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Impact of Distributed Generation in the Transmission System Expansion Planning

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Abstract

In this work, the impact of distributed generation in the transmission expansion planning will be simulated through the performance of an optimization process for three different scenarios: the first without distributed generation, the second with distributed generation equivalent to 1% of the load, and the third with 5% of distributed generation. For modeling the expanding problem the load flow linearized method using genetic algorithms for optimization has been chosen. The test circuit used is a simplification of the south eastern Brazilian electricity system with 46 buses.

Keywords: Distributed Power Generation, Power Transmission Planning, Genetic algorithms

1. Introduction

Brazil is the largest country in Latin America, having a land area of 8,514,876.4 km2, endpoints of 4300 km of distance between themselves, and 190 million inhabitants [1]. The Brazilian generation park currently consists in 134 hydroelectric plants, 93 thermoelectric plants, 485 small hydro, 187 biomass plants, 56 wind farms and one solar plant, in addition to the excess production of Itaipu imported from Paraguay totalling 111,618 MW installed [2].

In 2012 the growth of electricity consumption in Brazil was of 3.5% according to the data from EPE (the Portuguese abbreviation for the Energy Research Company) released in [3], led by the growth in segments of trade and services (+7.9%) and of the residential sector (+5.0%), while the industrial remained stable. The increase of the system load was of 4.2%, - 0.7 percentage points above the increase in consumption, which is associated with the fact that commercial and residential sectors are mainly assisted in low voltage, causing a greater loss rate.

Due to the growth of the demand, transmission systems must follow that growth through improvements, which in Brazil is done based on the generation expansion [1]. Table I presents data for the estimation of the growth transmission lines (km) during the period 2012-2021 [4]. Figure 1 shows the planned investments for construction of transmission lines and facilities until 2021.

The expansion planning of the transmission system solves the problem of the system's improvement in order to transmit increasing amounts of energy, to connect new generators to the system, and to ensure that loads that are not interconnected can be met safely and reliably. In such planning, there are technical, economic, environmental and social studies to address all the possible approaches which involve large works related to the transmission system. However, recently the system of power transmission with traditional centralized generation, and long transmission lines transporting large amounts of energy and

unidirectional flow of electricity have been criticized because of its high costs, high rate of losses, environmental impact, and security vulnerabilities. That is the reason why distributed generation (DG) is now seen as the future of the electrical system [5].

Table 1: Estimation of the transmission line expansion (km) [4]

	Existent 2011	Planned 2011 - 2016	Planned 2017 - 2021	Planned 2021
800 kV	0	0	7.325	7.325
750 kV	2.683	0	0	2.683
600 kV	1.612	4.750	0	6.362
500 kV	34.851	21.547	5.342	61.740
440 kV	6.679	47	66	6.792
345 kV	10.063	337	0	10.400
230 kV	45.349	7.874	444	53.668
Total	101.237	34.555	13.177	148.969

As the penetration of distributed generation is still small or non-existent in most countries, some works analyze policies, prospects, challenges, and government incentives for the deployment of distributed generation [6], [7] and [8], or the performance of DGs in energy markets' environment [9] and [10]. Others analyze the impact of DG systems in distribution systems on factors such as reliability, control, power quality, and system security [11], [12] and [13].

In Brazil, DGs are still a projection where laws and regulations involving smart grids are still being developed. In this way, the presented paper aims to conduct an analysis of the impacts that distributed generation will bring to the expansion planning of transmission systems, especially the one held by the consumers and injected into the network, such as the solar generation.

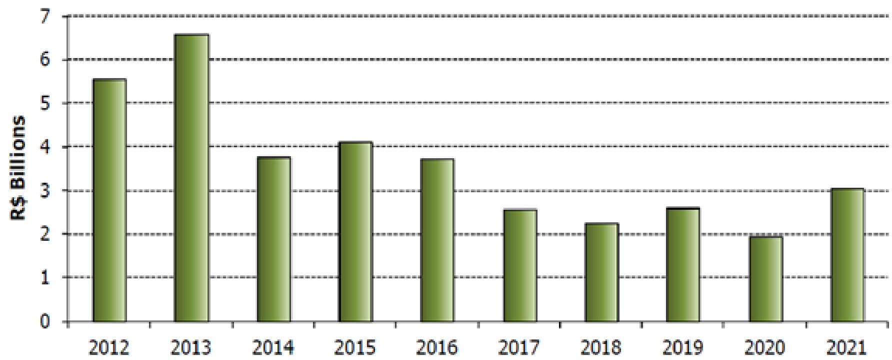

Figure 1: Planned investments in transmission lines [4]

This paper deals with the expansion optimization in a testing system for three different scenarios: 1) the anticipated load growth without taking into account the distributed generation; 2) considering a scenario in which distributed generation is equivalent only to 1% of the center power consumption loads; 3) a scenario in which DG is 5% of local consumption. In this way, the impact on the expansion cost of distributed generation will be obtained.

