OPTIMIZATION OF THE UNDERGROUND GRID NETWORK SYSTEM IN SÃO PAULO

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ABSTRACT

This paper presents the developed methodologies for the optimization of underground distribution systems with grid network designs. This type of system is used to guarantee high quality and reliability for important loads, keeping the interruption time inferior to the average of the aerial networks. For the maintenance of this standard of service, it is necessary to use complex electric networks with complicated operation. The objective of this study was to develop a software program for the analysis of distribution networks with this level of complexity, with meshes between the circuits and different tension levels connected to each other.

INTRODUCTION

Currently, the existing underground systems in São Paulo are normally installed in a grid secondary network configuration, for providing better service quality and reliability to the attended loads, since they have low interruption rates as a consequence of their ability to keep the power supply, even during contingencies of the primary feeders.

On the other hand, the circuits are extensive and have several branches, making the network technical analysis harder, for both operation and planning.

The proposal of this study was to develop and apply criteria, procedures and methodologies for the development of a computational tool for the analysis of meshed networks, capable of optimizing the topology of the circuits and configurations, including the management of the expansion planning and support to operation in real time, providing better reliability and flexibility in maneuvers for the load reestablishment. The contingency situations have also been analyzed, taking into consideration the typical characteristics from the network and the loads.

The optimization procedure of the primary network topology enclosed the analysis of alternatives to minimize the cost of the investments and losses, having as premise the maintenance or improvement of the supply reliability when compared to the current situation. The objective of this study was also to speed up the execution of the maneuvers, quantifying their cost/benefit relation and establishing new criteria of planning.

UNDERGROUND MESHED SYSTEM

The underground electric energy distribution system from AES Eletropaulo, in São Paulo City, is composed of 15 networks of 21 or 34kV, fed by 7 different substations. Each network possesses about 130 transformers, totalizing around of 1GVA of power capacity. The attendance area is the most critical region of the city and has approximately 8km². Each network is fed by four distinct circuits of mid-voltage, all originated from the same substation. The networks have spot systems in low voltage, with normally up to four transformers of 500 or 750kVA. Figure 1 illustrates a spot system.
This system presents high expansion since the 1960’s, especially because its area has a strong load growth. The high reliability expected, associated to a high expansion cost, is originated by the possibility of being operated in first contingency. In some cases, the second contingency is also supported.

In comparison to the aerial networks, beyond the great advantage by the low defect rates, there is this redundancy. That is, in case of losing a feeder, the load (customer) keeps being attended due to the system being projected to work in mesh in low voltage (spots).

On the other hand, as the system has extensive circuits, with many ramifications and in mesh, it has difficulties: operational, in fault localization, contingencies analysis, network load distribution, among others. Because of this, a fault can compromise the restoration of the network, providing a time of up to 12 hours for the complete reestablishment and affecting the supplying of an extremely sensible region as the city center. Beyond the delay in the localization and repair of the faults, there is difficulty in the decision of the contingencies maneuvers; therefore, some cases can involve vis-à-vis connection between two different grid networks.

SOFTWARE DEVELOPED

The software developed (SINAP T&D) has as main characteristics: the integrated analysis of networks at different voltage levels; the layout of networks through schematic or geo-referenced diagrams; and the lack of restrictions on the networks topologies (meshes in any voltage level, grid networks and distributed generation) and the number of load curves periods to the power flow calculus. Figure 2 shows a standard IEEE circuit (30 busses) registered in the program.

The networks used in SINAP T&D can work with different equipment, such as: cables, capacitors (serial and parallel), loads, filters, reactors, supply points, voltage regulator, transformers (2 or 3 windings; star, open or closed delta and zig-zag), among others. The networks data import can be made from other systems through XML, ACCESS, ANAREDE or ANAFAS files. Exports can be done by XML files.

The loads may have different models, as constant current, impedance or power. The circuit portions can be defined by the sequence impedance and capacitance, by tri-core or multiplex cables, and by sets of single-core cables. The loads may have: their registered demands for any number of levels within the 24 hours period or own measured curve or be associated with a typical curve from its class and consumption range. The capacitors, reactors and lighting points can also be associated with typical curves, which indicate the periods when they are connected or disconnected.

