OPTIMIZED SWITCHING USING HEURISTIC ALGORITHM TO SUPPORT THE RESTORATION OF DISTRIBUTION SYSTEMS

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ABSTRACT

This paper presents a methodology for switching optimization in the distribution network on the occasion of a fault, or to proceed a scheduled outage to make a preventive maintenance service. Additionally, a correspondent software (called CEMOP) has been developed for reconfiguration purposes due to forced or scheduled outages on distribution networks, considering parallel interconnection with other feeders. This project has been developed in partnership with CEMAR, an electric utility located at the northeast of Brazil which supplies approximately 1.8 million customers (approximately 6.6 million inhabitants), in the state of Maranhão, in Brazil.

INTRODUCTION

The interruptions in the supply of electricity arise when a fault occurs, such as, a phase to ground short-circuit due to a broken conductor, or due to preventive maintenance services in the network components. In both cases, one should have a switching plan to restrict to the minimum, the area to stay de-energized. In general, the following actions should be taken when a fault occurs at any point in the network:

a) Identification of where the fault occurred. In non-automated networks, this activity is accomplished by a maintenance crew, who checks the network by visualizing the fault and / or the operated protection device;

b) Isolate the smallest possible part of the system by opening the closest switches from the fault;

c) Flag normally open switches (which cannot be operated while the fault is not cleared) by placing warning flags. This action aims to ensure the safety of the maintenance crew who will do the repairs at the network;

d) Operate switching devices which will restore the supply to the upstream and / or downstream loads of the isolated section. Obviously, the switching is not performed if the network can be quickly repaired;

e) Correction of the fault;

f) Additional switching to return to the normal configuration of the system (when parallelism of circuits may occur).

The solution of electric network reconfiguration problem has been found, using a mixed methodology comprising a search process of solutions, using the depth-first search technique through the gradient method [1], combined with a ranking of alternatives based on the variables weighting.

PROCEDURES FOR THE SWITCHING SIMULATION

The actions and operations required to solve the outages in the distribution network of CEMAR are described in this item. These actions are important for understanding the reconfiguration methodology applied to the network problem in real operation.

The sequential actions are as follows:

a) Visualization of the medium voltage network in real time from GEOREDE (CEMAR´s GIS).

Not only the topological network data are read, but also the monthly consumption of distribution transformers, and billed / measured demand of medium voltage consumers.

The feeders current measurements of the respective substations (to adjust the consumers demand) are obtained from ELIPSE and NOTUS systems (SCADA systems of CEMAR).

b) Upon receipt of the location of the fault, the user informs through the interface of the computational model, which branch of the network the fault occurred. From this stage, the software is able to yield a possible reconfiguration of the network.

c) The software is capable of, based on technical criteria, such as loading, voltage level, number of affected consumers and the maximum current of the feeder, indicating the best switching and related switches, in order to isolate the fault.

d) The user can also manually simulate switching and generate a sequence of opening and closing of switches.

e) It should be pointed out that GEOREDE and OPER (distribution network management system) are not altered at any circumstances, and eventual changes in these databases must always be "mirrored" to GEOREDE system, by CEMAR´s Information Technology area.

f) The system will then present to the user the reconfigured network, highlighting which switches are temporarily operated (different state from the normal one).

CONCEIVED METHODOLOGY FOR SWITCHING OPTIMIZATIONS OF DISTRIBUTION NETWORKS [2]

The problem of reconfiguring electrical networks may be divided into two stages:
• Initially, one should operate the necessary switches to isolate the section of the network where the fault occurred, and signalize the switches which are connected to the faulted section that cannot be closed until the fault is not cleared;
• Subsequently, one must reconfigure the rest of the network.

To find the solutions, the depth-first search technique through the gradient method has been employed, and to establish the reconfiguration plan for the network restoration, four optimization attributes have been considered:
a) The main objective is to maximize the number of transferred consumers to mitigate the extent of the outage;
b) The second relevant objective considered is regarding the type of consumer affected by the switching;
c) The third goal, also considered relevant is to maximize the operational attribute, which takes into account:
• The amount of operated switches and;
• Type of switch operation (manually or remotely). It is noteworthy that in the latter option, a remotely controlled switch that was temporarily disabled, for example, due to a telecommunication problem, would have the same grade as a manually operated switch through load-buster tool (both would be operated locally).
d) The fourth objective, considered as being less important (because one assumes that the outage occurs in a short period), refers to the maximization of a technical quality index, which takes into account voltage levels and loadings of the resulting system including the neighbors feeders (if any) which have received load from the faulted feeder.
The subject as such defined is a problem with multiple objectives. For the evaluation of the solutions, the weighted average method has been used, by assigning different degrees of importance (by weight) at these four objective functions.

