DEVELOPMENT OF A GENETIC ALGORITHM FOR EVALUATING THE PERFORMANCE OF OVERHEAD POWER DISTRIBUTION LINES AND PROPOSING SOLUTIONS TO IMPROVE DISTRIBUTION LINE SAFETY

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ABSTRACT

This paper aims to present and discuss the use of a power flow methodology based on Gauss Elimination Method to evaluate the performance of distribution network taking into account the neutral conductor absence at specific sections, and a development of a methodology based on genetic algorithm (GA) capable of evaluating alternative solutions in different bars of the feeder, in order to propose appropriate solutions to improve the distribution network safety. Besides the technical aspects, the proposed GA methodology takes into account the economic feasibility analysis.

The results of power flow simulations have shown that the presence of single-phase transformers along with the absence of the neutral conductor at specific sections of the MV network may increase the neutral-to-ground voltage (V_{ng}*) levels of the feeders involved, jeopardizing the system´s safety. On the other hand, the solutions proposed by the GA methodology may reduce the network* V_{ng} *levels and improve the safety conditions, providing values close to the ones found before the neutral conductor theft.*

INTRODUCTION

The performance evaluation of medium voltage (MV) systems has a great importance for utilities for planning and operation of distribution network purposes. The occurrence of neutral conductor theft has been increasing due to the easiness associated with the reselling of the copper and aluminium conductors at the black market. The unpredictability of this action may cause undesirable consequences to the electric utilities, such as impacts at the energy quality, increment of expenses and time for the maintenance crews to repair and/or reinstall the conductors, equipment damages, increase of the step and touch potentials etc.

AES Eletropaulo (Brazil) has been suffering the aforementioned setbacks due to the absence of neutral conductor wires in its electric distribution network. The Utility is responsible for supplying about 6.3 million customers in the State of Sao Paulo, Brazil. The aim of this work is to present a genetic algorithm methodology to evaluate some alternatives along the MV network, in order to recommend appropriate solutions to reduce the V_{ng} levels and, consequently, improve the network safety. The power flow analysis based on Gauss Elimination Method [1, 2] evaluates the impact of neutral conductor absence at specific sections of the network regarding the performance and safety of distribution network, whereas the AG methodology proposes technical-economic solutions to mitigate the damages due to the neutral conductors theft.

The analyses presented in this paper have been part of the activities of an R&D Project carried out in partnership with AES Eletropaulo and the results have been applied in two different feeders of the utility.

SYSTEM SUMMERIZED DESCRIPTION

AES Eletropaulo´s distribution system is characterized by the presence of a common neutral conductor for the medium voltage (MV) and low-voltage (LV) circuits, multi-grounded at every 300 m and at every pole where there is an equipment installed (distribution transformers, reclosers, capacitor banks, voltage regulators etc.). The common multi-grounded neutral is employed in order to provide a low impedance path back to the substation [3].

The Gauss Elimination Method [1, 2] and GA methodology have been implemented in the Interplan software [4] and the simulations were performed for the feeder RGR-104, due to the high incidence of its neutral conductor theft. Feeder RGR-104 is a 13.2 kV circuit with 51 km long and, according to AES Eletropaulo, the neutral conductor is absent in about 20% of the total length.

Neutral conductors installed are 3/0 AWG Aluminium Wire at the main feeder and 1/0 AWG Aluminium Wire at the laterals.

Feeder RGR-104 is characterized by possessing wye-delta (Y-Δ) transformers, multigrounded neutral at every 300 m and at every pole where there is an electric distribution equipment installed, and also at poles adjacent to equipment. To evaluate the feeder's performance, simulations through Interplan power flow software have been employed, using as input, feeder RGR-104's geo-referenced data and phase and neutral current measurements at the substation. The methodology adopted in order to calculate the power flow allows, as well as other parameters, the phase and neutral current, neutral-ground voltage and electrical losses to be simulated. The Table 1 shows the measured values of phase and neutral currents at the substation of the feeder RGR-104.

