Use of Genetic Algorithm for Evaluation and Control of Technical Problems due Load Shedding in Power Systems

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Abstract— **The distribution system is the final connection between the power system and consumers. If the load shedding is necessary to ensure that operating restrictions, usually this load shedding will occur in the distribution system. This paper analyzes the load shedding in medium voltage performed in the event of reduced availability of the supply system (generation and / or transmission) that may occur due to contingencies or power rationing. For this, we propose a new methodology developed for load shedding (transfer and / or cutting loads) that is based on the methodology called Multiobjective Evolutionary Algorithm based on subpopulations tables. This algorithm which makes use of node-depth for representing distribution systems without computationally simplifications and was originally developed to address the problem of network reconfiguration, with respect to analytical losses and restoring power distribution systems. Despite the ability of this algorithm based on analyzing the unique issues for which it was designed, it does not parse the load shedding problems in distribution systems.**

Index Terms-- **Load Shedding, Power System Reconfiguration, Power Distribution Systems.**

NOMENCLATURE

CAO	Change ancestor operator
EA	Evolutionary algorithm
NDE	Node-depth encoding
PAO	Preserve ancestor operator.
DS	Distribution system
LS	Load shedding
NO	Normally open
NF	Normally close
MV	Medium voltage
HV	High voltage

INTRODUCTION

A. Motivation

The distribution system (DS) is the final connection between the power system and consumers and aims to provide energy consumers with good quality and affordable, always seeking to reduce the environmental impacts.

Supply power to the consumer in an appropriate manner should concern first the reliability of supply. For this, the planning process of the electric energy sector requires an advanced technological structure for the correct dimensioning and construction of generation units, transmission lines and distribution systems.

It is considered as a "good quality product", an electric system that has:

i) continuity, that is, is always available for final use;

ii) compliance, i.e., conforms to specified standards of performance;

iii) flexibility, the property to adapt to continuous changes in its topological structure;

iv) maintainability, that is, the property is returned to the fastest possible operation in case of system crashes.

To improve the reliability and quality of electric power supply, load points are grouped into blocks called sectors, separated by disconnect switches. These sectionalizing switches operate in the normal closed condition - NC, intended to isolate load blocks to enable a corrective or preventive maintenance.

It is usual to install in the same circuit, or between circuits, switches that operate in normal condition open-NO), which can be closed in load transfer operations between feeders and substations.

When a load is transferred to a receiver feeder, in order to relieve system load as a whole, depending on the transferred load amount, the voltage level of this feeder, their loading and loading substation in which it is connected, it is possible that the operational constraints of this feeder are not guaranteed, which would require additional maneuvers so that a feasible solution is found

Thus, this paper covers load shedding in medium voltage made in reducing the availability of supply system (generation and/or transmission) and it is based on a genetic algorithm with proven efficiency in literature, though originally applied to another type of problem

B. Review Of the Literature

To address this problem, some studies have been proposed in the literature, and can highlight the reasoned meta-heuristics, especially in Evolutionary Algorithms (EAs).

However, most of the analyzes of these algorithms are power restoration in the event of a fault [1]–[3].

Another common approach is to relieve the load due to underfrequency analysis and voltage instability but many of the analyzes indicate shutdown of the feeder as a whole at the substation output [4], [5]. Finally, another common limitation is about the size of the network, usually small networks.

C. Contribution

The main contribution of this work is the development of a methodology to give a proper network reconfiguration plan (change of network topology through the modification of the open/closed states of switches) with regard to the problem of load shedding (transfer and/or cutting), due to contingencies in High Voltage/Sub-transmission contemplating the:

i) minimization of the number of customers without electric power supply;

ii) minimizing the number of switching operations, so that this does not impede the implementation in practice; the absence of overload in the network and in substations;

iii) maintenance of voltage levels within ranges required by law and maintain the radial network.

It is important to note that the based algorithm [6] does not provide analyses of load shedding, being the proposed unprecedented contemplation of these parameters.

To deal with the problem in question, the proposed methodology for demand adequacy based on transfer and load shedding includes the demand amount to be relieved as input.

Furthermore, it is not limited by simplifications in the representation of the network as these fail to consider simplifications of the network elements, and in this case, the solution can not be provided in the network operation, the same effect as in the simplified network with-promising the reliability of the approach.

MODELING THE PROBLEM

A mathematical formulation that represents computationally the network reconfiguration problem is presented in this section.

The problem of load shedding is a subproblem of the problem of network reconfiguration and basically consists in determining a radial configuration that relieves the load amount requested and minimize the number of manoeuvres performed in view of a number of restrictions.

