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A Mixed GA and Tree-Gradient Method for Optimization of Distributed Generation

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Abstract. Because of use of alternative energy sources, the number of small production plants connected to a distribution system tends to increase continuously, especially solar energy based on photovoltaic cells. It happens due to excess of energy production in homes, condos, trades or industries with own generation sources. The present work aims to develop a methodology to locate and size power generation units in distribution feeders so that system losses become minimal. The methodology uses initially the *tree-gradient method* to determine the total amount of power that must be injected at each network node, in order to minimize active losses. Then, a discretization process is adopted in order to allocate the whole *optimal generation* to a restricted subset of nodes that will be responsible for active generation. The methodology is complemented with a post-optimization algorithm that combines clustering, *tree-gradient method* and a Genetic Algorithm (GA) to determine the best node(s) and the respective power(s) to be injected so that losses are minimal. The main result is the set of nodes where groups of consumers with own generation should be connected.

Key words

Tree-gradients; Genetic Algorithms; Distributed Generation.

1. Introduction

In the past, most used forms of power generation were hydroelectric, thermoelectric and nuclear. The hydroelectric stations usually generated high powers; however they are usually located far from consumers, requiring the use of long transmission lines. Thermoelectric and nuclear power plants generate less power however are located usually not so far to consumption centers, compared to the hydroelectric, facilitating its use. With the popularity of wind farms and cogeneration units, occurred a change in the characteristics of generation system. Nowadays, fewer power generating units located closer to consumer centers, and directly connected to the transmission and sub-transmission are present. Currently, with the development of new technologies and supported by legislation, each consumer may be also a producer of electricity to meet its consumption and sell the surplus electricity. With this change in behavior, research focused on the distribution system have become more common, especially to evaluate the impact of this new situation in the distribution system.

In the past, many studies have been conducted to sizing and location of capacitors in distribution systems. However, unlike the installation of generating units, the capacitors can be installed in a modular way and in any point of the network, since there are no physical obstacles for its installation. As for the generating unit does not have the portability of capacitor banks, making it difficult to determine the exact location where it should be installed and its power. However, the possibility exists to indicate the best points of the system where the connection should be done for the generating units and the maximum power that each node can absorb in order to optimize an objective function. Although cogeneration units are geographically located at fixed places, it is ever possible to construct a new feeder stretch to reach the best connection point. The necessary investment may be compensated by improvements in network operation.

The goal is to divide the system into regions, determine the power that must be generated in each region and the best node at which it must be connected so that losses are minimal. Additionally, there will be an analysis of the relationship between the optimal maximum number of injections and total losses of the system in order to assess the impact of increasing the number of generating units in the objective function value.

To solve this problem it has been divided into two parts: The first part is to determine the optimum power to be injected at each node of the system, so that losses are minimal. For this task we used the gradient method [1] as optimization tool in conjunction with the method of the sum of powers for the calculation load flow [2]. The gradient method is an iterative method which through the shunt of the objective function (total loss), according to the control variable (injection of active power), and a process of linearization, calculates the power to be injected into each nodes o that the objective function reaches its minimum point. Despite being highly efficient for some types of function, methods based on gradients cannot scan the search space efficiently and may converge to local minima. This way, to determine the best nodes to inject active power, it is not efficient. Thus a discretization process was elaborated in order to make possible to overcome this issue. For this purpose, an algorithm with two steps was developed. The first part of the algorithm is responsible to divide the system into a few sets of nodes, where each set is represented by just one node considered representative to install the generating unit. For splitting of the system, an algorithm similar to that found in [3] was used, in which going through the system starting from the terminal nodes towards the substation will define the set of nodes. The second part of the algorithm determines, among the nodes of each set, which is the best to install a generation and its respective value. This task will be carried out using a genetic algorithm combined with the tree gradient method, similar to that presented in [4] for capacitor banks. In case of generating units, the problem becomes a little more complicated, because its power will depend on factors such as sunlight and wind, for example. Aware of these limitations, the algorithm implemented in this work aims to present solutions for installations of a predetermined number of generating units. The method will divide the system into regions, which define how much power should be injected, and the best node to do it.

