not so high.
5. CHP (Combined Heat and Power) groups do not require large and expensive heat network.
6. Natural gas, often used as fuel in DG stations is distributed almost everywhere and stable prices are to be expected.
7. DG plants yield fairly good efficiencies especially in cogeneration and combined cycles.
8. DG offers great values as it provides a flexible way to choose a wide range of combinations of cost and reliability.

For these reasons, the first signs of a possible technological change are beginning to arise on the international scene, which could involve in the future the presence of a consistently generation produced with small and medium size plants directly connected to the distribution network (LV and MV) and characterized by good efficiencies and low emissions. This will create new problems and probably the need of new tools and managing these systems.

3. Problem Formulation

The problem is to determine sites, sizes and schedule of deployment of distributed generators, substations and feeders to minimize the sum of distribution network investment and cost of power losses. The following assumptions are adopted to formulate the problem:

1. Maximum number of installable DGs is given.
2. Total installation capacity of DGs is given.
3. Candidates of DG installation position for each load point are given.
4. The upper and lower limits of node voltage are given.
5. The current capacities of conductors are given.

For total cost minimization, the objective function is given by

\[ f(t) = \sum_{\forall year} \sum_{\forall SP, \forall S} (F_{SP} \sum_{\forall L} Y_{SP}^S \sum_{\forall P} X_{SP}^S + \theta_{SP}^S (X_{SP}^S) + \sum_{\forall SP, \forall SP, \forall P} (F_{SP} \sum_{\forall L} Y_{SP}^P \sum_{\forall P} X_{SP}^P + \theta_{SP}^P (X_{SP}^P))) \]

Constraints:

(1) (Maximum number of DGs)
\[ \sum_{\forall t, \forall LP, \forall P} Y_{LP}^P \leq D \]

(2) (Total capacity of DGs)
\[ \sum_{\forall t, \forall LP, \forall P} F_{LP} Y_{LP}^P \leq C \]

(3) (Only one DG can be installed in one load point)
\[ Y_{LP}^P \leq 1 \]

(4) (Upper and lower voltage limit)
\[ V_i \leq V_n \pm \Delta V \quad \text{for } \forall i \in \text{Network Nodes} \]

(5) (Current capacity limit)
\[ I_i \leq I_{i_{\text{max}}}^{\text{max}} \quad \text{for } \forall i \in \text{Network Sections} \]

Where,

SP : Candidate Substation Place node,
S : Existing Substation Node
L : Candidate Line
F : Existing Feeder
LP : Candidate Load Point,
P : Power Plant Node,
\[ F_{SP}^P : \text{Investment cost for installing project } \alpha \text{ which installed at } \odot \text{ location at year } t, \]
\[ Y_{LP}^P : 0-1 \text{ variable for determining whether project } \alpha \text{ (substation, feeder or DG) is installed at } \odot \text{ location at year } t (1: \text{ installed, 0: not installed}), \]
\[ X_{SP}^P : \text{Power consumption (substation or feeder) or generation (DG) of project } \alpha \text{ which installed at } \odot \text{ location at year } t, \]
\[ \theta_{SP}^P(\cdot) : \text{Function of operation cost (DG) or losses cost (substation or feeder) of project } \alpha \text{ at location } \odot \text{ at year } t \text{ with power } X_{SP}^P, \]
\[ D : \text{Maximum number of the distributed generations in the distribution network}, \]
\[ C : \text{Total injected power of distributed generations in the distribution network}, \]
\[ V_{i} : \text{Voltage magnitude of node } i, \]
\[ V_n : \text{Nominal voltage magnitude in the network, } \]
\[ \Delta V : \text{Maximum permissible voltage deviation}, \]
Current of section \( i \) in the distribution network, 

\[ I_i^{\text{max}} \]: Maximum current capacity of section \( i \) in the distribution network.

For a better comparison, and considering discount rate, for each cost at each year a uniform annual value is used.

4. Genetic Algorithms

Genetic Algorithms are general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time [7-8].

Generally, GA comprises three different phases of search: phase 1: creating an initial population; phase 2: evaluating a fitness function; phase 3: producing a new population.

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Applying GA operators creates further generations. This eventually leads to a generation of high performing individuals [7].

4.1 The Genetic Algorithm Operators

There are usually three operators in a typical genetic algorithm [7]: the first is the production operator (elitism) which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the 'crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better performing offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

5. The Proposed Algorithm

In order to determine the best sites, sizes and schedule of deployment of DGs, substations and feeders for distribution network, an algorithm has been created that would be appropriate given the particular constraints. This algorithm uses GA for optimization the problem. The major steps of the proposed algorithm are:

- Step 1: Initialize the variables of GA;
- Step 2: Creating an initial population by randomly generating a set of feasible solutions;
- Step 3: Evaluating each chromosome by running the load flow program;
- Step 4: Determining the fitness function of each chromosome in the population;
- Step 5: Applying GA operators to generate new populations;
- Step 6: Apply the crossover operator to complete the members of the new populations;
- Step 7: Apply the mutation operator to the new population;
- Step 8: Check the new population after applying the operators and correct them if necessary;
- Step 9: Let the current population be the new population;
- Step 10: If the convergence criterion is satisfied, stop. Otherwise go to step 3.

The general flowchart of the solution algorithm is shown in Fig. 1.

6. Objective Function Evaluation

According to Eq. (1), losses are one of the important parts of the objective function. For calculation of feeders and substations losses and also for considering the voltage and current limits in each network (chromosome) the required load flow software [9] is employed and it is run for each network. This power flow software is capable of modeling the distributed generations and unbalanced loads.

