A METHOD FOR DEFINITION OF THE ACTIVE POWER LIMITS OF DISTRIBUTED GENERATION THROUGH AN OPTIMAL STRATEGY

Manoel F. de Medeiros Jr. — UFRN – Brazil — E-mail firmino@dca.ufrn.br

Max C. Pimentel Filho — UNP – Brazil — E-mail maxchianca@hotmail.com

Clóvis B. M. Oliveira — UFRN - Brazil — E-mail clovisbosco@yahoo.com.br

ABSTRACT

Distributed generation is already a reality in almost all countries in the world. Wind farms, cogeneration systems and SHP (small hydropower) are already common elements that can be connected to medium voltage systems (up to 15kV). Additionally, with the development of technology and reduced costs, it is expected that the number of generations connected to the network increases, whether coming from solar collectors, biomass, SHP, wind, or any other kind which will become popular. Based on this premise, a new problem arises, what is the best place for each connection to the network. This work aims to develop a method that will determine the best connection point for each generation to the distribution network in order to achieve a reduction in active power flows in its sections, so that, the global network loading becomes minimal.

INTRODUCTION

Energy resources such as wind, biomass, cogeneration, solar, among others, have become more used, reducing cost of deployment and production. Thus, the configuration of the electricity sector has changed and is more common small producers directly connected to the system of sub-transmission or distribution.

The use of various sources of energy connected in different access points by energy producers, directly to the distribution network, is known as Distributed Generation (DG) [1].

The appropriate penetration of this kind of generation in power systems is reported as a challenge in conferences and papers published and in other important discussion forums in the area of power systems in recent decades [2]. From the viewpoint of the distribution network, the connection of DG units can cause positive or negative impacts at the voltage stability, levels of power flows on lines and transformers and at energy quality supplied by utility company. On the one hand, the injected power can support the voltage profile and stability of the system. On the other, can cause overvoltages [3], momentary voltage sags, fluctuations in the power factor [4], harmonic pollution, increase the generation cost [5] and in the case of single-phase generators, grid voltage unbalance.

Consider a medium voltage (MV) distribution system with the possibility of independent producers connecting to it. The problem that is proposed to solve is to determine the connection point of each producer, and the power generated by it so that the current lines are as small as possible. As consequence, there is a reduction of losses, relieving the feeders and delaying new investments to increase the ability of drivers or construction of new lines.

Due to the location of available energy resources, access requests by producers are directed to different buses of the distribution network. Thus, in the case of multiple requests for access, it is necessary that should be establish a criteria for defining the active power injected into the connecting buses. The determination of these power, although they may be different for each producer shall not violate the principle of treatment isonomic observed distribution by the utility. It is possible to systematize the access of producers, based on clearly defined criteria, all of which are submitted.

In order to assign the different powers to be injected an algorithm similar to that proposed by [6] will be used. It combines the classical gradient method in conjunction with a modified genetic algorithm so that the best connection points will be also found. The function to be optimized is the sum of the squares of the currents in all stretches. This way the minimal loading is pursued.

PROBLEM DEFINITION

A traditional distribution feeder consists of a MV line with laterals connecting a HV/MV substation to consumption points. The circuit model for simulation considers each customer connected to a node and the stretch between two nodes as a branch. The node is represented by known loads, and the stretches represented by two nodes connected by an electric line. In this work, it is considered that the generators to be connected are distributed at points relatively close to some nodes of the feeder.

The problem to be solved is to determine what the best node to connect the generation is, and how much power should be injected in order to maintain the current magnitudes in sections (stretches) as small as possible. In this work, just the maximum system loading is considered. Once the generation units are geographically located at different points near the feeder, just a couple of nodes are able to each connection. This was taken into account in order to provide a more realistic simulation, but in principle each generator unit could be connected to all nodes.

Maximization of distributed generation is a problem of optimal expansion of generation, however, in this case, no upgrade in network topology, ie, without additional investments in the distribution network is considered.