The optimization process will find the point of minimum cost for the expansion of the transmission system, respecting the problem constraints, such as flow limits in the power lines and the power balance in the buses. Although the optimization does not cover all the aspects that involve the transmission expansion, it is very useful to guide the planning, serving as a basis for further studies, such as social and environmental aspect. Its resolution is usually divided into two parts: the problem modeling and the optimization solution.

After this introductory section, section II presents a brief introduction to the concept of DC load flow used in this paper. Section III shows the expansion modelling, and section IV includes a brief review on the genetic algorithms concept – the method chosen for solving the optimization step of the solution. Section V presents the test circuit used, the scenarios and their results. Finally, section VI presents the main conclusions of the work.

2. DC Load Flow

The linearized model, or DC, is based on the fact that power flow is approximately proportional to the opening angle, moving from smaller towards larger angles.

It is mathematically defined as:

$$P_{km} = x_{km}^{-1} \times \theta_{km} = \frac{\theta_{km}}{x_{km}} = \frac{\theta_k - \theta_m}{x_{km}} \qquad (1)$$

Where:

- P_{km} - flow of the bar *k* for bar *m*;
- x_{km} = line reactance;
- θ_{km} = opening angle between buses *k* and *m*;

It is important to note that in this case the presence of transformers was not considered. If it is necessary to include these components in the modeling, the following formulation matrix can be used:

$$P = B' \times \theta \qquad (2)$$

Where:

- P = Vector of net injections of active power;
- B' = Nodal admittance matrix type;
- θ = Vector angles of the nodal voltages.

To solve the problem, one of the buses of the system was eliminated and its angle is set to 0 (slack bus). One of the reasons why the conventional load flow presents some convergence difficulties in planning studies is the lack of information on the system's reactive behavior (reactors, capacitors, taps, PV bus, etc.). The linearized model ignores the reactive part of the system, which will only be analyzed in later planning.

Further details on the deduction of DC load flow are available in [14].

3. Expansion modeling

In this study the DC model has been used for modelling the problem of expansion of the transmission system. This model involves the application of DC load flow equations for transmission systems, generating an optimization problem, which shows satisfactory results for planning and ease of convergence due to the fact that only the active powers are used. This model is interesting for the preliminary stages of planning. Disregarding transmission losses, the mathematical model is described as:

Minimize:

$$v = \sum c_{(ij)} n_{(ij)} \qquad (3)$$

Subject to:

$$S \times f + g = d \qquad (4)$$

$$f_{ij} - \gamma_{ij}\left(n_{ij}^0 + n_{ij}\right)\left(\theta_i - \theta_j\right) = 0 \qquad (5)$$

$$\left|f_{ij}\right| \le \left(n_{ij}^0 + n_{ij}\right)\bar{f}_{ij} \qquad (6)$$

$$0 \le g \le \bar{g} \qquad (7)$$

$$0 \le n_{ij} \le \bar{n}_{ij} \qquad (8)$$

$$(i,j) \in \Omega, k \in \Gamma \qquad (9)$$

Where:

- v = total cost of the transmission expansion
- c_{ij} = cost of building new circuits
- n_{ij} = number of new circuits
- S = matrix of connections between buses
- f = power flow
- g = active generations
- d = active demands
- γ = susceptance
- θ = phase angle
- Ω = set of possible paths
- k = generic bar circuit
- Γ = bus assembly of the circuit

Equation 3 is the objective function of the problem, in which the cost of system expansion v is calculated as the summation of the placement of each additional circuit c, multiplied by the number of circuits built into each line (n). Constraint 4 is the variation of the Kirchhoff's law of currents, adapted to the DC load flow context, while constraint 5 is a version of Ohm's law. However, the presence of a variable θ associated with the nodal matrix leads to a nonlinear equation. Constraints 6 and 7 represent the lines thermal limits and generation limits, respectively. Finally, constraint 8 ensures that the proposed number of circuits in each row is within the scope. A full subtraction of linear expansion modeling, including losses, can be found in [15].

