MAXIMISING PENETRATION OF ACTIVE POWER BY DISTRIBUTED GENERATION ON A REAL SYSTEM

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ABSTRACT

The aim of this work is to analyze the penetration of distributed generation in a high voltage (69 kV) distribution system taking as example the network named "Regional Natal" in Rio Grande do Norte State, Brazil. The methodology is based on an economic dispatch study, considering objectives as minimal losses, minimal risk of operational violations, and maximal individual penetration. A 14 bus IEEE network is also tested. The optimization problem is solved by the Particle Swarm Optimization algorithm. A methodology is proposed for defining maximal active power can be injected into pre-defined buses of grid.

INTRODUCTION

The global energy security and environmental concerns has induced several governs to encourage electrical production from renewable sources [1]. The actual Brazilian electrical grid has hydraulic predominance. In the future, the national strategic planning consider still this predominance and, for necessary complementation, increasing the participation of others renewable sources, in detriment of fossil fuel. Biomass, wind and solar potentials, abundant in the country, are already transformed in available electric energy, through specific auctions from alternative sources, as the biomass auction, occurred in 2008, and the wind energy auction, occurred in 2009. These renewable sources, apart from natural gas – not renewable, but less destructive on environmental relatively to others fossil sources -, tend to have major participation in national generation park, with generators directly coupled to National Interconnected Systems – NIS, or to regional systems, at several voltage levels [2].

This utilization of energy resources in different localizations, with generators connected to distribution electrical networks, directly, or through customer installations, dispatched or not by National Systems Operator (NSO), designated as Distributed Generation (GD) causes impacts of different nature when compared to traditional generation [3]. The proper penetration of distributed generation (DG) in power systems has been reported as a one of challenge in IEEE transactions and conference papers and in other important forums about this theme for over a decade [4]. From the perspective of the distribution grid, the connection of DG may cause both positive and negative impacts – depending on the considered case –, on voltage profile and stability, on lines and transformers flows, on protection selectivity, and on the power quality.

Due to the location of available energy resources, the access requests by producers may be directed to different buses of the distribution network. Impacts on the grid when several generating units in this case are different when compared with the connection of only one unit, separately. Thus, the Utility must define the values of the maximal powers to each producer. The question is to define these values, without violating the principle of equal treatment that should be observed by the distribution Utility. This is possible with the systematization of the accesses of the producers, based on well defined criteria, to which everyone will be submitted.

This work aims to examine the penetration of distributed generation on a typical high voltage (69 kV) distribution system, located in the Rio Grande do Norte State, in Brazil. The proposal includes the development of a methodology for defining maximal active power can be injected into pre-defined buses of the grid considering the possibility of multiple access of generating units. The definition of these maximal values is obtained from an optimization study, formulated as an optimum load flow that considers minimal losses, maximal individual penetration, and minimal risk of violations. This way, the proposal provides equal technical criteria for defining percentage limits at generation of independent producers based on an impartial criterion. Particle Swarm Optimization algorithm is used to address the problem of optimization proposes.

THE OPTIMIZATION PROBLEM

Optimal power flow (OPF) is a generic term introduced by Dommel and Tinnney [5] to designate a broad range of problems, in order to optimize specific operational functions. In economic dispatch problem the aim is to find out an optimal setting of generation units, respecting system operational constrains. In general, the objective is the optimization of the total operational cost that may be expressed by a function. The main involved economic factors are generators operational costs, especially fuel, if thermoelectric units are present. Alternatively, the transmission active losses may be the objective. In all cases, the optimum depends on different values of units active powers [6].

Traditionally, reactive power injection can be used to control losses [7] [8]. The same way, the DG units may

absorb reactive power to limit the voltage increase they cause [9]. This study however considers just the active power injections, assuming that the generators operate at unity power factors.
The considered optimum for purposes of this work is the highest active power that may be delivered to the distribution network by each one of the set of generation units, without bringing additional onus to the distribution Utility. Thus, global losses caused by the presence of DG should not exceed those of the base case, that is, without the presence of DG. From the Utility's point of view, unit production costs of the different producers are not relevant. These costs are not considered here.

PROBLEM FORMULATION

Mathematically, the problem will be solved through minimization of the objective function *Fob*, with three criteria of optimization: maximizing the penetration of generation (f_{dg}); keeping the losses of the system closer of that of the base case (f_{losses}); prioritizing the solution with node voltages closer of the media of the limit values (f_v). The partial objective functions are described by equations 1, 2 and 3:

$$f_{dg} = \sum_{i=1}^{n} (1 - P_{gi} / P_{nom,\ gi}) \quad (1)$$

were:
n: number of buses
P_{gi}: generated active power at the bus i
$P_{nom,\ gi}$: nominal active power of DG at bus i

$$f_{losses} = \frac{(Losses - Losses_{CB})^2}{Losses_{CB}} \quad (2)$$

Were: *Losses* – calculated losses at each iteration of the whole algorithm; $Losses_{BC}$ – losses of the base case.

$$f_V = \sum_{i=1}^{n} (V_i - V_{ref})^2 / Vref \quad (3)$$

Were: V_i – Voltages of the buses calculated at each iteration of propos algorithm; V_{ref} – reference voltage (equals to the media of limit values).