The algorithm presented in this work evaluates the optimal level of generation penetration in the network, determining the best access points and their limits of active power injection. The criteria that guided the search were the optimal level of loading of the sections between the nodes.

Thus, the proposed method is based on two search steps: a) determining which buses access and their respective active power injection, by gradient method b) designation of the producers to best buses, by genetic algorithm.

As objective function it was decided to adopt the equation 01 which represents the sum of the squares of the currents of all sections of the feeder.

$$fo = \sum_{i=1}^{Nbranch} i_{x_i}^2 + i_{y_i}^2 \qquad \text{(eq. 01)}$$

a) Determining which buses access and their respective limits of power injection by gradient method

The gradient method is extremely effective in optimizing convex functions, finding the optimal point easily. However, by functions that have local minima the gradient method may not be efficient because it can't explore the full search space. In this work, the gradient method is used in conjunction with a genetic algorithm. The gradient method assumes eq. 01 as the objective function and the active power generated (Pg_i) as a control parameter. As the active power generated can be modeled by an admittance multiplied by the square of the node voltage (V_i) module, according to eq. 02, the admittance was used as control variable. This choice has been made in order to increase the accuracy in the calculation of the gradient.

$$Pg_i = G_i.|V_i|^2 \qquad \text{(eq. 02)}$$

By the gradient method, the search equation is defined by eq. 03.

$$x_i^{t+1} = x_i^t + \propto . \frac{\partial fo}{\partial x_i} \qquad \text{(eq. 03)}$$

Adapting eq. 03 for the proposed problem and presenting in matrix form, one has eq. 04.

$$\begin{bmatrix} G_1 \\ \vdots \\ G_n \end{bmatrix}^{t+1} = \begin{bmatrix} G_1 \\ \vdots \\ G_n \end{bmatrix}^{t} + \propto . \begin{bmatrix} \partial fo / \partial G_1 \\ \vdots \\ \partial fo / \partial G_n \end{bmatrix} \qquad \text{(eq. 04)}$$

b) Assignment of producers to optimal buses

The application of a genetic algorithm will enable the exploration of the search space efficiently, supplying a deficiency of the gradient method. For the modified GA proposed in this work, the individual will be defined as a set of nodes. The size of this set is equal to the number of possible network accesses. For example, if a system could be accessed by the three generating units (DG1, DG2 and DG3) as in Figure 01, the size of the set will be three.

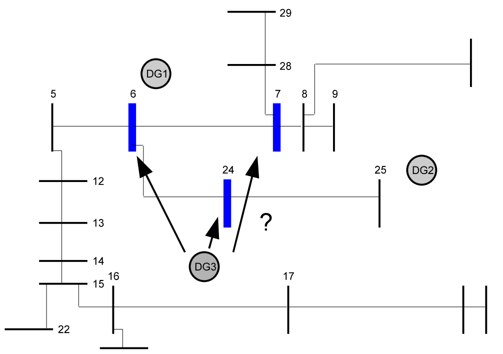

Figure 01. Radial network with three energy producers (DG).

After determining, randomly, each node to compose the individual, an optimal load flow calculation by the gradient method is performed for evaluate its fitness. The nodes that compose the individual may generate active power during the optimization process. As a result, the load flow calculation will determine the optimal value of active power to be allocated at each node, in order to minimize the objective function.

Table 01. Optimal load flow algorithm results for a individual, determining the active power injection at each node, and their respective evaluation.

Individual	Active Power	Fitness/Evaluation
Node 24	P1 kW	Fo
Node 06	P2 kW	
Node 07	P3 kW	

After evaluating an individual, the value of fitness is deposited in a vector of pheromone like as the ant colony algorithm, in the positions of the nodes that compose the individual.

After all individuals have been evaluated, they are sorted and divided into two groups of equal size. The first group consists of individuals with the best fitnesses, and the second the worst. The selection process is achieved choosing randomly an individual from the first group and another one from the second. Then, a crossover between them is implemented. For each crossover, only one child is generated. After all children have been generated, the worst set of the individuals is replaced for the set of the new children.