2. Search Algorithm

A. Tree-Gradient Method

The problem addressed in this work is to minimize the total losses of the distribution system through optimal allocation of active power in the system. Firstly the objective function must be defined. As the algorithm aims to minimize total losses of the system, the function defined in (1) is adopted, corresponding to the sum of the losses in all parts of the system.

$$Loss = \sum_{i=1}^{nNode} \frac{R_i.\left(Ps_i^2 + Qs_i^2\right)}{V_i^2} \tag{1}$$

Where:
Loss – Total Losses of the System (kW);
Ps_i – Active Power summation at node *I* (kW);
Qs_i – Reactive Power summation at node *I* (kVAr);
V_i – Voltage at node *I* (V);
nNode– Number of the nodes of the system.

The gradient of the objective function with respect to the control variables (generations at the nodes) are defined by (2). Fig 1 represents a portion of the distribution system.

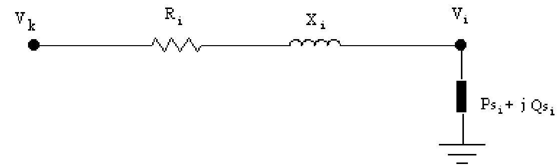

Fig.1. Reduced Equivalent Distribution System

$$\frac{\partial Loss}{\partial Pg_k} = \sum_{i=1}^{nNode} \frac{\left(2.Ps_i\frac{\partial Ps_i}{\partial Pg_k} + 2.Qs_i.\frac{\partial Qs_i}{\partial Pg_k}\right).V_i^2 - \left(Ps_i^2 + Qs_i^2\right).2V_i.\frac{\partial V_i}{\partial Pg_k}}{V_i^4} \tag{2}$$

Where:
Pg_k – Active power generated at node *k*.

After calculating gradients the search equation for the method is defined by (3):

$$Pg_i^t = Pg_i^{t-1} - Step.\frac{\partial Loss}{\partial Pg_k} \tag{3}$$

Where:
P_g^t –Liquid active power ;
t – Iteration;
Step – Step of the method;
$\frac{\delta Loss}{\partial Pg_k}$- Gradient.

The gradient method determines the active power injections so there is a decrease in total losses. However, to evaluate the impact of each active power injection in the system it is necessary to perform a load flow calculation. For this purpose the forward backward sweep method for distribution systems ([5]) was adopted.

The application of the method starts from the definition of which nodes must supply power and what should be the corresponding limit. Considering known the system circuit data, the following algorithm provides the optimal generation:

ALGORITHM

B. Initialize the variables;
C. Perform a iteration of load flow calculation;
D. Using (1) and choosing a convenient step, calculate the increment of active power that will be injected into the node;
E. Check the operational limits;
F. Return to ii until convergence is reached.

B. Post Optimization *Method*

Applying the gradient method explained in section A to a system with *n* nodes, and considering that all nodes are candidates for active power injection, the process provides the active power to be injected at each node of the system so that the point of minimal losses is reached. However, injecting power into all nodes is something technically unfeasible. Thus, it is appropriate to decrease the number of candidate nodes to supply power, so the value after reduction of losses is as close as possible to the minimum value.

Figure 2 shows part of a distribution system, where nodes 56, 55 and 51 are terminal nodes. This system has been submitted to complete the gradient method with all nodes receiving active power, and for each node is assigned an optimum power to be generated, (G_i). It is desired to determine a set of nodes where only one receives a power generating unit. For this task, the algorithm starts of the end nodes towards the source, by adding the active powers to each of them, when the sum value becomes greater than the generator unit (GU), define a candidate set of nodes to receive a generated unit, ie a cluster, as shown in Fig 2. Restarts the process, starting from the sequential to the last node before computed in the previous step, until the sum of the potential of each node pass to be greater than another generated unit. The process ends when all the nodes are covered, or when all generating units are contemplated. In the following the algorithm is presented formally

