IMPACT OF DISTRIBUTED GENERATION ON THE OPERATIONAL PLANNING OF MEDIUM VOLTAGE DISTRIBUTION NETWORKS USING GENETIC ALGORITHMS

Alexandre A. A. de SOUZA Nelson KAGAN Miguel Edgar Morales UDAETA Klaus de GEUS
University of Sao Paulo – Brazil Federal University of Paraná - Brazil
alexandre.augusto.souza@usp.br; nelson@pea.usp.br; udaeta@pea.usp.br; klaus@degeus.com.br

ABSTRACT

This paper presents a study of the impact of Distributed Generation (DG) in the operational planning and design of Medium Voltage (MV) distribution networks. The proposed model considers the planning of MV networks for reducing power losses, voltage drop and investments in reinforcements using Genetic Algorithm (GA). Planning MV distribution networks involves cable replacement, sizing and positioning of capacitor and DG and phase load balancing .The objective function to be minimized includes operational costs of proposed changes, power losses and voltage constraints. A power flow for radial distribution networks based on a backward/forward sweep using current summation was developed to validate the solutions.

INTRODUCTION

Operational planning of power distribution feeders requires a considered effort for operation and design of affected feeders. Studies for electrical grid planning require a high level of human intervention, as well as considerable time for their analysis.

Grid planning is required due to the constant need for network expansion caused by the rapid growth of demand in urban, rural and public policies related to social inclusion. Normally, for analysis and study purposes, electrical power systems are subdivided into three large blocks, which are: generation, transmission and distribution [1]. Investments made in the distribution sector represent a significant percentage of the budgets of distribution utilities.

Recent advances in small-scale electricity generation increase the Distributed Generation (DG) use to assist energy efficiency improvement. The wide availability of equipments can provide its use for small and large consumers. Furthermore, by reducing the costs of generation and transmission of electricity, DG becomes a competitive alternative to provide services to consumers meeting all accepted criteria for energy distribution.

Most of the cases, DG is installed close to the requested load, using the existing distribution grid. Some studies are requested to analyze the impact of the DG installation related to power losses reduction, improvement of voltage level and increase of reliability. However is also necessary make some additional changes in the control and protection system in some particular cases according to the installed DG.

In this context, this paper presents an evolutionary approach for supporting studies for the Medium Voltage (MV) electrical distribution network. The goal is to propose solutions regarding technical e financial issues. The main interventions in feeders considered in this study are: replacement of cables by others of smaller impedance, sizing and positioning of capacitor and DG and phase load balancing.

THEORETICAL FOUNDATION

The techniques involved in this work are: Genetic Algorithms, Power Flow for Distribution Networks and MV Distribution Network Planning will be described next.

Genetic Algorithms

Genetic Algorithms (GA) is a metaheuristics optimization method that solves a problem iteratively through the improvement of a candidate solution based on certain criteria. It is based on the theory of natural selection, and usually in a GA, each individual in the population corresponds to a possible solution.

The algorithm operates on a population of individuals based on the fact that individuals with good genetic characteristics are more likely to survive and produce increasingly fit individuals.

Being a stochastic optimization, the AG has incorporated probabilistic elements that help prevent local optima and find the global optimal. The main steps involved in a GA are: population initialization, crossover, mutation, selection and termination based on a criterion. Using the operation of recombination, two parents are combined to form a child. The mutation operation adds randomness to the population and, consequently, prevents the search to be trapped in local optima [2].

Power Flow for Distribution Networks

The calculation of power flow in electrical networks is performed by determining the magnitude and angles of voltages and currents in network points, as well as other variables of interest. In general, power distribution systems are predominantly radial and show the (R / X) relationship very high [3]. As a consequence, flow calculation methods such as conventional Newton-Raphson and fast decoupled are inefficient when applied to this type of system.

Furthermore, the computational effort associated with these methods in order to perform the factorization, matrix inversion and solution of nonlinear equations systems becomes too high. Thus, for the solution of radial systems, more appropriate methods were proposed, such as the Method of Sum of currents [4] and the Method of Sum of Powers [5]. The method of Sum of Currents uses a forward and reverse scanning process for determining the voltages and currents. The scanning method is the most suitable for radial systems, and can also be used on networks with few meshes [6].