The crossovers are carried out gene-gene by a roulette wheel weighted by the pheromone. For each node, a fitness proportional value is deposited at the pheromone vector. Nodes with high pheromone value have more chance to be chosen than those with low value. At each iteration, a mutant individual may be generated by random changing one or two genes (nodes).

PROPOSED ALGORITHM USING GA

The complete algorithm consists of the steps described below.

1. Read input data;
2. Determine for each generator the set of nodes that will be able to be accessed;
3. Generate randomly a set of individuals, each one with three genes. The first gene determines the connection point of the first generating unit; the second corresponds to the second, and so on;
4. Run an optimal power flow for each individual. Deposit the fitness of each individual node in position of each gene in the vector of pheromone;
5. Sort by individuals and their ability and divide them into two sets;
6. Perform randomly crossover between the two sets, through a roulette weighted by pheromone;
7. Generate a mutant according to the rate of change;
8. Replace all children of lesser ability and mutants;
9. Return to step 4 until the maximal number of iterations is reached;
10. Provide the results of the top five individuals to the user.

SIMULATION RESULTS

The proposed method was tested simulating a local system with 87 nodes and an installed capacity of 3.0 MW, as shown in Figure 02.

Table 02 presents a summary of two simulation results, the first considering the base case and the second the optimized case by the gradient method, considering all nodes as candidates to receive active power. This table aims to compare the results of two extreme cases with the proposed method. The base case would be the worst case and the case without any intervention would be optimized by the gradient of the best result that can be achieved through the allocation of active power in the system.

Table 02. Simulation results of base case and injection of active power by unconstrained optimal load flow.

Branch/ Node	Base Case (amp./volt.)	Optimal (amp./volt.)	Variation (%)
2	70 A	26 A	62.3%
5	29 A	3 A	89.9%
72	8 A	3 A	60.9%
2	13.5 kV	13.7 kV	1.1%
7	13.0 kV	13,7 kV	5.0%
72	12.6 kV	13.7 kV	9.3%
Objec. Func.	346	42.7	87.7%
Perdas (kW)	90.4	10.4	88.5%

Table 03 shows the results of the constrained optimal load flow for the best individual. The AG parameters are: 20 individuals, 10 generations, mutation rate of 5%, and crossover of 100%.

Table 03. Comparison between the results of the best individual defined by the proposed method and the global optimum.

Node/ Branch	B. Solution (amp./volt.)	G. Optimal (amp./volt.)	Variation (%)
2	26 A	26 A	~-1%
5	6 A	3 A	54.9%
72	3 A	3 A	1.0%
2	13.7 kV	13.7 kV	0.1%
7	13.7 kV	13.7 kV	0.2%
72	13.7 kV	13.7 kV	0.5%
Objec. Func.	68	42.7	37.8%
Loss (kW)	21.4	10.4	51.5%

Finally, Table 04 presents the list of best five solutions.

Table 04. Four best individuals defined by the algorithm.

Individual	Losses (kW)	Obj. Function
[6 14 40]	20.3	63.2
[6 11 40]	20.7	63.6
[40 72 58]	19.3	64.2
[40 11 56]	20.7	65.4

