

# Distributed Generator Placement in Power Distribution System Using Genetic Algorithm to Reduce Losses

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## Abstract

This paper presents a genetic algorithm based distributed generator placement technique in a distribution system for minimizing the total real power losses in the system. Both the optimal size and location are obtained as outputs from the genetic algorithm toolbox. The results are verified using two popular power flow analytical tools for distribution system load flow. The paper also evinces the importance of selecting the correct size and suitable location for minimizing the system losses.

**Keywords:** Distributed generation, distribution system, genetic algorithm, loss reduction

## 1. Introduction

In the past, due to the “economy of scale” the power generating stations were often large and their capacities were in the range of 150-1000 MW [1]. Clearly, such big power stations require large facilities, including land and personnel needed to operate, and high capital cost. Moreover, since these big power stations cannot be constructed closer to load centers for some obvious reasons, there was a need for long Extra High Voltage (EHV) or Ultra High Voltage (UHV) transmission lines, including transmission substations. Similar to power stations, these transmission lines and substations need an ample amount of money in design, construction, operation and maintenance.

The lengthy structure of these transmission lines makes them vulnerable to natural hazards such as heavy wind, snowstorms and lightning. These natural hazards, in some cases, become the major reason for partial or full black out of the power system triggered by some line outages. These conditions added with economical and environmental pressures have,

in the recent past, been changing the generation approaches of traditional electric power utilities. Some of the economical and environmental factors associated with large power plants are listed below:

- Environmental impacts
- Transmission right of way problems
- High investment and long term planning
- Land requirement for power plant construction and resettlement

What are the alternatives, then? By considering the above factors, one of the best alternatives for a change in the traditional way of generation and delivery arrangement is to introduce distributed and dispersed generation, which can be conveniently located closer to load centers.

Distributed generation (DG) is not a new concept. If one looks back on the evolution of the electric power industry, electricity was introduced as an attractive alternative for steam, hydraulics, direct heating and cooling which

were produced near the point of consumption in a small scale. The main idea behind the Distributed Generation is that generation is small scale, which can be easily placed closer to the point of consumption. Distributed and dispersed generators are, by definition, small size generators, which can come from traditional or some revolutionary technologies.

The current trend is a deregulated electricity market, where competition is introduced in generation, transmission and distribution. This gives DG applications a very favorable market. People with an interest of having their own electricity generating facility can do so and the rest of the power, after their consumption, can be sold for the benefit of all. This releases the government burden of investment in the generation sector and could result in a reduction in electricity price and improve the quality of supply.

It is also interesting to note that there was a shrinking in "economy of scale" in the electric energy production, in the recent past. A recent study indicates that the cost per kWh ratio between large (traditional) to small (DG) generating units has dropped from 60 percent in 1960 to 30 percent in 2000 [1]. This is due to the fact that there is technological advancement in fuel conversion, heat containment or insulation and thermal engineering and automation and control. Some DGs can be fully automated and need to be brought offline only once a year for maintenance.

Various advantages and the "climate" of the current electricity business, strongly favor the application of DGs. However, there are many issues that need to be considered before allowing the Distributed and Dispersed generators to operate in power systems, in large numbers. Given the choices, where would the DG be placed in the system to enjoy maximum technical benefits such as low losses [2], higher reliability, increase in loadability and better voltage profile? Apart from these, there are other issues, such as various stability problems related to DG and the protection of DG that have to be properly considered. Since, stability and protection issues are out of the scope of this paper, only DG placement in the distribution system is studied, especially, to reduce the total real power losses in the distribution system.

The rest of this paper is organized as follows: Section 2 gives a brief introduction to

various Distributed and dispersed generation applications. Various benefits of DG are also summarized in the section. A methodology to calculate total system losses is given in Section 3. Section 4 describes the GA for DG placement, including the Genetic Algorithm Optimization Toolbox. Numerical results along with some observations and discussions are given in Section 5. Finally, the major contributions and conclusions of the papers are summarized in Section 6.

## 2. Distributed Generators

Distributed generation includes the application of small generators, typically in the range of 15 kW to 10 MW in capacity [1]. These small plants are scattered throughout a power system to supply electric power to various customers. They can provide power to a single home, business or industrial facility.

In general, the term "distributed generation" includes all use of small electric power generation whether placed on the utility system or at an isolated location, which is not yet connected to the central grid. On the other hand "dispersed generation" is, basically, a subset of distributed generation that are located at customer facilities or off the utility system. Usually, the generation facilities in a very small range, 10 to 250 kW are classified as dispersed generation. There are several major customer applications of distributed or dispersed generation:

1. Own electricity generation with or without grid backup.
2. Generating a portion of electricity to save peak period to reduce the cost of electricity purchased during the peak hours.
3. Sell excess generation back onto the grid, when there is a surplus of power.
4. Standby or emergency power.
5. Improving the quality of supply and increase reliability.
6. Serving niche applications, such as "Green Power" or "remote Power".
7. Meeting continuous power, premium power or cogeneration needs of the residential market.