6.1 GA Implementation

A binary coding represents the solution of the problem. As in the example, 4 sizes of DGs, 4 sizes of feeders and 3 sizes of substations are used for network planning, 3 bits are considered for coding of each equipment for each year: one bit for presenting and 2 bits for type of equipment. Therefore, for achieving the schedule of deployment of all equipments from first planning year to horizon year, the resultant chromosome includes above-mentioned coding for all of years.
Selection of chromosomes for applying various GA operators is based on their scaled fitness function in accordance to the roulette wheel selection rule. The roulette wheel slots are sized according to the accumulated probabilities of reproducing each chromosome. Crossover and mutation operators are carried with the prespecified probabilities. After applying the operators, it is possible that the construction of chromosome is destroyed, therefore a check and correction of the chromosomes part (network) if necessary, are then made.

7. Numerical Example

In order to test the proposed algorithm, a real distribution network has been considered. Fig. 2 shows the sample network diagram before planning (year =0). Table 1 shows more details of this network's specifications.

Different experiments with different random number seeds were carried out to investigate the performance of the proposed algorithm. A number of tests on the performance of the proposed algorithm have been carried out on the example to determine the most suitable GA parameters setting. It was seen that the setting parameters are independent of DG technology and are dependent to the network. Table 2 shows the control parameters of GA have been chosen after running a number of simulations. The best chromosome presents the best sizes, sites and schedule of deployment for all of the equipments among the planning years. Fig. 3 shows these results for those years that DGs are proposed for the network and horizon year (years=1,3,7,10). Total permissible DG capacity (4000 kVA) has been used in the proposed plan.

Table 1

<table>
<thead>
<tr>
<th>Specifications of example</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of distribution load nodes</td>
<td>69</td>
</tr>
<tr>
<td>Number of substation place</td>
<td>3 (70,71,72)</td>
</tr>
<tr>
<td>Demand of network (year=1)</td>
<td>10689 kVA</td>
</tr>
<tr>
<td>Demand of network (year=10)</td>
<td>46763 kVA</td>
</tr>
<tr>
<td>Capacities of DGs</td>
<td>500,1000,1500, 2000 kVA</td>
</tr>
<tr>
<td>Maximum total capacity of DGs (C)</td>
<td>4000 kVA</td>
</tr>
<tr>
<td>Maximum number of DGs (D)</td>
<td>8</td>
</tr>
<tr>
<td>Permissible voltage drop</td>
<td>5%</td>
</tr>
<tr>
<td>Investment cost of DG</td>
<td>1030 $/kW</td>
</tr>
<tr>
<td>Operation cost of DG</td>
<td>0.085 $/kWh</td>
</tr>
<tr>
<td>Power cost</td>
<td>690 $/kWh</td>
</tr>
<tr>
<td>Energy cost</td>
<td>0.07 $/kWh</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>GA Resultant Control Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Size</td>
<td>40-50</td>
</tr>
<tr>
<td>Crossover Probability</td>
<td>0.35-0.40</td>
</tr>
<tr>
<td>Mutation Probability</td>
<td>0.002-0.003</td>
</tr>
<tr>
<td>Generation Distance (G)</td>
<td>0.8</td>
</tr>
</tbody>
</table>
For better analysis, using GA, the example network has been planned without DG. Table 3 shows comparison between results of two solutions. The results show that power losses will decrease with optimal DG allocation in the network. With optimal DG allocation, the power losses have decreased up to 38% and total costs for planning period are decreased about 28.7% for the example network. Furthermore, with optimal DG planning, it is necessary to install substation 3 at 8th instead of 5th year.

<table>
<thead>
<tr>
<th></th>
<th>DG</th>
<th>no-DG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Capacity of Installed DGs (kVA)</td>
<td>4000</td>
<td>-</td>
</tr>
<tr>
<td>Total Investment Costs (1000 $)</td>
<td>5044</td>
<td>1682</td>
</tr>
<tr>
<td>Year of Installation of Substation 3 (72)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Total Power Losses (kW)</td>
<td>10480</td>
<td>16888</td>
</tr>
<tr>
<td>Total Costs of Planning (1000 $)</td>
<td>9057</td>
<td>12708</td>
</tr>
</tbody>
</table>

8. Conclusion

Distributed Generations are predicted to play a more important role in the structure of electric power system in near future. With so many new distributed generations being installed, it is critical to assess the power system impacts accurately. These DG units can be employed in a manner to avoid the degradation of power quality, reliability, and control of the utility system. On the other hand, DGs have a great potential to improve distribution system performance and it should be encouraged. For this reason, it is important that distribution network planners can have useful and efficient tools to take into account the opportunities of DGs, and avoid the costly and time-consuming impact studies. On the basis of these considerations, in this study a new implementation of Genetic Algorithm for optimal planning of distribution network with Distributed Generation is illustrated. In this paper, the total costs including investment costs of all equipments, costs of losses, and operation costs of DGs were considered for optimum planning of distribution networks. The effects of the proposed GA method to solve the problem are demonstrated by an example. The proposed method was successfully applied to a real distribution network considering a 10 year planning period. The results showed that this developed GA method could be employed for optimization of a network more than one hundred node. Furthermore, it can be seen that considerable saving can be achieved simply by adding some generation units in the right positions.

References:


Fig. 3: The resultant networks after planning with GA

a- network of 1\textsuperscript{st} year (G1=1000, G2=500 kVA)

b- network of 3\textsuperscript{rd} year (G3=2000 kVA)

c- network of 7\textsuperscript{th} year (G4=500 kVA)

d- network at the end of planning years (horizon)