COORDINATION AND AUTOMATIC SELECTIVITY OF DEVICES PROTECTION IN DISTRIBUTION NETWORKS

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ABSTRACT

Among the several components of distribution systems, protection devices present a fundamental importance, since they aim at keeping the physical integrity not only of the system equipment, but also of the electricians and the population in general. The correct application of the protection devices demand an elevated amount of time, being extremely laborious due to the great number of devices, besides the very dynamic behaviour of distribution networks and the need for constant expansion. This article presents a computational tool developed with the objective of automatically determining the adjustments of all protection devices in the distribution networks so as to obtain the best technical application, optimizing its performance and expediting the making of protection studies.

INTRODUCTION

Computational tools for the making of protection studies available in the market today are basically curve plotters where the user's direct interference is necessary in the launching, as well as in the coordination and selectivity analyses, being susceptible to errors on the part of the user and not always considering the best technical analysis.

One of the main objectives of protection devices is isolating the faulty sites safely and interrupting the least possible consumers. Hence the protection devices interfere directly with technical indicators of continuity established by the Brazilian government, which, when violated, are reflected in heavy penalties to electrical power distributors.

These questions motivated the development of algorithms and of a computational tool for the optimization of protection devices for distribution networks, as much regarding coordination and selectivity, as regarding allocation of devices. At the Universidade Federal de Santa Maria (Federal University of Santa Maria, Brazil), there is presently a software being developed, which is denominated ASP or Análise de Sistemas de Proteção (Protection Systems Analysis) which aims at allowing the correct automatic dimensioning for all the protection devices of the distribution network, indicating possible problems of selectivity and safety, as well as determining its best application for the reliability of the system. This software also allows the analyzing of electrical behavior at any one point of the distribution system as it refers to active and reactive potencies, load and short circuit currents, tension, potency factor, charging of the conductors and transformers, potency losses, besides analyzing the possibility of installation of maneuvering and protection devices, aiming at performance optimization as allowed by available resources

TOPOLOGY ALGORITHM

So as to allow the making of reliability analyses of a distribution system, it is necessary to know the topological representation of the system being studied with existing connections to networks, the network extensions, network extensions, load flow, short circuit currents and protection, as well as maneuvering devices originally installed.

Traditionally the topological representation of electrical networks is done through matrix equations, where all element connections are interpreted so that one is able to reproduce as faithfully as possible the actual configuration of the distribution network being studied. In this type of system, the denomination conventionally used is "knot", to identify the remarkable points in the network, and "ramification" for elements which are connected between two knots (initial and final ones).

Nevertheless, for actual distribution systems, the matrix may have a dimension that is too elevated, with few elements different than zero. These conditions do not allow the rational use of computational memory. Besides, memory problems grow with the elevation in dimension of the incidence matrix. For this reason, a method for the representation of the radial distribution networks was developed, which considers only the information about the connections that really exist, foregoing the use of matrixes. To achieve that, it was necessary to construct two sets, one containing the information on knots, and the other containing the information on ramifications. As each ramification is represented by an initial and a final knot, it is essentially necessary that the initial knot be the closest to the main source providing power, that is, the substation.

Therefore it was necessary to attribute two characteristics to the elements to represent the connections existing between them:

φ_r - information about the ramification within the "ramification" set;

β_r - information about the feeding ramification of the ramification being considered.

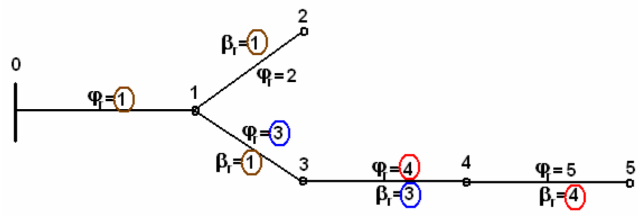

FIGURE 1 - Representation of Parameters φ_r and β_r.