Therefore, a general problem formulation of load shedding can be expressed as:

$$\begin{aligned} Min.\quad & \phi(\mathrm{F}), \varphi(F,F^0), \gamma(F,F^0)\ e\ \omega(F) \qquad (1)\\ s.a: \quad & Ax = b \\ & X(F) \le 1 \\ & B(F) \le 1 \\ & V(F) \le 1 \\ & F\ is\ a\ forest, \end{aligned}$$

where F is a graph forest representing a distribution system configuration, and every tree in the forest corresponds to a feeder connected to a substation; $\phi(F)$ is the number of customers out of service in a configuration F; $\varphi(F,F^0)$ is the number of switching operations necessary to transfer the maximum number of consumers possible, to obtain a configuration F from a configuration F^0; $\gamma(F,F^0)$ is the amount of load relieved to obtain a configuration F from a configuration F^0, after exhausted attempts to load transfer. $\omega(F)$ are the power losses in the system, in the configuration F; A is the incidence matrix of F; x is the vector line current in configuration F; b is a vector containing the complex currents in load bars $(b_i \le 0)$ or current injections on substations $(b_i > 0)$; $X(F)$ is the greatest value of network loading in configuration F, provided by the ratio $x_j / \overline{x}_j$, in that, $\overline{x}_j$ is a higher current limiting for each current x_j in a line j. $B(F)$ is the greatest value of voltage drop in a configuration F, provided by the ratio $b_s / \overline{b}_s$, in that $\overline{b}_s$ is an upper limiting for each current injection b_s provided by a substation s; $V(F)$ is the greatest value of voltage drop in a configuration F, provided by the greatest value of $|v_s - v_k| / \delta$, and v_k is the magnitude of voltage, in $p.u.$,on bus k and v_s is the magnitude of voltage, in $p.u.$, on bus s that connects with the bar k, and δ is the maximum permissible voltage drop.

The formulation presented can be summarized as:

i. penalties for solutions that violate restrictions $X(F)$, $B(F)$ e $V(F)$;

ii. use of the Node-Depth Encoding Representation (NDE) [7], an abstract data structure capable of storing and manipulating generating forests efficiently, ensuring that all modifications will produce also a generating forest;

iii. solve $Ax = b$ using the forward-backward sweep load-flow algorithm with NDE, that organizes all nodes according to a relationship known as parent-child model [8] setting in each forest F, that is, without the need for an algorithm that makes ordering.A equação é então reescrita como:

$$\begin{aligned} Min.\ \ & \phi(\mathrm{F}), \varphi(F, F^0), \gamma(F, F^0), \omega(F)\ \ e \\ & w_x X(F) + w_b B(G) + w_v V(G) \end{aligned} \qquad (2)$$

$$\begin{aligned} s.a:\ \ & Load\ Flow\ with\ NDE, \\ & F\ is\ a\ forest\ provided\ by\ NDE, \end{aligned}$$

and w_s, w_b e w_v are weights defined according to the value of operational constraints, as follows:

$$w_x = \begin{cases} A, & if,\ X(F) > 1 \\ 0, & otherwise; \end{cases}$$
$$w_b = \begin{cases} B, & if,\ B(F) > 1 \\ 0, & otherwise; \end{cases} \qquad (3)$$
$$w_v = \begin{cases} C, & if,\ V(F) > 1 \\ 0, & otherwise; \end{cases}$$

wherein A, B and C are positive values.

NODE DEPTH ENCODING REPRESENTATION

A graph F is a pair $\big(N(F), E(F)\big)$, wherein $N(F)$ is called a finite set of nodes and elements; $E(F)$ is a finite set of elements called edges. A DS can usually be represented by graphs, where the nodes represent the sectors and the edges connecting the bars represent the switchgear.

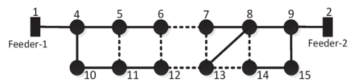
The graph shown in Figure 1 is a DS with two feeders. Each feeder is represented by a tree formed by solid lines and dashed lines. The edges represented by solid lines symbolize normally closed switches – NC, and dashed edges symbolize normally open switches – NO. Nodes 1 and 2 are the roots of trees 1 and 2 and these nodes correspond respectively to the sectors 1 and 2 in the graphs forest and symbolize the substations - SS, 1 and 2.

The NDE representation [9] is basically a graph tree in a linear list containing the nodes of the tree and its depths. This structure can be implemented in a vector of ordered pair (n_x, d_x), wherein n_x is the node identification and d_x is the depth of the node in this tree. The order in which the pairs are willing in this list is essential and can be achieved by a depth-first search algorithm, inserting the pair (n_x, d_x) the list each time the node n_x is visited by the algorithm.