4. Genetic algorithm

The Genetic Algorithm (GA) is a computational algorithm proposed by Holland in 1975 [16]. It provides a range of algorithms based on common optimization for a certain problem by analogy with the Darwinian principle of natural selection and genetic reproduction [17].

Basically, it creates an initial population of possible solutions to a problem. Using the criteria of selection, mutation and recombination applied to each generation, the population of solutions shows that the genetic material is transmitted to descendants, according to the probability of survival of individuals. Algorithm 1 shows the different phases of the optimization process.

INPUT: *Population, fitness function and stopping criterion.*
OUTPUT: *Individual with the largest chromosome fitness function.*
AUXILIARY: *Number of generations and chromosome (feature vector).*
1. Random generation of the initial population.
2. Evaluation of each chromosome through the fitness function.
3. **Stop** each generation, **make**
    4. Create a new population by following steps:
        5. Select the two chromosomes to be parents.
        6. Perform the crossover parents to a new generation.
        7. Apply mutation to change any position on chromosome.
        8. Place new offspring in the new population.
    9. Replace the old population by the new.
    10. Evaluate the new population.
    11. Stop when you reach the stop criterion
12. Return the individual with higher fitness function.

Figure 1: Genetic algorithm

5. Case Study and Results

In this case study three scenarios were presented: 1) considering a forecast growth in demand taking into account the distributed generation; 2) considering a distributed generation equivalent to 1% of the load; 3) considering a distributed generation equivalent to 5% of the load.

Figure 2 presents a diagram of the proposed methodology. An initial population of possible solutions generated by a random process is created. The objective function gives the expression cost, and if the problem is constrained, the evolutionary operator is applied to obtain the new generation. This cycle is repeated until the best solution in the population meets the requirements or until the maximum number of generation is reached. As can be seen the methodology follows the genetic algorithm idea.

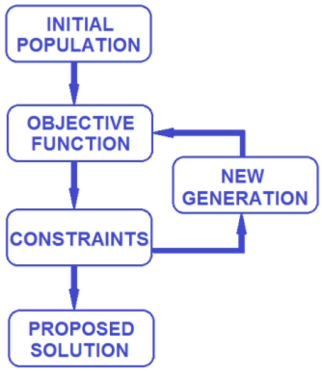

Figure 2: Diagram of the proposed methodology

For the simulation an algorithm using software MATLAB (MATrix LABoratory) has been created. A transmission network with 46 buses was used as a case study (Figure 3). This network represents a simplified version of the south eastern part of the Brazilian system chosen, and its data can be found in [18]. Altogether, there are 79 transmission lines; the expected total demand is of 6.800MW, and for this paper it was not considered the possibility of redispatch of generating plants.

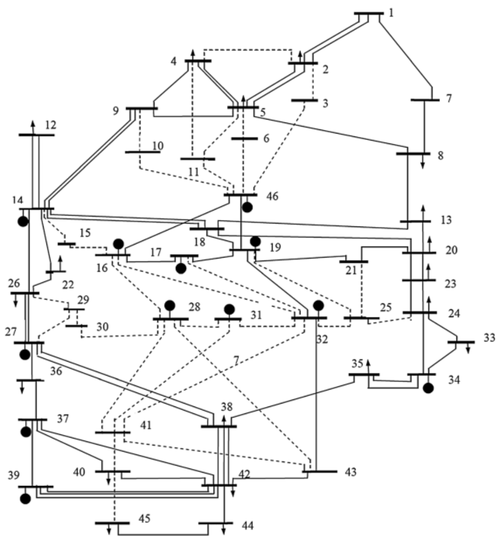

Figure 3: 46 buses circuit [18]

A. Scenario 1:

In the first scenario the presence of distributed generation was not considered, only the growth of the test system for the demand of 6.800MW. The solution found by the proposed method can be seen in Figure 4, in which the top graph shows the evolution of the best solution (the bottom line, in black), and the average of the solutions (the upper line, in blue) over the generations. It is important to note that a limit of 200 generations has been stipulated. However, the algorithm used 88 interactions to reach

solution.

The bottom graph depicts the amounts of transmission lines represented by 79 variables in the optimization problem. The solution proposes building two new circuits in lines 3, 4, 11, 46, 47, 73 and 74, and one new circuit in lines 23 and 52. The other lines remained with their initial circuits.