The parameter φ_r serves only to identify the order of the network ramifications within the ramification set. We opted for a numerical increasing order. The parameter β_r takes on the value of the parameter α_r from the ramification which is a back of the ramification being considered.

TABLE 1 - Ramifications for the Network in Figure 1.

Initial Knot	Final Knot	Characteristic φ_r	Characteristic β_r
0	1	1	-
1	2	2	1
1	3	3	1
3	4	4	3
4	5	5	4

We remark that the definition of parameters β_r and β_n is extremely simple, that is, to determine such values it is only necessary to verify which tract provides power to the analyzed ramification and knot respectively. Another advantage of this algorithm is that it allows the sets of knots and ramifications to be built step by step, without the need to recalculate the parameters β_r and β_n defined previously. This is quite useful when one wishes to add other feeders or new tracts because besides expediting the process, it is also possible to ascertain if the network information is correct and complete.

SELECTIVITY ALGORITHM

This methodology for representation of distribution networks topology provides the electrical way of the system being analyzed, allowing the identification of the dependencies between maneuvering and protection devices and the punctual evaluation of the electrical powers, such as, load currents, short circuit currents, conductors´ ampacidade and network extensions. This allows for the analysis of the electrical behavior at any one point of the distribution network (flow algorithms of power and short circuit will not be demonstrated in this article due to the limitation in number of pages.)

The device most abundantly used in distribution networks is the fuse key, which are basically devices that operate according to the principle that a current that passes by an element generates heat proportional to the square power of its intensity. When a current reaches the maximum tolerable intensity by the fuse element of the key, the generated heat does not dissipate fast enough, melting a component and interrupting the circuit. This way the fuse elements have the opposite operation characteristic in the relation time-current, that is, the higher the circulating current, the less time of element fusion.

Through the topology algorithm, using the currents summation method, a calculation of the flow of power is done, determining the maximum values of load current in each device. Based on these currents the ASP executes a preliminary dimensioning of the minimum fuse element to be applied in each key so that a burning of the fuse element does not occur due to the maximum load current (Nominal element Current). This value is determined through the Equations 1 and 2, followed by Table 2.

$$K.In \le Ie \qquad (1)$$

$$K = \left(1 + \frac{C\%}{100}\right)^n \qquad (2)$$

In = Maximum nominal current in the ramification;
Ie= Nominal fuse element current;
C% = Annual growth rate of the system being studied;
N = Number of foreseen years until the next study.

TABLE 2 – Sustainable Fuse element Currents

Fuse Element	Nominal Current	Fusion Current
6K	6A	12A
10K	10A	20A
15K	15A	30A
25K	25A	50A
40K	40A	80A
65K	65A	130A
100K	100A	200A

After the preliminary dimensioning of the minimum elements to be applied, the ASP, through the calculated topology and short circuit currents, identifies the correlation between the protection devices and the need to readjust the fuse elements, so that there will not be a simultaneous burning of elements, preventing the lack of coordination.

Independently of their nominal values, due to the operational characteristic of the fuse elements, they may fuse in quasi zero time to very elevated currents. So being, the selectivity between the elements must obey Table 3, which limits maximum fault current values so that the elements operate in coordination.

OBS: For "reclouse keys" an auxiliary Table is considered.

TABLE 3 –Selectivity between Fuse Elements

Protection Key	Protected Key					
	10K	15K	25K	40K	65K	100K
	Short Circuit Current in Protection Key					
6K	190	510	840	1340	2200	3900
10K	-	300	840	1340	2200	3900
15K	-	-	430	1340	2200	3900
25K	-	-	-	660	2200	3900
40K	-	-	-	-	1100	3900
65K	-		-	-	-	2400

For each fuse key, the key back is analyzed, the analyzed key being characterized as the "Protective Key", and the key the front as the "Protected Key". The elements of the Protected Key are dimensioned according to the value of the short circuit current simulated in the site of the Protective Key.