Distributed and dispersed generation can come from a variety of sources and technology. DGs from a renewable sources, such as wind,

solar, low-head hydro and biomass, are often referred to as “Green Energy” or “Clean Development Mechanism” power projects. In addition to these, DG includes fuel cells and so called micro turbines which are based on the “revolutionary” concept of very high speed gas turbines.

DG offers a long list of benefits, which can be, primarily, classified into three broad categories, namely, economical, technical and environmental advantages. Economical advantages cover saving world fuel, saving transmission and distribution cost and reducing wholesale electricity price. On the other hand environmental advantages include low noise and low emission.

Technical advantages cover a wide variety of issues such as peak load saving, good voltage profile, reduced system losses, improved continuity and reliability, removal of some power quality problems and relaxed thermal constraints of Transmission and Distribution (T&D) feeders. Reducing the total system losses could be of interest to some utilities in the developing countries as some of them are losing 15-20% of their total generation as losses while this figure for a well-developed power system is well under 10%. However, the placement and size of the DG are two crucial factors in loss reduction as will be shown in the paper.

### 3. System Losses in the Grid

Transmission and distributions losses constitute a major portion of system losses. This is an old and well-researched area. However, there is a great potential for loss reduction in some of the developing countries in Asia, as presented in [3]. System losses, in practice, mean two types; one is the capacity or kW loss and the other one is energy or kWh loss, which can result in a larger monetary value at the end of each year [4]. Even though the losses cannot be completely removed, they can be brought down to an acceptable value.

#### 3.1 Power Flow Solution

Network equations can be formulated systematically in a variety of forms. The node-voltage method, which is the most suitable form for many power system analyses, can be used to calculate voltages and phase angles at various nodes. Thus, the resulting equations in terms of

power, known as the power flow equations, become nonlinear and must be solved by iterative techniques [5].

There are three well-known power flow solution techniques, which are Gauss-Seidel, Newton-Raphson (N-R) and the Fast decoupled methods. Among the three methods the N-R method was chosen for its accuracy and computational time.

#### 3.2 Line Flows and Losses

After the iterative solution of bus voltages, line flows and line losses can be calculated. The complex power  $S_{ij}$  from bus  $i$  to  $j$  and  $S_{ji}$  from bus  $j$  to  $i$  are

$$S_{ij} = V_i I_{ij}^* \quad (1)$$

$$S_{ji} = V_j I_{ji}^* \quad (2)$$

The power loss in line  $i$ - $j$  is the algebraic sum of the power flows determined from the above equations.

$$S_{Lossij} = S_{ij} + S_{ji} \quad (3)$$

Total system losses can be calculated from (3) by adding the real part of all the line losses, including transformer losses.

Alternatively, the B matrix loss formula can also be used for loss calculation. This was originally introduced in the early 1950s as a practical method for loss and incremental loss calculations [6]. The equation for the B matrix loss formula is as follows.

$$P_{Loss} = P^T [B] P + B_0^T P + B_{\infty} \quad (4)$$

This can be written:

$$P_{Loss} = \sum_{i=1}^n \sum_{j=1}^n P_i B_{ij} P_j + \sum_{i=1}^n P_i B_{i0} + B_{\infty} \quad (5)$$

Where  $P_i$  is the real power generation at the  $i$ th generator bus, and  $B_{ij}$  is an  $n$  by  $n$  matrix. For quadratic loss coefficients,  $B_{i0}$  is a dimensionless vector of linear loss coefficients and  $B_{\infty}$  is the constant of loss coefficients. All  $B$  can be calculated based on load flow solutions.

An N-R load flow, losses calculation as well as  $B$  loss coefficients are implemented in

“lineflow”, which is written in MATLAB [5]. The loss is used as an evaluation function in the Genetic Algorithm Optimization Toolbox (GAOT) to search the optimal size and location of DG.

#### 4. Genetic Algorithm (GA)

Genetic algorithms are an optimization method that employs a search process imitated from the mechanism of biological selection and biological genetics [7]. 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.

##### 4.1 GA Optimization Toolbox (GAOT)

The algorithm discussed above was implemented as MATLAB toolbox, i.e. a group of related functions, named GAOT. Each module of the algorithm is implemented using a MATLAB function. This provides a high degree of modularity and extensibility as a result of the decision to pass the selection, evaluation, and termination functions to the GA as well as a list of genetic operators. Thus the base genetic algorithm is able to perform evolution using any combination of selection, crossover, mutation, evaluation and termination functions that conform to the functional specifications [8]. The fundamental process behind GA is a simulated

evolution. Other functions in GA are briefly summarized below.