In Figure 4 one can see that the total cost of the best solution for the expansion of the system was of 115,009 monetary units (m.u.), while the average cost of the last generation stood at 123,589 m.u.. It was verified that all power flow in lines remained within the limits, making it a technically workable solution.

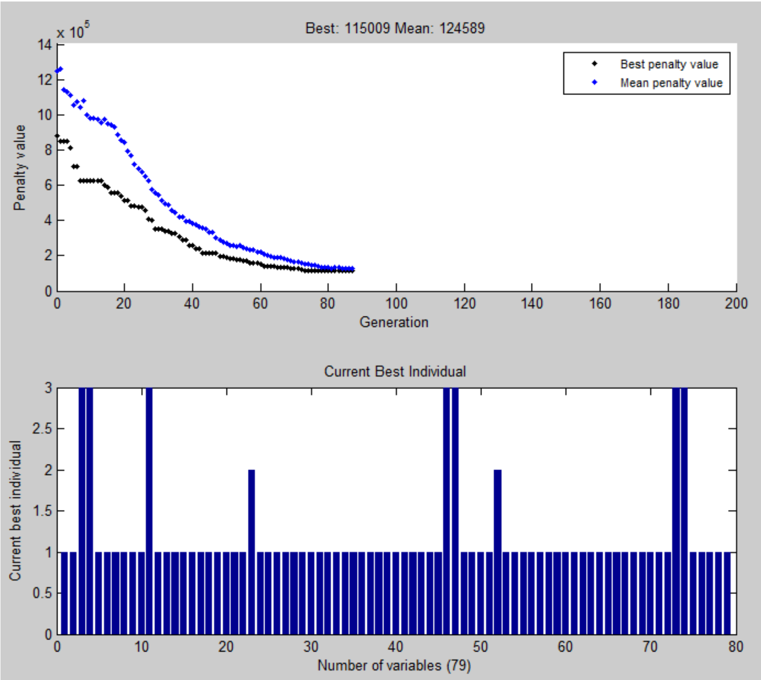

Figure 4: Proposed solution to the first scenario

B. Scenario 2:

The second scenario was conducted to determine what would be the impact of the distributed generation when it is equivalent to 1% of the total system load. For this scenario it was considered the gathering of distributed generation by consumers proportionally balanced.

The solution obtained can be seen in Figure 5. For this scenario it was necessary 130 generations to find the solution. However, genetic algorithms are a heuristic way of optimization, and there are no guarantees that the solution is always the same, or that would require the same number of interactions, since the initial population is generated by random process.

The total cost for the best solution found is of 101,024 monetary units. A reduction of 13,985 m.u. (12.16%) was obtained when compared with the base case (scenario 1).

This means that if the presence of distributed generation in consumer centers is considered, that can supply around 1% of the load, and it would lead to a reduction of 12.16% on the investment required for the construction of new transmission lines. It is important to note that this percentage depends on several factors, such as the circuit topology, plants (which have suffered a redispatch), the presence or absence of congestion lines, etc.