The optimization attributes have been thus modeled:

a) Number of transferred consumers (QC): To evaluate the proposed criterion, indices have been attributed to the amount of transferred consumers. Thus:
• Transfer up to 50 consumers: Low grade (value 0);
• Transfer 51-500 consumers: Average grade (value 5), and;
• Transfer more than 500 consumers: High grade (value 10).
Thus, Q.C. may take the values 0, 5 or 10.

b) Type of consumers affected by the switching (TC): The following indices have been proposed to evaluate this item:
• Switching to feeder without VIP (very important customer): High grade (value 10), and;
• Switching to feeder with VIP: Average grade (value 5).
Thus, T.C. may take the values 10 and 5.

One observes that this item has been proposed to contemplate the effects on some types of load, which may be susceptible to momentary variations, as well as significant drop voltages, which may cause inconveniences, either in steady state situations (may cause production loss, malfunction of equipment of life support, etc.), or during transient periods (may cause breakdown of appliances, equipment, etc.).

c) Operational attribute (IO): This item is composed by the following variables:
• Number of operated switches and;
• Form of switches operation.

Thus, the index is then calculated by the equation (1):

$$I.O. = \frac{p_{qc} * N_{qc} + p_{fa} * N_{fa}}{p_{qc} + p_{fa}} \tag{1}$$

Where:
• N_{qc} and N_{fa}: Grades regarding the amount and form of operation of involved switches, respectively;
• P_{qc} and p_{fa}: Weights assigned to the amount and form of operation of switches, respectively.

The grades for the amount of switches and form of operation, in turn, are calculated by:

$$N_{qc} = \frac{N_{qc1} * S_{qc1} + N_{qc2} * S_{qc2}}{S_{qc1} + S_{qc2}} \tag{2}$$

$$N_{fa} = \frac{N_{fa1} * S_{fa1} + N_{fa2} * S_{fa2}}{S_{fa1} + S_{fa2}} \tag{3}$$

Where:
• N_{qc1} and N_{qc2}: Grades for the amount of operated switches:
  - Up to 3 operated switches: High grade (value 10), and;
  - Over 3 operated switches: Low grade (value 5).

• N_{fa1} and N_{fa2}: Grades attributed to the type of switches operation:
  - Remote: High grade (value 10), and;
  - Local: Low grade (value 5).

• S_{qc1} and S_{qc2}: Switched loads with 3 or more than 3 switches;
• S_{fa1} and S_{fa2}: Downstream loads of the faulted section which is operated locally or remotely;

d) Technical quality index (IT): This index is calculated by the weighted average between two variables and their respective weights:
- Voltage level: The score is obtained by separating the load in three voltage levels (critical, precarious and adequate);
- Loading: The loading distribution is also divided into 3 ranges (high, medium, low).

Thus, the index is then calculated by the equation (4):

$$I.T. = \frac{p_v * N_v + p_c * N_c}{p_v + p_c} \quad (4)$$

Where:

- N_v and N_c: Voltage and loading grades, respectively;
- p_v and p_c: Assigned weights to voltage level and loading, respectively.

The voltage and loading grades, in turn, are calculated by (5) and (6):

$$N_v = \frac{N_{v1} * S_{v1} + N_{v2} * S_{v2} + N_{v3} * S_{v3}}{S_{v1} + S_{v2} + S_{v3}} \quad (5)$$

$$N_c = \frac{N_{c1} * S_{c1} + N_{c2} * S_{c2} + N_{c3} * S_{c3}}{S_{c1} + S_{c2} + S_{c3}} \quad (6)$$

Where:

- N_{v1}, N_{v2} and N_{v3}: Grades assigned to the voltage levels 1 (critical), 2 (precarious) and 3 (adequate): Values 0, 5 and 10, respectively;
- Adequate voltage level: 0,93 p.u. $\leq$ v $\leq$ 1,05 p.u.;
- Precarious voltage level: 0,90 p.u. $\leq$ v $<$ 0,93 p.u.;
- Critical voltage level: v $<$ 0,90 p.u. or v $>$ 1,05 p.u..
- N_{c1}, N_{c2} and N_{c3}: Grades assigned to the loading intervals 1 (loading inferior to 70%), 2 (loading between 70% and 100%) and 3 (loading above 100%): Values 10, 5 and 0, respectively;
- S_{v1}, S_{v2} and S_{v3}: Loads supplied by voltage levels 1, 2 and 3, respectively;
- S_{c1}, S_{c2} and S_{c3}: Loads supplied by loading intervals 1, 2 and 3, respectively.