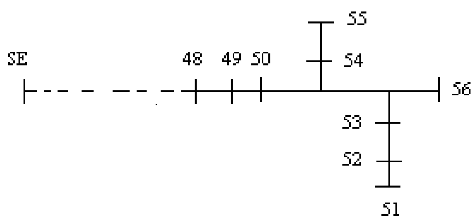

Fig. 2. Radial Distribution System

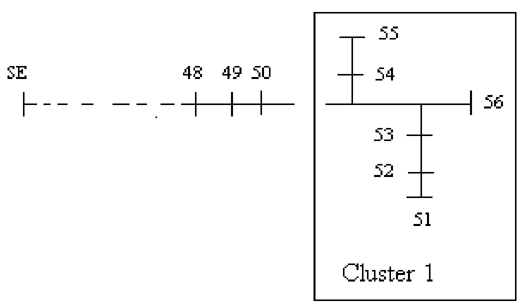

Fig. 3 Split System

ALGORITHM

i. Initialize the variables;

ii. Performs a optimal load flow calculation by Gradient Method;

iii. Determine the number of the generator unit and the respective active power;

iv. Starting of the end nodes and moving toward the substation, define the clusters;

v. Finalize the process.

C. *Genetic Algorithmic*

In this paper, the genetic algorithm (GA) has the function of choosing, in each cluster, the best node that you must install a generator associated with it. To better explain the procedure, suppose a feeder where you want to install three generating units. After applying the gradient method and the post optimization algorithm, the system is divided into three sets of nodes. For each set the AG will determine the best node to install the generating unit and its value. Thus, an individual can be defined by a vector with three elements. The first element represents the first set of candidate nodes, the second element will be the second set, and so on. Fig. 04 shows an example of characteristics of an individual.

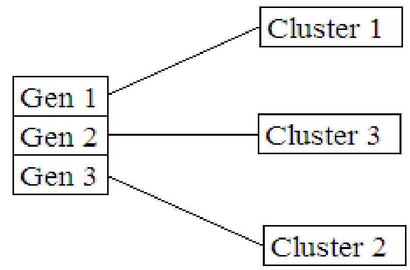

Fig. 4. Individual Caracterization

Characterized the individual, one performs an optimal power flow by tree-gradient method, but the only nodes are authorized to receive the power that makes up the individual. After the calculus of optimal power flow for the individual, as a result have to his fitness and active power that should be injected at each node of his. With the characterization of an individual and determining his fitness, the next step for implementation of the algorithm is the definition of the process of crossing between them. Randomly choosing two individuals (parents), the new individual (child) is determined by doing a lottery at each gene. Figure 04 illustrates two children generated from a cross between two parents. To create the children, do it to each gene. For example, Gene 01 from parent 1 is the node 2 and, from the parent 2, is node 07. Making it a lottery between them, the winner will compose gene 01 of son 1 and the other will be the gene 01 of the son 2. Repeating the process for each gene, at the end, it has two sons.

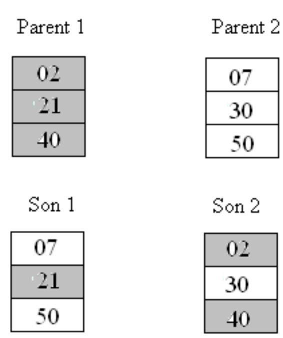

Fig. 5 Crossover exemple

In addition of the crossover, mutants will be generated. The mutant is an individual where one or more genes are changed randomly. To generate a mutant, an individual is chosen randomly. Each individual gene may also be selected randomly. If the gene was selected, the corresponding node is changed by another from the same cluster, chosen randomly too. This process is performed for each gene. Defining the mutant, a load flow calculation is carried out to determine its new features.

Defined the individual, the process of crossover and mutation, follows the algorithm below for the method.