##### *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.

##### *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.

##### 4.2 GA for DG placement

The use of GA for DG placement requires the determination of six steps as illustrated in Fig. 1.

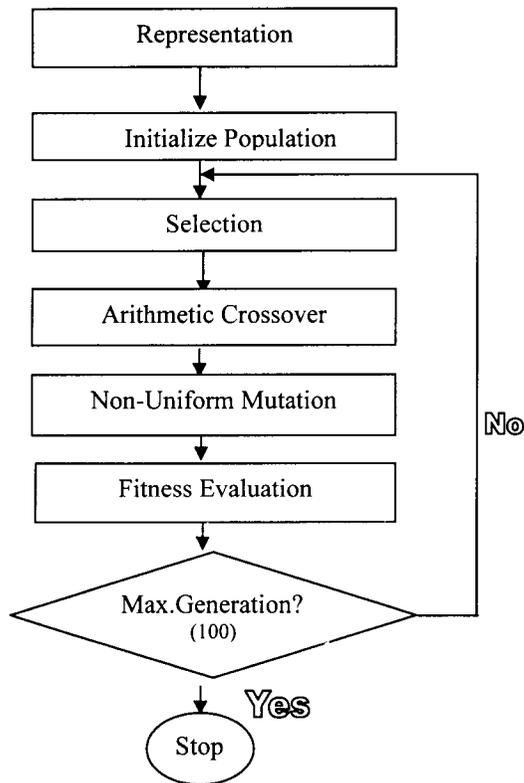


Fig. 1. Flowchart of GAOT.

#### Step 1: 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 produce better solutions.

#### Step 2: Initialize Population

The GA must be provided with an initial population as shown in Fig. 1. The basic call for this function is given by the MATLAB command called “**initialzega**”. This creates a

matrix of random numbers with the number of rows equal to the population size and the number columns equal to the number of rows plus 1 for the  $f(x)$  value which is found by applying the “**evalFN**” function. A total population size of 400 is used in this study.

#### Step 3: Selection

Among the three implemented selection functions, which are Roulette Wheel, Normalized Geometric Select and Tournament, Normalized Geometric Select is chosen.

#### Step 4: Reproduction

To produce the new solutions two operators, Arithmetic Crossover and Non-Uniform Mutation are used.

#### Step 5: Fitness Evaluation

The total system losses was used as the fitness evaluation function, which is an output of the lineflow software tool described in Section 3.

#### Step 6: Termination

A maximum generation criteria is used here to stop the simulation. A maximum generation of 100 is used in this study.

### 5. Simulation Results

The distribution system used in this paper is depicted in Fig. 2. The system is a modified version of the system presented in [9]. It is a balanced three-phase loop system that consists of 30 nodes and 32 segments. It is assumed that all the loads are fed from the substation located at node 1. The loads belonging to one segment are placed at the end of each segment. The system has 30 loads totaling 4.43 MW and 2.72 Mvar, real and reactive power loads respectively.

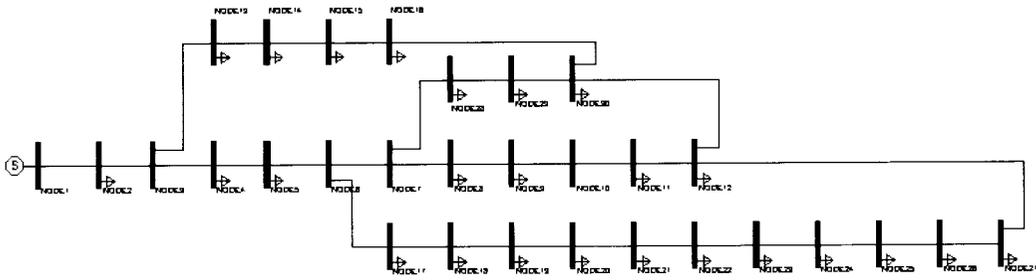


Fig. 2. Single line diagram of the test distribution system.

In order to see the best location of DG in the distribution system with the view of minimizing the total real power losses, the GAOT was used. The toolbox has reached a stable (optimum) solution with 100 iterations as depicted in Fig. 3, and corresponding detailed outputs are given in Table 1.

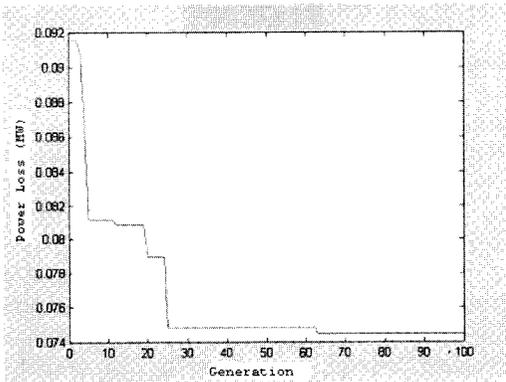


Fig. 3: GAOT output: power losses vs iterations.