Through penalty function ($f_{penalty}$), to be added to f_{dg}, three types of constraints are considered: limiting system power losses; keeping the voltage system between maximal and minimal values (0.9/1.1 p.u.); and avoiding overload on branches. The global objective function is:

$$F_{ob} = f_{dg} + f_{losses} + f_v + f_{penalty} \quad (4)$$

$$f_{penalty} = a.p_{losses} + b.p_{Vmax} + c.p_{Vmin} + d.p_{Imax} \quad (5)$$

were:
p_{losses}, p_{Vmax}, p_{Vmin} and p_{Imax} – penalty terms from losses, maximal voltage, minimal voltage and overload constraints, respectively, calculated for each particle at each iteration of the proposed algoritm;
a, b, c, d – weighting coefficients.

The penalty terms are computed as:

$$p_{losses} = \frac{Losses - Losses_{CB}}{Losses_{CB}} \quad (6)$$

$$p_{Vmax} = \frac{\sum_{i=1}^{n} (V_i - V_{max})}{V_{max}} \quad (7)$$

$$p_{Vmin} = \frac{\sum_{i=1}^{n} (V_{\min} - V_i)}{V_{min}} \quad (8)$$

$$p_{Imax} = \frac{\sum_{j=1}^{b} (I_j - I_{max})}{I_{max}} \quad (9)$$

Were: *Losses* – losses, calculated for each particle at each iteration; $Losses_{CB}$ – losses of base case; V – voltage calculated from node i for each particle at each iteration; V_{max} and V_{min} – maximal and minimal acceptable voltages for node i; I – current calculated from branch j for each particle at each iteration; b – number of branches; I_{max} – thermal limit for branch j.

Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an algorithm developed by Kennedy and Eberhart inspired in the social behavior of a bird flocking [10]. Groups of individuals reach some objective, like finding of food, by means of cooperation. Supposing an n-dimensional search space the PSO technique may be summarized as following:

- Each member is named a particle, and each particle (e.g., j-th particle) is represented by an n-dimensional vector, and may be described as $X_j = [x_{j1}, x_{j2}, \ldots\ldots, x_{jn}]$. In this work, for minimizing f_{dg}, the particle position X represents the value of active power P_{gi} calculated for the DG units. The vector dimension n corresponds to number of buses of the analyzed network (i is the numeral of each bus).
- The set of m particles in the swarm is called population, and is described as pop = $[X_1, X_2, \ldots, X_m]$. Here, the PSO was simulated with four particles.
- The best previous position for each particle is described as $Pbest_j = [pbest_{j1}, pbest_{j2} \ldots, pbest_{jn}]$.
- The best position among all particles, achieved so far, is called *global best* and described as $Gbest = [gbest_1, gbest_2, \ldots, gbest_n]$.
- The rate of position change for each particle is called *particle velocity* and described as $V_j = [v_{j1}, v_{j2}, \ldots, v_{jn}]$.
- At iteration k the velocity for each i-bus of j-particle is updated by:

$$v_j^{k+1} = w * v_j^k + c_1 * r_1 \left(pbest_j^k - x_j^k\right) + c_2 * r_2\left(gbest^k - x_j^k\right)$$

Where w is the inertia weight, c_1 and c_2 are the acceleration constants, both equal to 2.1 in this work, and r_1 and r_2 are two random values in range [0,1]. The inertia weight w was set in 0.9.

- The j-particle position is updated by:

$$x_j^{k+1} = x_j^k + v_j^{k+1}$$

The new values of particle positions are tested into the objective function f_{dg} until stopping criterion is achieved. The global best represents the solution.

Proposed Algorithm

The followed algorithm meets the steps previous mentioned.

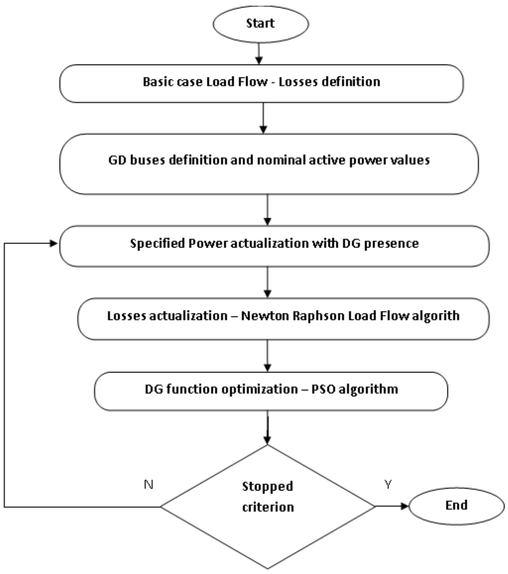

Fig 1 – Flow chart for implementation of the algorithm.