ALGORITHM

i. Define a initial population;
ii. Perform an optimal load flow calculation by the gradient, determining the fitness of each individual and the active power that will be generated at each gene node;
iii. Sort the individuals;
iv. Splitting the population into two groups, perform the crossover between two individuals selected randomly from each group, generating two *children*;
v. Perform an optimal power flow calculation by gradient and determine the fitness of every children and the active power generated at each node;
vi. Generate a number of mutants determined by a mutation rate previously chosen;
vii. Sort parents, children and mutants, eliminating individuals with lower fitness, keeping the original size of the population;
viii. Repeat the process until the maximum number of generations is reached;
ix. Choose the individual with the best fitness such as optimal solution.

D. Global Algorithmic

After presenting each individual optimization algorithm, the full algorithm is described below.

ALGORITHM:

i- Load the system characteristics and initial parameters of the method;
ii- Perform a optimal load flow calculation by gradient method, defining the optimal active power to be injected at each node;
iii- Apply the post optimization algorithm to define the clusters;
iv- Apply the GA to choose the best configuration.

3. Results

To test the method has been chosen two local distribution systems of 13.8kV. The first with 87 nodes, an installed capacity of 2MVA and total losses of 90kW, the second has71 nodes, an installed capacity of 2.5MVA and losses of 370.0 kW.

Table I shows the main results of the two systems for the base case and for the global optimum, where the optimal active power, result of applying the gradient method, is injected into all nodes of the system without restrictions.

TABLE I. COMPARATIVE OF CASE BASE AND OPTIMAL RESULTS

	Max. Volt. Deviation(%)	Total Losses (kW)	Total Distributed Gener. (KW)
C. Base	0.907	90.00	0
Global Opt.	0.992	8.53	1,480.00
C. Base	0.742	370.0	0
Global Opt.	0.968	44.99	1863.00

Table II shows the results of the system 1 after optimization, considering the installation of three generators. In the table, nodes 1, 2 and 3, shows in which node system was allocated active power and then the power injected into each of them, the total injected and losses.

TABLE II. POST OPTIMIZATION RESULTS FOR SYSTEM I

Configurations			Injected Power			General Results	
Node 1	Node 2	Node 3	1° Node	2° Node	3° Node	Min. Volt.	Total Losses
6	9	29	356	292	325	0.95	29.64
6	60	11	291	402	330	0.88	32.84
23	56	11	0	169	323	0.86	38.60

Table III shows the same data as in Table II, but now only the results of the system 2 simulation.

TABLE III. POST OPTIMIZATION RESULTS FOR SYSTEM II

Configurations			Injected Power			General Results	
Node 1	Node 2	Node 3	1° Node	2° Node	3° Node	Min. Volt.	Total Losses
4	7	12	468	843	687	0.91	59.66
32	7	49	50	1568	2	0.87	104.89
4	7	42	604	800	10	0.86	100.60

Table IV is a comparative to the case of generating allocation only in one node of the system, in two nodes, three nodes, and all nodes of the system.

TABLE IV. COMPARATIVE OF THE TOTAL LOSSES WHITH DIFERENT NUMBER OF GENERATIONS

	Total Loses (kW)			
Number of Nodes	1 Nodes	2 Nodes	3 Nodes	All Nodes
System 1	50.6	33.58	29	8.53
System 2	106.13	101	59	44.99

4. Conclusions

After adopting a gene, it is not guaranteed that the result found is the global optimum. Analyzing the results and comparing with the method of gradient overall, we note that the values obtained are very close to the global optimum. I.e., the same result will not be the global optimum for that setting, it is very close to a solution overall. In all optimizations there was an improvement in voltage profile.

When increasing the number of generators to be installed, the benefit achieved is not proportional. For example, in table IV, system II, losses for 3 nodes is 59 kW and for all nodes is 44.99 kW.

In this work it was not considered the load variation during the day, the only method for performing load. An evolution of this work will consider a typical load curve for calculation of power injections.

Another weak point of the algorithm is the choice of the step to be applied to the gradient method. Poorly chosen steps can lead to non-convergence of the algorithm or slow convergence. A further development of this work is the use of Newton's method by replacing the gradient one in order to verify computational efficiency is obtained.

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