The software program SINAP T&D uses MS Access databases to store the networks data. Users are able to create any number of databases and they can be stored in any computer accessible over the network.

The layout module allows the viewing of multiple windows while working. The networks can be visualized through geo-referenced or schematic diagrams, with "zoom" and "pan" resources to help the view. Besides the network graphic display, the program includes additional windows to present the attributes and visualize the results of electrical calculations, such as equipment configurations, power flow, short circuit, phasorial graphics, etc.

The program has a module for network graphical editing that allows inserting, modifying and deleting all the equipment that compose the electrical systems. The editor allows the creation a complete network topology even taking as a starting point an empty database (with no network registered). The edition of the network can be made using the geo-referenced and schematic diagram, with the possibility of a swap between then. Besides the equipment editing, the editor has features that allow the setup and timing of switch maneuvers.
Among the developed resources, two deserve highlighting: the opportunity to examine different voltage levels simultaneously allows more complete and accurate studies; and the use of equivalent networks, where you can explore parts of the circuit individually, without compromising the technical calculations. Figures 3 and 4 present the same network – with different levels of tension – complete and with the use of equivalents.

The main developed functionalities have contemplated: importation of topological and measurement data; easy visualization and manipulation of the net; geo-referenced and schematic representation; integrated analysis of the primary and secondary network: loads calculation, voltage levels, losses and short circuit using network equivalents; network analysis under contingency (loss of one or two primary circuits); market projection; reliability calculation; analysis of the load transference between spot networks; algorithm of excellent configuration of the network; and calculation of the load flow by different models (Gauss and Newton Raphson, balanced or not).

CASE STUDY

The developed system presents diverse resources for the study of electric networks. The main necessities at the beginning of the research (network diagnosis, short circuit calculus and contingencies analysis) are shown as example of the applications done.

Network diagnosis

One of the main functionalities of the software is the network diagnosis in normal operation. This resource allows analyzing the loading in any point of the circuit, where all the calculated parameters can be obtained, for any level of the daily load. The user has also as option, to define the technical limits of the network and to use the visual identification of the points with transgressed criteria. Figure 5 presents, as example, an underground network circuit being diagnosed for its most critical period of the day (2pm). The busses in red indicates voltage drop under the desired level. In this case, none transformer or cable presented loading out of the set limits.

Short circuit

The short circuit module from SINAP T&D calculate, for any point on the network, different types of fault: three-phase, double-phase, double-phase-ground, phase-ground and phase-ground with impedance. For each case, the user can view the tensions and currents (phase and sequence), the asymmetric currents and the Thévenin impedances. This analysis is of vital importance for the design of network protection systems, such as the use of intermediaries’ switches in the circuit, which must be precisely adjusted to actuate in faults before the circuit breaker of the substation. Figure 6 illustrates the simulation of a short circuit in a grid network of AES Eletropaulo.
Contingency
The contingency analysis is basic for the planning and the operation of the underground circuit, mainly because of the importance of the attended loads and the existing disequilibrium between the primary feeders of each network. The module created allows the analysis of simple and double contingencies, supplying support reports to the user decisions, as the diagnosis of the transformers, primary feeders or spots (respectively, figures 7, 8 and 9).

CONCLUSION
This paper presented the software program developed for the support of the planning and operation of the underground distribution grid network from AES Eletropaulo in the city of São Paulo.

The development of this tool brought to the company the capacity to evaluate new premises and configurations for the optimization of their meshed network system, making possible a better use of the investments and a better and more reliable operational performance. The software allows, on a practical way: analyzing the load distribution (avoiding a system disordered growth), studying the network reconfiguration possibilities on contingency situations, planning expansion and operation (with faster switching and quantifying its cost/benefit) and analyzing alternatives to minimize investment and losses costs (associated with maintenance or improvement of the supply reliability).

Also, new criteria for load transfers between circuits or in case of eventual faults have been defined, reducing switched off loads in case of outages. The continuous use of this tool will provide better flexibility and reliability in maneuvers for load reestablishment, assisting in the network analysis for normal operation or contingency cases.

REFERENCES