SIMULATION RESULTS

Network characteristics

The proposed algorithm was applied for the problem of maximizing penetration of distributed generation in a high voltage (69 kV) distribution system located in Rio Grande do Norte State, Brazil. The network has 25 nodes and 42 branches. The loads are represented by high voltage customers (69 kV) and distribution substations (69 kV/13.8 kV) that supplies urban and rural areas. The system may be considered as weakly meshed. There are no generators in the base case. The slack bus is the boundary with the transmission system, which supplies the total load of 457 MW, including active losses.

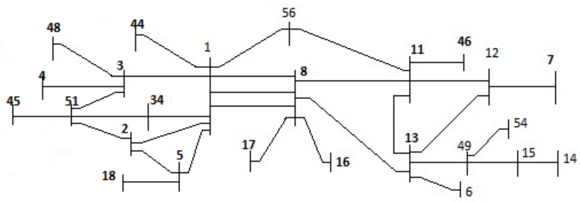

Fig. 3 – Distribution system – R. G. do Norte, Brazil.

Results

The insertion of distributed generation was tested for several buses in the shown part of system, ever at the pairs. The authors adopted 70 MW and 105MW as nominal values of active power of the generators, at all 175 MW, corresponding to about 40 percent of the total active demand. This percentage is enough great to meriting analysis impacts on the network.

Tables 1 and 2 present results for different sets of buses of submitted to test : bus 7 with bus 56, resulting in a maximal penetration of active power of about 150 MW; and bus 7 with bus 18, resulting in a maximal penetration of active power of about 100 MW. The base case losses are 6 MW.

Table 1: Percentage of Maximal penetration of GD – R. G. do Norte system . DG7-70MW and DG56-105MW (rated values)

Simulations	1	2	3	media
iterations	7	9	8	8
Percentage of DG (DG/DG nominal)				
DG7	66,5%	68,1%	67,9%	67,5%
DG56	100,0%	99,6%	100,0%	99,9%
Relative losses to base case	97,8%	99,8%	99,7%	99,1%

Table 2: Percentage of Maximal penetration of GD – R. G. do Norte system . DG7-70MW and DG18-105MW (nominal)

Simulations	1	2	3	media
iterations	9	8	9	9
Percentage of DG (DG/DG nominal)				
DG7	58,5%	61,3%	61,4%	60,4%
DG18	58,4%	58,7%	58,7%	58,6%
Relative losses to base case	97,1%	99,1%	99,9%	98,7%

The algorithm was also tested using on the 14 bus IEEE system, network with different characteristics in respect to the first. In this case, the buses 3 and 4 were selected to simulate injections, because they presented the lowest voltage at the base case. After power penetration, the active losses resulted lower than those of base case (13 MW).

Table 3: Percentage of Maximal penetration of GD - IEEE 14 bus system. DG3-20MW and DG4-30MW (rated)

Simulations	1	2	3	media
iterations	4	5	5	5
Percentage of DG (DG/DG nominal)				
DG3	82,1%	80,0%	85,5%	82,6%
DG4	57,9%	54,2%	51,8%	54,6%
Relative losses to base case	71,6%	72,6%	72,2%	72,1%

At each iteration of the algorithm a complete Newton Raphson load flow is performed. The PSO is stopped when the global best particle is not changed for 30 continuous iterations, or before, if the velocity of the particle falls under a predetermined tolerance. Fig. 2 exemplifies the iterative process to obtain the optimal values using the particle swarm optimization algorithm for the first pair tested. The best global position among the particles corresponds to the optimal objective function value and represents the set of active powers of generators that reaches the maximal penetration on the entire network.

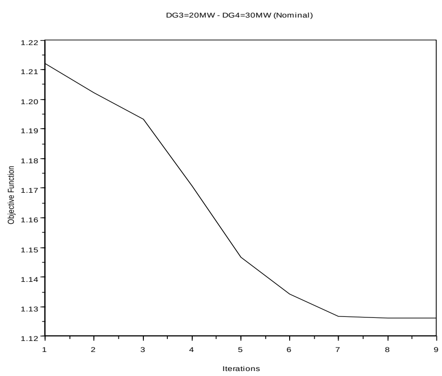

Fig. 2: Objective Function Value X iterations – IEEE network with GD3=20MW and GD4=30MW (nominal)

CONCLUSIONS

This study provides a methodology that can indicate the absorption capacity of generators in points defined within the studied regional system, considering the current normal configuration and contingencies and future configurations, and can serve to studies of planning of the operation and expansion of the grid, as well as reference to target other studies such as power quality and transient electromagnetic.

Metaheuristic algorithms may produce different results each simulation. However, the methodology embedded in the PSO proposal has small errors between the various simulations presented.

Acknowledgments

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