Finally, the Merit Index (MI) of the alternative is calculated from the equation (7):

$$I.M. = \frac{p_q * Q.C. + p_t * T.C. + p_{IO} * I.O. + p_{I.T.} * I.T.}{p_q + p_t + p_{I.O.} + p_{I.T.}} \quad (7)$$

Where:

- Q.C., T.C., I.V. and IT: Attributes of optimization, for the amount of transferred consumers, type of consumers affected by the reconfiguration, operational and technical index, respectively;
- p_q, p_t, $p_{I.O.}$ and $p_{I.T.}$: Attribute importance degrees, represented by means of weights.

In the optimization tool there are a few restrictions which are considered to limit the type of solution to be evaluated, such as:
- The candidate solutions will always return to their normal configuration;
- The parallelism between feeders will be considered only by switches which are located upstream of voltage regulators.

RESULTS

As an real example of CEMOP application, a reconfiguration case of feeders RNC-01C4 (in red) and SLF-01C4 (in blue) is presented in Figure 5 as follows, due to a fault at section "33806" of feeder SLF-01C4, both located in Greater São Luís – state of Maranhão.

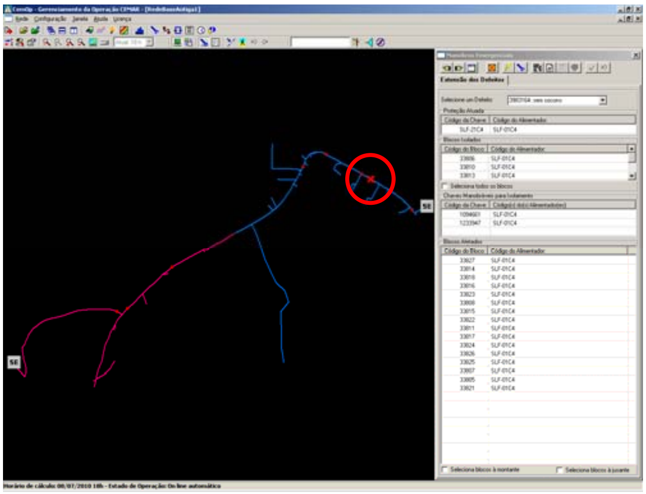

Figure 5 – Fault simulation at section "33806" of feeder SLF-01C4

Figure 6 and Figure 7 present the upstream and downstream de-energized sections, respectively, due to the tripping of protections devices.

By clicking at the button (), CEMOP software yielded the Alternative # 1, as being the best solution, as shown in Figure 8, taking the following measures: Closing the tie switch 0022144, opening the switch 1233947 and opening the switch 1094661.

By performing the switching operations suggested by the Alternative # 1, that is, clicking at the button (), one has the new configuration as shown in Figure 9 as follows.

The feeder RNC-01C4 helps the feeder SLF-01C4 by acquiring the loads between the interconnection switch 0022144 and the normally closed switch 1233947. In this case, the loads located between the switch 1233947 and 1094661 will be restored after clearing the fault.

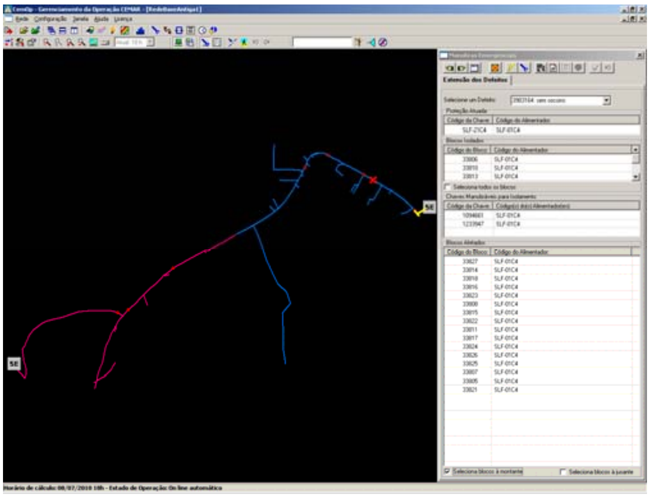

Figure 6 – Upstream de-energized section affected by the fault at feeder SLF-01C4