The network can be represented by a tree where the initial switch of the feeder is the root and the cables are the branches [7]. Nodes represent the connections between conductor cables and may contain transformers, capacitors or DG. The scanning method consists of two paths, one direct and one reverse. In the reverse direction, it begins from an initial estimate of nodal voltages of branches at the bottom of the tree, calculating the currents until it reaches the root. From the initial values for currents, the forward scan is performed, calculating the voltage values of the transformer until the most distant branches are reached.

The process is stopped when the magnitude of the difference in values of tension between two successive iterations is less than or equal to a prescribed tolerance. In this work, the Method of Sum of Currents has been adopted.

MV Distribution Network Planning

The problem of power network planning is characterized as a combinatorial optimization problem. There are several physical and budget constraints that are usually linear. However, the expansion constraints are modeled using non-convex functions [8].

Usually the problem can be represented as a mixed integer nonlinear programming model [9]. To solve this problem, classical methods such as quadratic and mixed integer programming can be used. However, in some cases, the methods may fail to achieve maximum global, reaching only the maximum local.

The problem can be solved with the use of an evolutionary approach regardless of the type of objective function [10]. Metaheuristics methods such as GA, Particle Swarm Optimization, Simulated Annealing or their variations are commonly used to solve network planning [10]. A compilation of structured models and techniques dedicated to the planning of electrical networks using DG is presented in [11].

The main interventions in feeders to solve problems related to quality indices are:

- Replacement of cables by others of smaller impedance;
- Capacitor placement;
- Phase load balancing.

These contributions combined represent a large search space, characterizing its combinatorial nature.

PROPOSED METHODOLOGY

In this section the formulation of the problem will be presented, as well as the encoding and the power flow.

Problem Formulation

For the determination of acceptable voltage values and losses in a MV feeder, the following alternatives were considered in this study:

- Cables changing;
- Phase load balancing;
- Capacitor positioning and size;
- DG positioning and size.

Given an existing feeder, cables changing consist of replacing cable types in certain areas, reducing energy losses and voltage drop. Therefore, the estimated costs of installing new cables are considered.

Phase load balancing is one of the possible technical solutions to improve voltage levels on a feeder and consists of uniform load distribution in the three phases. In some feeders, load imbalances are caused by three phase electrical equipments with unequal load demands in phases.

The installation of capacitors allows a better management of reactive power, bringing benefits like electrical losses reduction and improvement of voltage level.

In order to find the best option regarding technical and economic constraints, many combinations must be tested to determine the most viable. Phase load balancing is the cheaper solution; however, it is only suitable in situations where the imbalance of the feeder is relevant. The installation effects of DG are also considered in the power flow simulation of the feeder during the optimization process.

The objective function was defined to minimize the voltage drop, losses and cable change operating costs, phase load balancing, capacitor e DG positioning and sizing. Each of these criteria characterizes a multicriteria problem which considers the minimization of the functions shown in the equation (1).

$$F.O. = \min f_1, f_2, f_3 \qquad (1)$$

where:

f_1: voltage drop violation;

f_2: electrical losses violations;

f_3: cost of changes.

As criteria are considered with different magnitudes, the method of Criterion Global was used to normalizing each objective by determining the optimal value and the worst case. Thus, the objective function can be defined as (2).

$$\min\left(\frac{f_1}{fmax_1} + \frac{f_2}{fmax_2} + \frac{f_3}{fmax_3}\right) \qquad (2)$$

where:

f_1: Higher voltage drop simulation;

f_2: Sum of losses in feeder simulation;

f_3: Cost of cable changing, phase balancing and capacitor and DG;

$fmax_1$: Voltage drop of the original feeder;

$fmax_2$: Sum of electrical losses of the original feeder;

$fmax_3$: Worst case of the cost for the changes. It is considered the highest possible cost.

The chromosome has variable size. The first gene sequence is reserved to represent the cables, the second shows the phase of the loads, the third represents capacitor positioning and size, the last sequence represents the DG positioning and size. The representation of the system cables is made using the relationship shown in Table 1 in order of decreasing resistance.

TABLE I. CABLE VALUES

Binary codification	*Comercial cable*
001	06 AWG
010	04 AWG
011	02 AWG
100	1/0AWG
101	2/0 AWG
110	3/0 AWG
111	4/0 AWG

The representation of the phase of the loads is done via the relation shown in Table 2.