One may verify by the Selectivity Table between fuse elements that the higher the level of the punctual short circuit, and the more fuse keys there are in series, the higher will be the resulting protected fuse element. In most cases, elevated fuse elements compromise the selectivity of other protection devices, such as recloser and the protection devices of over current of the feeder module. Thus, the ASP analyzes the performing times of the fuse in relationship to the operating time of the other protection devices, verifying the possible lack of coordination among devices. In case of lack of coordination identified among devices, the ASP verifies the necessary action for the correction, be it through the readjusting of the protection (recloser), or be it through the readjusting of the fuse. In the latter case, ASP identifies which keys should be removed or rearranged, according to the optimization algorithm (described in IV), allowing the reduction of fuse elements and the coordination among all protection devices of the system in study.

OPTIMIZATION ALGORITHM

Based on topology methodology presented in Item II, an algorithm was designed for the evaluation of insertion or removal of protection devices with the purpose of reducing the number of devices in series in the critical area allowing for the use of elements with inferior fusion times and making selectivity viable with the protection of the substation and/or distribution reclosers. This algorithm takes into account the minimization of the relation between the expected value of interrupted power by protection device or interrupted consumers, according to the algorithm requested by the user.

The most important factors for reliability analyses are the frequency of faults to which the system is submitted and the measurement of their durations. The frequency of faults may be quantified through the indicator denominated Fault Rate [ω_o], defined as the number of faults during a certain period by the total length in kilometers of the network. This indicator may be considered by protection device or by feeder, according to the option of the user.

Now the duration of faults is associated to other factors and may be accounted by three indicators: the Average Time of Dispatch [τ_{des}] defined as the interval between the record of the complaint of lack of power by the client to the Call Center until the start time of dispatch of the electricians team; Average Time of Traveling [τ_{loc}] defined as the interval between the start of traveling until the time the electricians team locates the fault; and the Average Time of Maintenance [τ_{man}] defined as the interval between the time of location of the fault until the time of its correction and the reestablishment of power supply.

The algorithm proposed presents three distinct stages of calculation:

1st Stage: Determining the load potencies or consumers accumulated in each knot of the network:

Through the topology algorithm, one obtains the accumulated potencies or the accumulated number of consumers in each "network knot". Consequently, it can be integrated to the electrical load modeling system through typical load curves [S_{SE}], [S_{EP}] and [S_{EM}].

2nd Stage: Definition as the possible tracts of commutation by the protection and maneuvering devices;

The interpretation of the network path by the topology algorithm determines the commutation devices and protection in series, the length of the network accumulated to each tract up to the end of the circuit and the tracts of the network protected by protection devices, since it is the protection devices that interrupt faults the front of the maneuvering devices [ℓ_{SE}], [ℓ_{EP}] and [ℓ_{EM}].

3rd Stage: In the third stage a punctual optimization evaluation is done for each device by a test in three batches of calculation: the batch for faults in the tracts protected by the feeder breaker, plus the batch for faults in the tracts the front of each protection device, together with the batch for faults in the tracts the front of each maneuvering device, which are later maneuvered to isolate the faults and allow the partial reestablishment of the load.

1st Batch: Power interruption estimative for faults in the tract protected by the breaker.

$$\left[(\omega_o \cdot \ell_{SE}) \cdot S_{SE} \cdot (\tau_{des} + \tau_{loc} + \tau_{man})\right] \qquad (3)$$

ω_o : Rate of faults per network kilometer;

ℓ_{SE} : Commutation Zone of the breaker;

S_{SE}: Power supplied by the feeder;

τ_{des} : Average time of dispatch;

τ_{loc} : Average time of traveling;

τ_{man} : Average time of maintenance.