Table 1: Measured and simulated values of phase and neutral currents at the substation of feeder RGR-104.

I_D (A)	I_E (A)	I_F (A)	I_N (A)
445	452	417	32

The contributions for the ground resistances of the consumers´ pole grounding and adjacent feeders are not considered in the simulations. Therefore, unless otherwise indicated and based on measurements along the feeder, the average ground resistivity (ρ_g) has been assumed to be 300 Ω.m and the average ground resistance (R_g) to be 50 Ω for grounded poles. The analysis with the GA proposed methodology takes into account the alternative solutions presented in the Table 2.

Table 2: Alternative solutions evaluated by GA methodology to mitigate the damages due to the neutral conductor absence and improve the feeder safety condition.

Grounding configuration options	**Total installation cost price (USD)**
1500mm length four parallel rods	130.00
1500mm length six parallel rods	193.00
2400mm length four parallel rods	145.00
2400mm length six parallel rods	220.00
Neutral conductor options	**Total installation cost price (USD/km)**
Reinstallation of 1/0 AWG Aluminium Wire in the MV line sections without neutral conductors	1,450.00
Reinstallation of 3/0 AWG Aluminium Wire in the MV line sections without neutral conductors	1,790.00
Installation of Bimetallic Steel / Aluminium Wire 7N9 53% IACS	2,520.00
Installation of Bimetallic Steel / Aluminium Wire 7N7 53% IACS	3,480.00

GENETIC ALGORITHM METHODOLOGY

A methodology that uses the technique of Genetic Algorithm [1] has been proposed, based on research of optimization methods for technical and economical assessments and on research oft alternative solutions to mitigate the problems due to the theft of neutral conductors in distribution networks.

GA methodology is a particular class of evolutionary algorithms that uses techniques inspired by evolutionary biology of Darwin's natural selection. The elements which define a state of the problem form an population, represented by chromosomes. These, in turn, are represented by genes. Thus, using some concepts of inheritance as crossover, mutation and natural selection of the fittest ones after a few generations, one expects to find the best solutions.

GA methodology is based on a combinatorial analysis, in which one seeks an optimal solution. The basic principle of GA technique is the adaptation of the population due to the inheritance of good genes of previous generations, and the good characteristics of individuals will be passed to future generations, according to the evaluation process. Figure 1 shows the Genetic Algorithm flowchart.

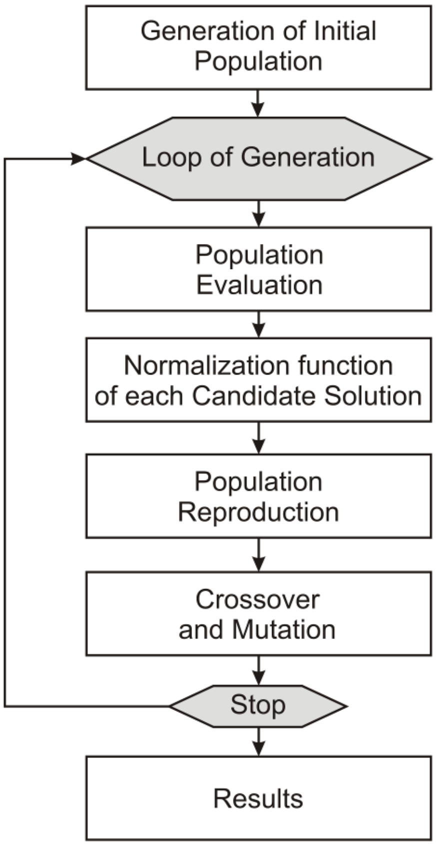

Figure 1: Genetic Algorithm Flowchart.