This process runs offline. Figure 1-b illustrates the NDE snown in Figure 1-a. As can be seen in Figure 1-b, the forest as a whole, is represented by the union of NDEs of all the trees of the forest.

From NDE, two operators have been developed to efficiently manipulate the forest F^0, producing a new forest F. Are the operatos PAO (Preserve Ancestor Operator) and CAO (Change Ancestor Operator).

Each operator making changes to the forest through cutting actions and / or graft generating a new forest. Both are computationally efficient, requiring complex runtime $O(\sqrt{n})$, wherein n is the number of sectors, to create a new forest. Detailed information of these operators can be found at [2].



(a)

$$T_1 = \begin{bmatrix} depth \\ node \end{bmatrix} = \begin{bmatrix} 0 & 1 & 2 & 3 & 2 & 3 & 4 \\ 1 & 4 & 5 & 6 & 10 & 11 & 12 \end{bmatrix}$$
$$T_2 = \begin{bmatrix} depth \\ node \end{bmatrix} = \begin{bmatrix} 0 & 1 & 2 & 3 & 2 & 3 & 3 \\ 2 & 9 & 15 & 14 & 8 & 7 & 13 \end{bmatrix}$$
(b)

Figure 1 – a) A distribution system with two feeders modeled on graphs with two dispersion trees; b) NDE vector graph Forest of Figure 2a. [10].

DEVELOPMENT

This section will present: a) the methodology used as a basis; b) how the utilities currently conduct this study; and c) the proposed methodology.

A. MEAN

Evolutionary algorithms, including genetic algorithms are the most popular, are optimization techniques based on the mechanisms of evolution and genetics.

Therefore, the artificial intelligence technique called Genetic Algorithm (GA) becomes a very attractive alternative for troubleshooting the load shedding type as too versatile and robust optimization problems difficult mathematical modeling and not to use the calculation of equations with derivatives, but act directly in the search for viable solutions in space, working with probabilistic transition rules.

The peculiar features that ensure its robustness are working with parameter encoding rather than the original problem parameters; search optimum solution from a set of various solutions and not from one solution; employ an evaluation function for the different solutions found and using probabilistic and not deterministic rules in search of these new solutions. It must be warn, that genetic algorithms have no guarantee of optimality of the solution.

Thus, the methodology used as base, called Evolutionary Multiobjective Algorithm in Tables – MEAN, [2] makes use of NDE and was originally developed to treat problems of network reconfiguration, as far as the resistive loss reduction and restoration of power.

This algorithm has tables that store the best individuals (network configuration) to certain pre-set parameters, such as network load, loading of the substation, voltage drop, resistive losses, aggregation function and number of manoeuvres.

In this version of MEAN, after the isolation of a sector in fault (since it is a problem of restoration) and reconnection of loads out of service, the generation of new individuals is made by application of RNP operators.

Firstly, a subpopulation P_{sort} is randomly selected, and then within that table an individual F^0 is randomly choosed. Following this procedure, the PAO and CAO operators are applied and the individual is evaluated by MEANS of forward-backward sweep load-flow algorithm technique with NDE type current sum. This new individual F will be included in a subpopulation table if it is not filled, otherwise the F will replace the worst individual inside the table. This procedure is performed until the maximum number of generations has been reached.

The table store the best individuals for certain solutions. Thus, T_1 stores the solution with the lowest aggreagation function values, T_2 are solutions with the lowest values of resistive losses; T_3 store solutions with lower network load values; T_4 stores the solutions with the lowest substation load values; T_5 stores the solutions with the lowest maximum voltage drop values; T_{5+i} $(1 \le i \le 5)$ store solutions with lowest values of resisitive losses, and with i pairs maneuvers after the insulation failure and reconnection of loads without supply.

B. Methodology Currently Used

Currently, there is a technical guidance proposed by the Brazilian electric sector regulator agent and performed by energy utilities called (PCMC – Load Shedding Manual Plan), which suggests the implementation of complementary actions on MT through the PCD (Load Shedding Distribution Plan), but lacks flexibility, because it is a static load cutting plan against certain contingencies in supply.

This plan is drawn up for a period of four months of study, based on procedures, which although marked out in day to day experience, are not able to evaluate a large number of alternatives and/or transfer cutting loads, considering the measurement data and the current state of the network.