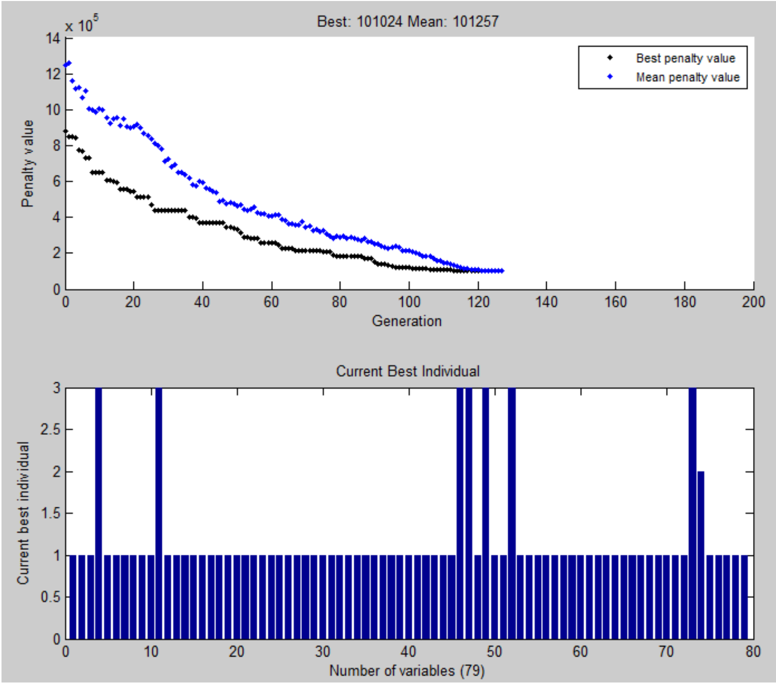

Figure 5: Proposed solution to the second scenario

C. Scenario 3:

The third scenario was conducted considering a distributed generation with 5% of the total load. This level of distributed generation in Brazil is above any realistic estimate for short or medium term, although it becomes much more coherent if scenarios like the European power system is considered. The solution obtained is shown in Figure 6. Taking into account the same number of generation limits (200) as the previous scenarios, one can see that the number of generations obtained is the same as scenario 1 (88).

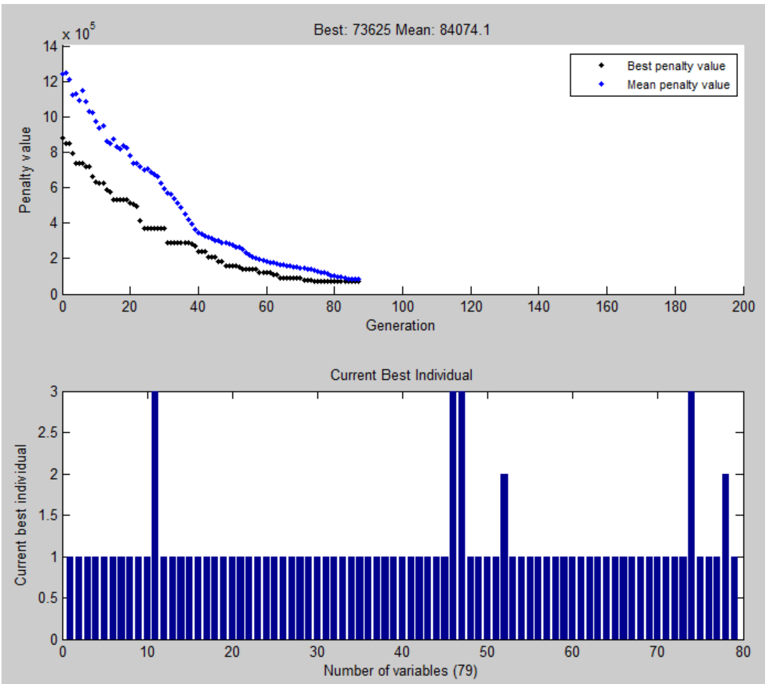

Figure 6: Proposed solution to the third scenario

In this scenario, the cost of the best solution was of 73,625 m.u., which corresponds to a reduction of

41,384 m.u. (35.98%) when compared with the base case. Once again, this percentage can vary sharply according to the circuit topology, redispatch plants, and the congestion in lines, among others. So, this result is a good indicator that distributed generation can contribute significantly to the reduction of the cost for building new transmission lines.

If it is considered the most basic type of distributed generation, for example photovoltaics, consumers themselves bear the costs of the equipment and its installation. The government’s investment is relatively small, consisting primarily in tax incentives and opening lines of credit specialist. A part of the contribution necessary for these government initiatives may come precisely from the savings of the placement of new transmission lines.

It is noteworthy that reducing the number of transmission lines to be built has other benefits, besides the advantageous economic investment, such as lower environmental impact, both in the form of fewer areas that need to be occupied by the towers. This can be done by using a smaller amount of materials and consequent lower emissions of greenhouse gases related to manufacturing, transportation and installation of equipment, towers and cables. Relevant information about the environmental impact of transmission systems can be found in [19].

6. Conclusion

In this work the impact of distributed generation in the transmission expansion planning was analyzed. Three scenarios in the system with 46 buses were considered. The scenarios were conducted in order to optimize the expansion without the distributed generation; with distributed generation equivalent to 1% and 5% of the total system load, resulting in expansion costs of 115.009 monetary units, 101.024 monetary units and 73.625 monetary units respectively, representing economies of 12.16% and 35.98%, in comparison to the case without distributed generation. Considering the distributed generation, the government’s investment is relatively small. Basically only tax incentives and specialized lines of credit, and a part of the necessary contribution may come from the savings of the placement of new transmission lines.

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