One defines as an individual, the set of grounding solutions and conductors substitution of a specific configuration of the network, which will be represented by a finite size vector. The principle is analogous to the adaptation of living organisms in different environments. Initially, one draws the initial set of individuals, in which the population will be chosen, selecting the best suited beings, to apply later on the possibility of mutation and crossover. Finally, one assesses all individuals of this generation and, if a parameterized maximum number of generations is reached, one meets the most adapted individual. Otherwise, the cycle restarts from a selection of the best beings.

Steps of GA methodology for determining adequate solutions to improve network safety

a) Selection of individuals

The selection of individuals is carried out by employing the tournament method, i.e., one picks up randomly three individuals in the population and one selects only the most adapted individual.

b) Mutation

The aim of mutation is to generate new individuals with diverse characteristics, i.e., create greater variety of genes.

c) Recombination

A recombination or crossover is required to increase the variety of individuals, or to increase the population of the most suited ones.

d) Assessment

The evaluation is performed through a Merit Index, which is composed by the grades assigned to the variables of "technical loss at the grounding" and cost of the proposed alternatives (Table 2). The technical loss variable is related to the value of ground resistance (R_g) and the leakage current through the grounding rod, i.e. the smaller the value of R_g for a given leakage current, the smaller the technical loss in the ground; and consequently, the lesser the neutral-to-ground voltage (V_{ng}).

The Merit Index is assessed by the difference between the technical loss of the solution candidate individual and the initial technical loss of the individual (neutral stolen feeder configuration), represented by a certain cost to obtain this candidate, from the initial individual.

Codification of the individual

The encoding of Genetic Algorithm individuals is accomplished through a vector divided in two segments: Grounding genes and Conductor Substitution genes. Figure 2 presents a vector (chromosome) in its simplified version for a case of *n* grounding configurations and *m* neutral conductor substitution options.
One points out from Figure 2 that each candidate (individual) is formed by a set of poles (with a specific R_g) and branches (with a specific neutral conductor).

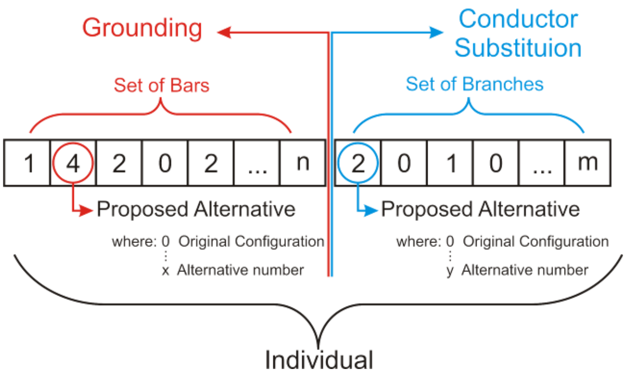

Figure. 2: Codification of a finite size vector (representing a chromosome).

The first part of the encoding vector is composed by the grounding configuration options (Table 2), in which each gene (grounded bar) will be set to the values "0" to "x", which are the grounding arrangement alternatives. Thus, contrary to conventional binary encoding, where there are only two possibilities in which the gene may worth, i.e., either "0" or "1", each gene may alternatively be worth "0" to "x". In this paper, the genes (grounding bars, whether where there is equipment or where the bars are grounded every 300 m) may have 5 grounding configuration options (Table 2):

- poles without grounding;
- 1500 mm long four parallel rods;
- 1500 mm long six parallel rods;
- 2400 mm long four parallel rods;
- 2400 mm long six parallel rods.

The second part of the encoding vector is composed by the neutral conductor options (Table 2), in which the options for each gene of conductor substitution (absent neutral conductor branch) will be set to the values "0" to "y", which are the conductor substitution alternatives. Thus, contrary to conventional binary encoding, where there are only two possibilities in which the gene may worth, i.e., either "0" or "1", each gene may alternatively be worth "0" to "y". In this paper, the genes (absent neutral conductor branches) may only have 5 neutral conductor options:

- MV branch without neutral conductor;
- MV branch with 1/0 AWG Aluminium Wire;
- MV branch with 3/0 AWG Aluminium Wire;
- MV branch with Bimetallic Steel / Aluminum Wire 7N9 53% IACS, and;
- MV branch with Bimetallic Steel / Aluminum Wire 7N7 53% IACS.