Mostly, the actions indicated by the current method, include the opening of the breaker at distribution substation feeder by removing all power supply operation

A. MEAN-LS

For determination of a methodology that take into account analysis of demand adequacy in regard to the transfer and / or load sheeding which no restrict the space of MEAN search, three new subpopulation tables were inserted and stores: i) so-lutions with lesser amounts of maneuvers (feasible) suited to the required demands; ii) solutions that improve demand, con-sidering load sheeding; iii) solutions that improve demand re-quired with larger values of transferred consumers.

Obviously, when the charge transfer analysis, the circuit that will receive the transferred charge amount must be able to transport such charge. Thus, an usual criterion for circuit load fixation on normal system operation is to define the number of circuits that will receive the load to be transferred. Usually, two circuits rely one other circuit and establishes that the loading of the circuits that receive loads does not exceed the thermal limit. Thus, is adopted:

$$S_{term} = S_{reg} + \frac{S_{reg}}{n} \tag{4}$$

where: n is n is the number of circuits that will receive the load; S_{term} is the corresponding load to the circuit thermal limit, and S_{reg} is the circuit loading for operation under normal conditions, and is given by:

$$S_{reg} = \frac{n}{n+1} S_{term} \tag{5}$$

in the case that two relief circuits corresponds to 67%of thermal capacity limit. With the advent of automation and automatic switches flexibility is increased (higher "n") and hence higher load of feeders in normal conditions of operation

To minimize the table of number of operations, each rows of table stores the best individual with a number of maneuvers pairs. For example, in the first row are the best individuals with one pair of maneuvers, the second line with two pairs, and so on. if individual is generated better match than any individual present on each table, the worst is replaced by that individual.

To contemplate the existing of special loads (hospitals, large customers etc.) one of the alternatives is to prevent the transfer of sectors with these kinds of consumers restricting the relocation of special loads. Thus, the special customers remaining bound will not be reassigned to another feeder, this maneuver independently be useful to reduce voltage drops, the network load or the substation. Another way is to penal-ize these sectors based on load prioritization index, prepared by the distribution utility.

In order to optimize the computer processing, since the runtime requirements are very limited, the computational development conducted was directed to the software execu-tion by the Graphics Processing Unit (GPU), given its large processing capacity, using parallel computing platform CUDA (Compute Unified Device Architecture) [6]. Thus, the use of CUDA platform ensures increased MEAN-LS perfor-mance and methodologies of power flows, which is a compu-tational optimization prerequisite for fast make MEANS-LS calculations.

B. Communication System

The MEAN-LS makes use of a complex system of data acquisition on-line to thereby achieve accurate and highly reliable results. The following are the information storage systems along with information processing technology.

a) ACAAM

The Computational Application of Acquisition and Measurements Storage (ACAAM) is an application that aims to provide communication between the MEAN-LS and intelligent measuring systems installed along the MV of the Power Utility distribution networks, enabling instant purchase electrical parameters of feeders and storage of historical measurements in the database.

Thus providing real-time information to calculate demand and power flow in the distribution networks.

b) SCADA

The Supervisory Control and Data Acquisition System (SCADA), existing in the infrastructure of the electric company, is responsible for monitoring and supervising the variables and the existing control systems devices. In this way the data obtained by the SCADA are used on demand correction of transmission and distribution network

c) GSE

The GSE data server is responsible for the stores of distribution network information (switches, buses, sections, etc.) in real time. Thus, the load management software developed (that uses the algorithm proposed) uses the information from the maneuvering switches states attending the GSE in order to fit the setting of the network topology and the current state of the keys at parse time.

RESULTS

This section evaluates the performance of the MEAN-LS for the problem of load relief applied to a system of distributing tion presented in [11] and illustrated in Figure 3 and Figure 2. The experiment aims to show the ability of the algorithm to improve the quality and quantity of the alternative front solutions currently in use.

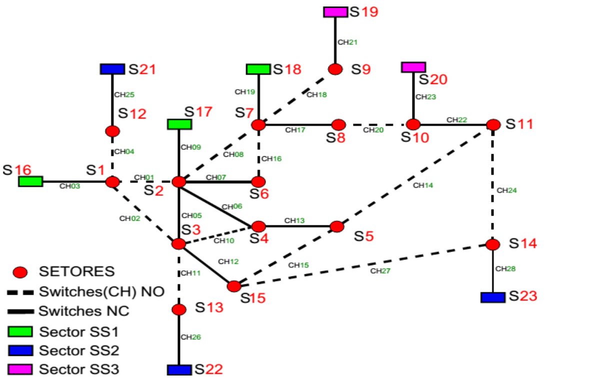


Figura 2 - Validation System in Sector Representation where “SS” are Substations.