TABLE II. PHASE REPRESENTATION

Binary codification	*Phase*
001	A – Single phase
010	B – Single phase
011	C – Single phase
100	AB – Two phases
101	BC – Two phases
110	AC – Two phases
111	ABC – Three phases

The coding system can be seen in figure 1. In the situation shown, the problem has five cables and three loads, five nodes that can receive a capacitor and five nodes that can have a DG installed. Genes of the consumer phase, cables, capacitor and DG are dimensioned to represent seven values.

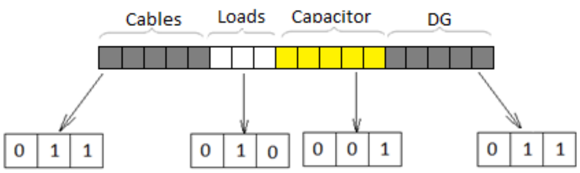

Figure 1- Coding system

Each generated individual must be decoded and evaluated using a power flow to calculate its voltage drop and electrical losses. If the individual is invalid, a fix is executed in order to evaluate a power flow and assignment of its fitness value. An individual is considered invalid when it presents an incompatible phase or a cable with a lower resistance value than the original cable. This criterion of correction of generated solutions is important due to the fact that a single phase load can never be transformed into a two phase load.

Figure 2 illustrates the case of a recombination that results in an individual with problem due to its cable definition. After recombination, decoding the individuals it was found that cable 3 was value "010". However, the installed cable in the field is "011", and therefore the change proposed by the algorithm must not be accepted. According to Table 1, cable labeled "011" representing the gauge "02 AWG" cannot be replaced by a gauge "04 AWG". The change causes an increase in resistance of the cable, violating an important constraint. The procedure adopted is simply correcting the individual to a feasible value, in this case, to its original value.

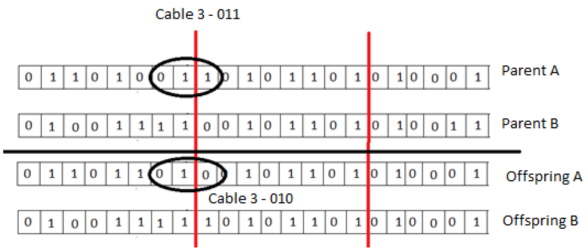

Figure 2 - Invalid offspring

All experiments were performed with the method of selection through the stochastic tournament equal to 5% of the population and two points recombination. The best average values of the objective function were obtained with a smaller population size and a higher number of generations. The population size was set at 100 individuals, with 15,000 generations. In most cases, the search process has stabilized at approximately 10,000 generations. The mutation probability was set at 1%. The stopping process was defined using the maximum number of generations for the study.

Power Flow

In order to calculate power flow considering the application of GD, it was necessary to adapt the method of the back/forward sweep to include bars controlled voltage (PV) in the MV feeders. The operation of GD units is usually adjusted to provide active power with a constant power factor [8]. In this study was implemented a power flow method based on Sum of Currents considering the influence of GD in MV distribution network.

RESULTS

The proposed model of GA was coded in C# programming language and the power flow in C++. The simulations were taken from a real feeder, whose data was obtained directly from the electric power facility of the state of Paraná. The proposed optimization approach was applied to the electrical distribution system showed in figure 3. The feeder has 302 nodes and provides energy for 3400 residential and 991 commercial consumers. The medium calculated current is 272 A, voltage operation of 13,8 kV and a minimum voltage of 0,91 pu. Phase load balancing of the feeder is 92%.

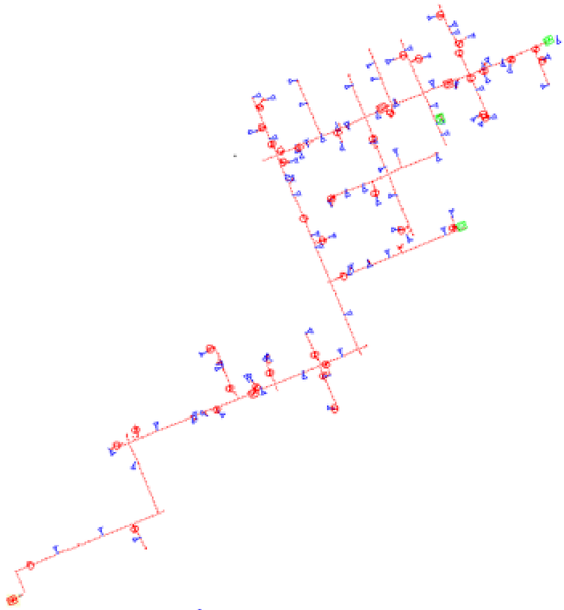
Figure 3- MV Feeder

The capacitor cost is shown in table 3.