Evaluation Function

The Genetic Algorithm should find the best solution to maximize the evaluation function f_{eval} (losses, cost) as follows:

$$f_{eval}(losses, cost) = \left(\frac{Initial\_Configuration\_Losses - Analysed\_Individual\_Losses}{Instalation\_Costs} \right)$$

Where :

- *Analysed_Individual_Losses*: economic value of the grounding losses of the analysed alternative, based on the study period (years), on the initial year energy cost (US$ / MWh), on the market growth rate (% per annum) and internal rate of return (% per annum);

- *Initial_Configuration_Losses*: economic value of grounding losses of the system original configuration, i.e, network with some branches without neutral conductors, adopting the same period and economic indices and;

- *Installation_Costs*: economic value of the chosen alternative, considering the same parameters aforementioned.

Figure 3 shows the results of a simulation, with the proposed alternatives in Table 2.

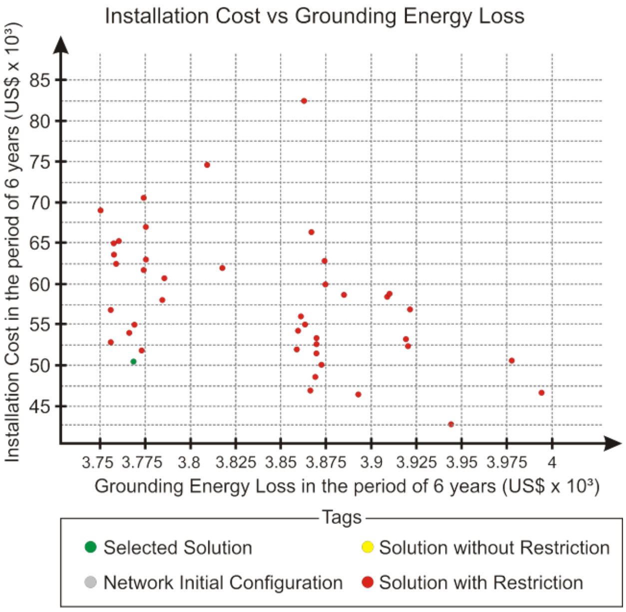

Figure 3: Alternative solutions presented by GA proposed methodology.

Fig 3 shows that the best alternative is the one which presents a grounding energy loss value around US$ 3,770.00, and an installation cost of approximately US$ 50,000.00 in a 6 year period.

CONCLUSIONS

This paper has evaluated the performance of MV distribution networks due to the lack of neutral conductors in some of its branches and proposed technical solutions to mitigate the damage caused by the operation of the network under these operative conditions. Feeder RGR-104 has been used to simulate due to its high incidence of neutral conductor theft.

To evaluate the performance of the feeder taking into account the network neutral conductor thefts, a new methodology for power flow method based on Gauss Elimination has been developed and implemented into Interplan software [4]. The simulation results show that the absence of neutral conductors, in conjunction with the imbalance caused by the wye-transformer connection along the feeder, greatly increases the levels of neutral-ground voltage, decreasing the security of the network.

A new methodology based on Genetic Algorithm has been developed to improve the network security, proposing appropriate solutions (including changes in grounding systems and replacement and / or installation of new conductors) to keep the network neutral-to-ground voltage levels (V_{ng}) within adequate technical and safety conditions.

As an alternative to eliminate the frequent thefts of aluminum neutral conductors in certain regions of the feeder, bimetallic conductors have been used in branches with high theft incidence.

The results presented in this paper may be used as reference for planning improvements in the performance of distribution networks. However, it should be stressed that the results tend to be conservative because one has neglected the influence of of consumer´s pole grounding and the groundings of adjacent feeders near the studied feeder and also, the variations in ground resistance and soil resistivity should be taken into account.

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