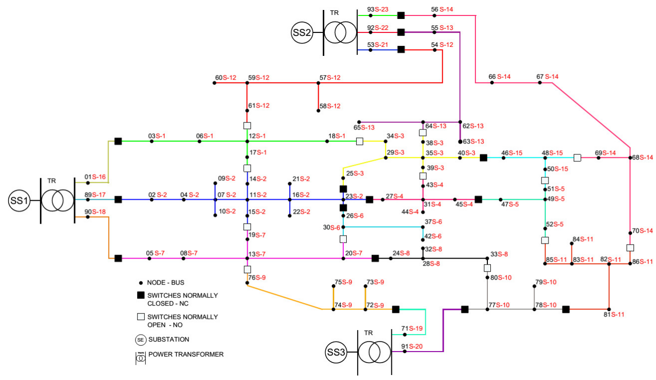


Figura 3 - Validation System

The initial parameters used in MEAN-LS are $G_{\max} = 15000$, the maximum number of individuals that are generated; $S_{Pi} = 5$ is the number of individuals that can be stored in a table T_i. The weights w_{ii} penalise the restrictions on aggregate function (eq. 2), where $A = 100$, $B = 100$ e $C = 100$.

The results presented in Tables I and II were obtained using a distribution system consisting of 86 bars, 23 sectors, 28 keys and 8 feeders, represented by Figure 2. Table II shown the results obtained by the application of MEAN-LS.

It is observed that, for each characteristic, the outcome results are distinct. In the more general case, Fitness, by which the user configures the weights of each feature to be optimized, the voltage drop was the smallest and the biggest shipment of feeders. In table III are presented the results of the sequencing.

TABLE I. RESULTS BY TYPE OF RESTRICTION

Features.	Gen	Losses (kW)	Voltage Drop (%)	Feeder Load (%)	Substation Load (%)	Actions
Fitness	360	547,51	4,84	78,15	66,95	5
Losses	1345	417,96	7,55	70,25	109,17	6
V drop	312	945,56	5,27	78,15	81,31	3
Feeder Load	75	845,20	9,54	48,15	83,43	2
Substation Load	1312	422,01	10,39	48,15	81,69	4

TABLE II. SEQUENCING OF MANEUVERS BY FEATURE

Sequence	Fitness	Losses	Voltage Drop	Voltage Drop	Feeder Load	Substation Load
1	A19	A21	A 22	A 22	A 13	A 13
2	F 18	F 18	F 14	F14	F14	F14
3	A 22	A13	A 7	-	-	A 5
4	F 14	F 14	-	-	-	F 2
5	A 17	A 5	-	-	-	-
6	-	F 2	-	-	-	-

A. Open Switch, F. Close Switch

It is observed that the restrictions Fitness and Power outage resulted in load shedding (odd number of switching's).

After 15,000 assessments made by the algorithm, Fig. 4 shows the convergence of the best individual for the subpopulation table related to the aggregation function

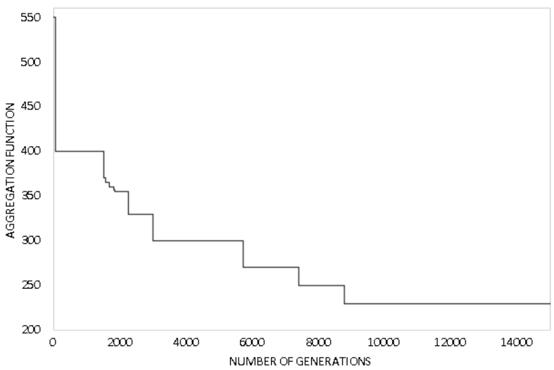


Figure 4 - Best Individual from found by the MEAN-LS at each iteration.

CONCLUSION

A computational tool developed for evaluation and management of the electrical system by providing subsidies to support the controller's decision-making when the need to transfer and / or cut a certain amount of load in this paper was presented.

The system developed made use of robust methodologies for calculation of power flows, technical performance assessment network, demand calculations, evaluation of transfer scenarios and selective cutting loads and optimized sequencing of maneuvers, as well as the adoption of Smart Grid concepts for electric data real-time network and the use of high-performance hardware (parallel and GPU processing) for the rapid diagnosis of the problem and solution presentation achievable.

The methodologies involved have been deeply studied and algorithms were meticulously structured and optimized for work with parallel processing.

The use of CUDA ™ platform ensured an increase in performance of MEAN-LS and methodologies of power flows.

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