TABLE III. CAPACITOR COST

Type	*Installation cost (R$)*
300 kVar	3070
600 kVar	3500
900 kVar	5600
1200 kVar	8200
1500 kVar	10200

The GD cost is shown in table 4.

TABLE IV. GD COST

Id	*PG(kW)*	*QG(kVAr)*	*Installation cost (R$)*
1	2000	1200	2300
2	3000	1500	4600
3	4000	2000	6600

The predominant solution to the feeder was a combination of cable change and GD without phase load changes and capacitor placement. The cable changes have been located near the suggested point of DG installation.

Executing the optimization without the possibility of use of DG, the final voltage was 0,972 pu with a installation of one capacitor unity of 300 kVAr.

The summary of the simulations is shown on table 5.

TABLE V. SUMMARY OF SIMULATIONS

Total Cost (R$)	*Phase load Balancing (%)*	*Capacitor (kVAr)*	*DG (Id)*	*Minimum voltage (pu)*
3.070,00	92,0	300	--	0,972
2.550,00	92,0	--	1	0,960

CONCLUSION

This paper presented a methodology based on GA to provide support for the operative planning of medium voltage feeders with the insertion of DG. A power flow based on current sum method with controlled voltage bar was developed for the solutions validation.

The advantages of the method of Sum of Currents were remained, as the guarantee of convergence. Some simulations indicated the need for exchange of cables in one of the sections of the feeder, this happens due to the increase of the current caused by the reversal of power flow when a DG is inserted.

The GA has reached the goal of minimizing the violations of losses, voltage drop and cost of changes for the proposed solutions in the network.

This work contributes to analyze the impact of the insertion of energy sources in operational planning of MV systems as well as developing a power flow to consider the existence of DG. The insertion of DG in network planning is very important to MV and its use will be adopted and encouraged by several branches involving the generation, transmission and distribution of energy.

REFERENCES

[1] W. D. Stevenson, 1988, *Elements of Power System Analysis*, vol 4, McGrawHill, p.32.

[2] K.K. Deb, 2001, *Multi-objective optimization using evolutionary algorithms*, John Wiley & Sons, Chichester, UK.

[3] G. O. M. Srinivas, 2000, Distribution load flows: A brief review. *IEEE PES SUMMER MEETING*. Singapore, p. 942-945.

[4] D. E. Goldberg, 1997, Genetic algorithms in search optimization and machine learning, John Wiley & Sons, United States of America.

[5] D. Shirmoharmnadi, H. W. Hong, A. Semlyen, G. X. Luo, 1988, A Compensation-Based Power Flow Method for Weakly Meshed Distribution and Transmission Networks, *IEEE Transactions on Power Systems*, Vol. 3, No. 2, p. 753-762.

[6] R. P. Broadwater , A. Chandrasekaram, C. T. Huddleston, H. A. Khan, 1988, Power Flow Analysis of Unbalanced Multiphase Radial Distribution Systems, *Electric Power Systems Research, 14*, p 23-33.

[7] D. M. Falcão, 2003, *Fluxo de Potência em Redes de Distribuição Radiais*. COPPE-UFRJ: [s.n.].

[8] G. Latorre, R. D. Cruz, J. M. Areiza and A. Villegas, 2003, Classification of publications and models on transmission expansion planning, *Power Systems, IEEE Transactions on 18*, No. 2, p. 938-946.

[9] S.L. Moulin, M. Posss and C. Sagastizabal, 2010, Transmission expansion planning with re-design, *Energy Systems*, Volume 1, No. 2, p. 113-139.

[10] J. Olamaei, T. Niknam and G. Gharehpetian, 2012, Application of particle swarm optimization for distribution feeder reconfiguration considering distributed generators, *Applied Mathematics and Computation*, vol. 201, pp. 575-586.

[11] P. C. Ramaswamy and G. Deconinck, 2012, Smart Grid Reconfiguration Using Simple Genetic Algorithm and NSGA-II, *IEEE PES ISGT Europe 2012*, Berlim.