2nd Batch: Power interruption estimative due to faults in tracts protected by protection devices (Fuse and Reclosers).

$$\sum_{f=1}^{n}\left[(\omega_o \cdot \ell_{EP_f}).S_{EP\,f}.(\tau_{des}+\tau_{loc}+\tau_{man})\right] \quad (4)$$

ω_o: Rate of faults per network kilometer;

ℓ_{EP}: Commutation Zone of the protection device;

S_{EP}:Power interruption by the protection device;

τ_{des}:Average time of dispatch;

τ_{loc}: Average time of traveling;

τ_{mar}: Average time of maintenance.

3rd Batch: Power interruption estimative due to faults in the tracts of the maneuvering devices.

$$\sum_{f=1}^{n}\left[(\omega_o \cdot \ell_{EM_f})S_{EP_f}(\tau_{des}+\tau_{loc})\right] + \sum_{f=1}^{n}\left[(\omega_o \cdot \ell_{EM_f})S_{EM\,f}(\tau_{man})\right] \quad (5)$$

ω_o: Rate of faults per network kilometer;

ℓ_{EM}: Commutation Zone of the maneuvering device;

S_{EP}: Interrupted power by the protection device the back of the maneuvering device;

S_{EM}: Interrupted power by the maneuvering device;

τ_{des}: Average time of dispatch;

τ_{loc}: Average time of traveling;

τ_{man}: Average time of maintenance.

With the sum of all three batches, it is possible to determine the power interruption estimative of the system $[Wo]$.

Recalculating the power interruption estimative, inserting, rearranging or removing the maneuvering and/or protection devices, it is possible to determine the impact of each action on the performance of the system being studied. Through this algorithm it is possible to determine the importance of each protection or maneuvering device to the system, having the ASP determine the order of removal of the excessive protection devices.

CONCLUSIONS AND RECOMMENDATIONS

The main objective for the development of this software was to create methodologies and algorithm for the optimization and use of maneuvering and protection devices in distribution systems that will result in useful and reliable tools of easy application for electrical energy company.

In its initial version, this software was used by two companies of electrical energy distribution in Brazil for optimization and revision of adjustments of approximately 22183 protection devices in 462 circuits. The tool was guaranteed by professionals in the area of protection and received great acceptance by them. It is important to remark that the program developed was prepared to meet the needs of the dealerships, according to their predefined criteria of protection and reliability. It benefited the areas of operation, planning and maintenance with special emphasis on the reliability of electrical energy supply associated to the operational safety of the system.

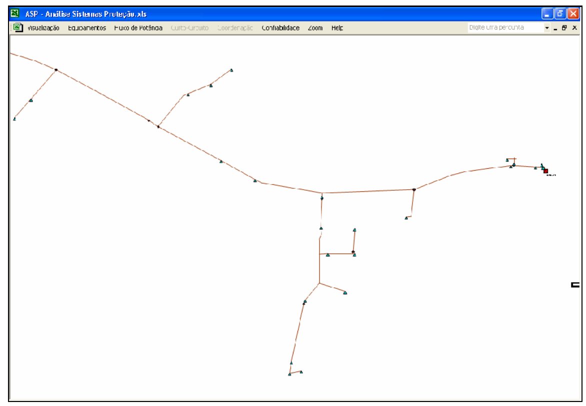

FIGURE 2 – Topological Representation

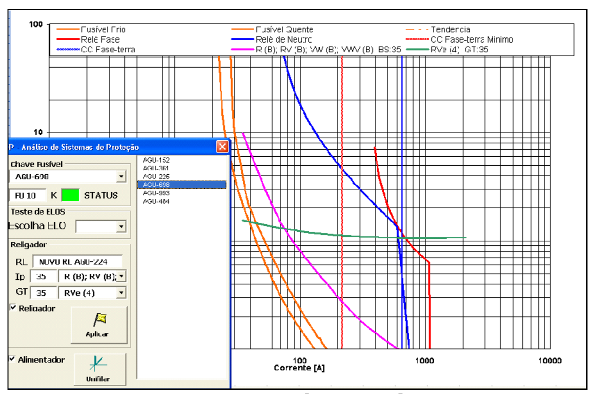

FIGURE 3 – Graphic Coordination

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