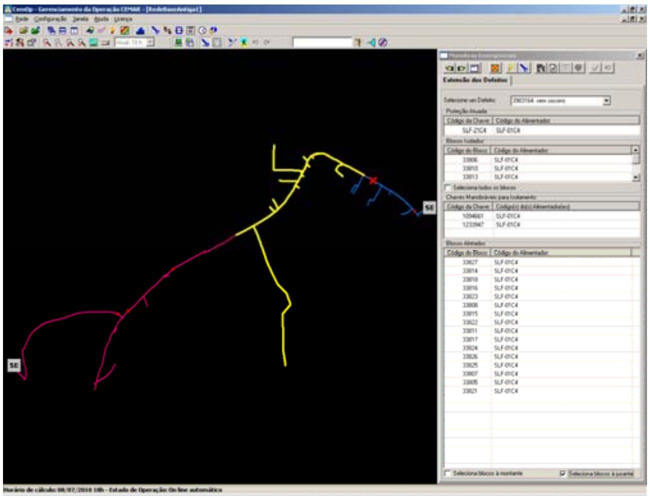

Figure 7 – Downstream de-energized section affected by the fault at feeder SLF-01C4

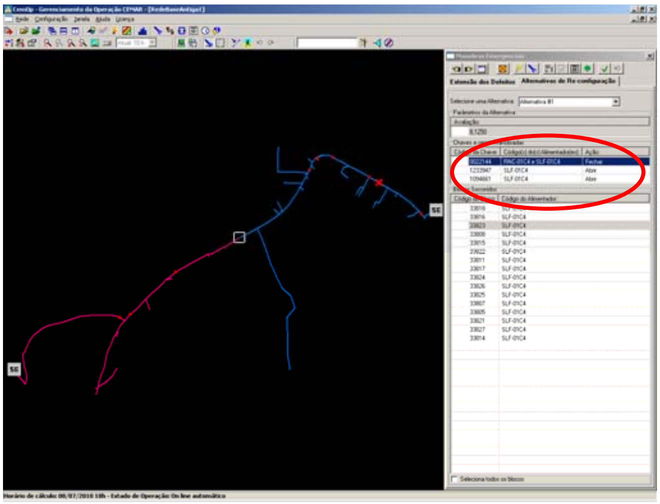

Figure 8 – Best solution (Alternative #1) yielded by CEMOP software

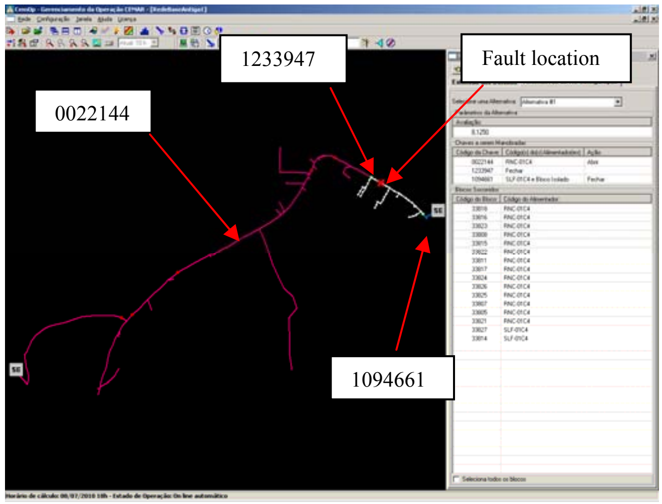

Figure 9 – Reconfiguration suggested by the Alternative # 1

CONCLUSIONS

CEMOP shows an evolution in real time operation of CEMAR´s dispatch center, since it presents alternatives for immediate switching in response to outages that happen at the distribution network of utility´s concession area.

Thus, one allows that typical planning data, such as, loading and voltage levels (accordingly updated by feeders current measurements gathered at substations), with operational data, such as number of affected consumers and type of operated switches, as well as taking into consideration the importance of consumers involved in the reconfiguration, may be evaluated through weights attributed to each variable so as to indicate the best alternative(s) to a particular fault.

Additionally, one considers the possibility of additional research and developments on the current topic in order to improve the reconfiguration alternatives of the tool, whether due forced outages or by scheduled ones, taking into account the reconfiguration cases within the substations.

REFERENCES

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