Table 1: GAOT Outputs

Best Placement	Node 27
DG Size (MW)	3.143
Total Losses with DG (kW)	74.5

According to the outputs, the optimum location for a DG is node 27 and the corresponding size of DG unit and the total system losses for the given load values are 3.1403 and 0.0745 MW, respectively. Before the introduction of DG, the total system losses was 0.386549 MW.

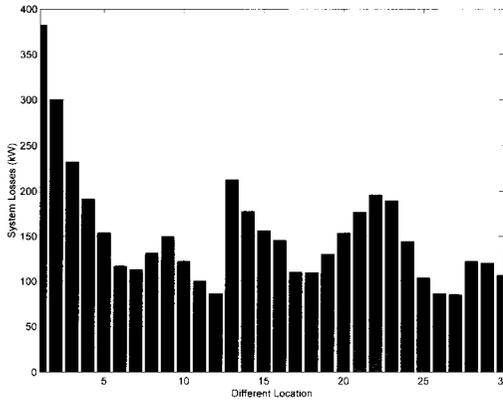
There is a drastic reduction in the losses due to the installation of DG in the system as shown in Table 2.

Table 2: Total Real Power Losses with and without DG

Without DG (kW)	With DG (kW)	Percentage Reduction
386.5	74.5	80.72%

The above results were verified using two analytical tools, namely UWPFLOW and PSS/ADEPT.

UWPFLOW is a research tool for load flow analysis of power systems, including balanced three-phase distribution system. This program was developed by the University of Waterloo and available free for research [10]. PSS/ADEPT is an interactive and integrated analytical software tool for simulating, analyzing and performance optimizing of three-phase distribution unbalanced feeders. This program was developed and maintained by Shaw Power Technologies, Inc (PTI).

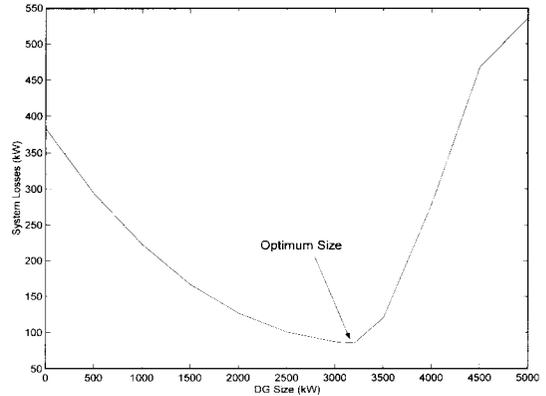


**Fig. 4:** Real power losses with optimum DG at different nodes using PSS/ADEPT.

Fig. 4 shows the total real power losses of the system for different locations of DG with the size obtained from the previous section. Notice, with the DG with optimal size at different locations, the total system losses have reduced in all the cases, ranging from 75 kW to 380 kW maximum. According to the results, nodes 12, 26 and 27 give the low real power losses. Node 27 gives the lowest losses and this is in agreement with the results obtained from the GAOT.

In order to verify the optimal size at the above location, a number of load flow simulations were carried out with different sizes of DG, starting from 0 to 5 MW. The results are shown in Fig. 5. As can be seen from Fig. 5, the minimum system losses were achieved with a DG size of 3.15 MW. This is corroborating to the result obtained with the help of GAOT. Moreover, another interesting observation can be made from Fig. 5. Notice, beyond a value of 4.2 MW of DG size, the total system losses have increased more than the system losses without DG units. The correct size of DG is playing an important role in minimizing the losses by decreasing the current drawn from the substation from a long distance.

Minimizing the losses in the system would bring two types of saving, in real life, one is capacity saving and the other one is energy saving. Other benefits of DG such as better voltage profile, higher reliability and better power quality against voltage sags and swells can be easily understood.



**Fig. 5:** Real power losses for different size of DG at node 27 using PSS/ADEPT.

## 6. Conclusions

A genetic algorithm based distributed generator placement technique in a distribution system for reducing the total real power losses in the system is presented in the paper. The genetic algorithm toolbox gives both optimal size and the locations as outputs. These results are verified using two popular load flow programs.

This study shows that the proper placement and size of DG units can have a significant impact on system loss reduction. It also shows how improper choice of size would lead to higher losses than the case without DG. However, in practice there will be many constraints to be considered in selecting the site. Given the choices, the correct sizes of DG units should be placed in the right location to enjoy the maximum technical benefits.

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