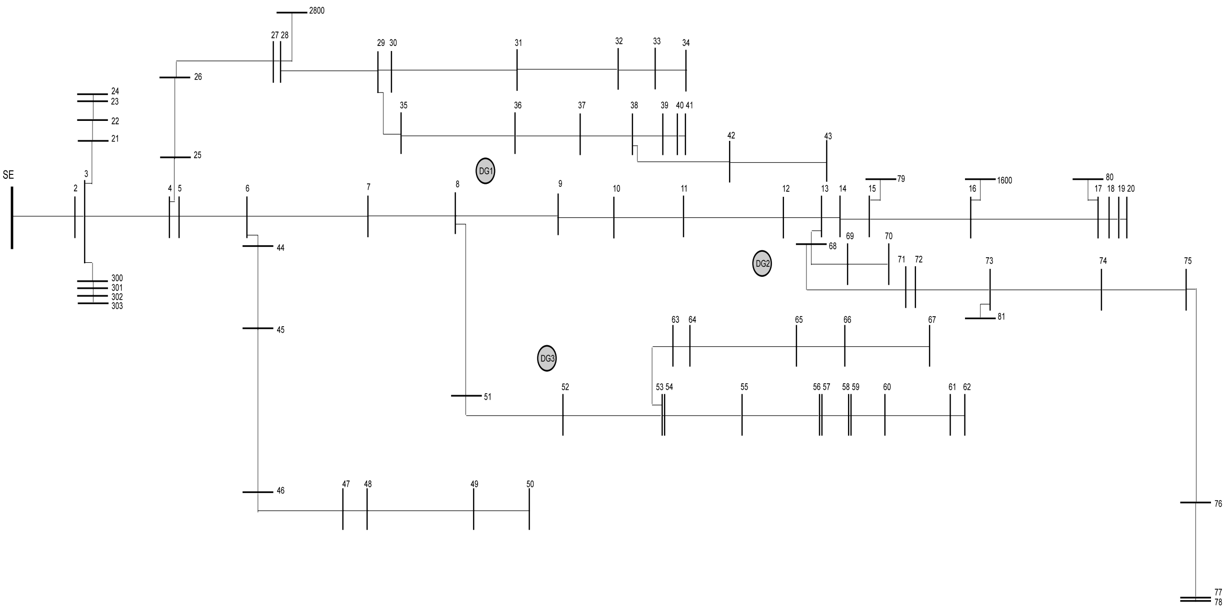

Figure 02. Radial network consists of 87 buses with three independent producers making up the distributed generation system called GD1, GD2 and GD3.

CONCLUSIONS

According to the results one can conclude that the presented method, even using just three units, achieves good results when compared to the base case and the global optimum. It must be here pointed out that a substantial improvement in the total losses was obtained, if compared with the base case. It is expected that with the increased number of units, tends to improve this result. All stretches presented reductions in current with respect to the base case. Stretch 5, for example, decreased its loading by approximately 90%, and in the stretch 2 decreased the current from 70 A to 27 A. Analyzing the voltages, they also improved, getting closer to the rated value. Although the method does not guarantee the global optimum, the results were encouraging. However, one of its shortcomings is the step adjustment for the application of the gradient method. Higher values lead to divergence and low values lead to a slow process. For future works, Newton's method should be used instead of gradient. Because of power delivery systems present varying loads, a new solution should include variable loads during the day. Certainly, with the application of the method, the feeders can operate with lower current levels, reducing losses and increasing the period of use of the stretches, without the need of retrofit.

REFERENCES

[1] T. Ackerman, G. Andersson and L. Söder, 2001. “Distributed generation: A definition”, Electric Power Systems Research 57, 195–204.

[2] D. Singh, D. Singh, and K S Verma, 2008, “Comparative Analysis for Penetration of Distributed Generation in Power Systems”, *IEEE International Conference on Sustainable Energy Technologies, ICSET*.

[3] J. Morren and S. W. De Haan, 2009, “Maximum Penetration Level of Distributed Generation without Violating Voltage Limits”, *CIRED*, paper 0271.

[4] C.B.M. Oliveira, J. T. de Oliveira and M.F. de Medeiros Jr., 2009, “New Method based in Particle Swarm Optimization for Power Factor Remote Control and Loss Minimization in Power Systems with Wind Farms Connected”, *15th International Conference on Intelligent System Applications to Power Systems, ISAP '09.*

[5] M. Alhajali, M. Cregan, D. Flynn and D.J. Morrow, 2008, “The impact of generation mix on scheduling of power systems with high wind penetration”, *Universities Power Engineering Conference, UPEC*, pages 1-5.

[6] M.C. Pimentel Filho, M.F. de Medeiros Jr., 2011, “Optimal placement of various voltage regulators by means of sensitivity parameters from a radial load flow”.. *Electrical Power and Energy Conference (EPEC).*