DECISION SUPPORT SYSTEM TO DESIGN DISTRIBUTION NETWORKS

Leonardo M. O. de QUEIROZ – ANEEL – Brazil – leonardoqueiroz@aneel.gov.br
Celso CAVELLUCCI – UNICAMP – Brazil – celsocv@densis.fee.unicamp.br
Jose F. V. GONZÁLEZ – UNICAMP – Brazil – jfvg@densis.fee.unicamp.br
Vinicius J. GARCIA – UNICAMP – Brazil – jacques@densis.fee.unicamp.br

Christiano LYRA – UNICAMP – Brazil – chrlyra@densis.fee.unicamp.br
Paulo M. FRANÇA – UNICAMP – Brazil – franca@densis.fee.unicamp.br
Joselaine de ALMEIDA – UNICAMP – Brazil – josi@densis.fee.unicamp.br

ABSTRACT

This paper outlines a methodology to automate the elaboration of constructive distribution network projects. It helps the network designer in the execution of the tasks related to the project elaboration process by giving a set of computational tools. These tools were arranged as a Decision Support System (DSS). Through the use of combinatorial optimization techniques, knowledge based systems (expert systems), load flow calculation models and mechanic stability calculation, notable improvements in the standardization of projects are expected by reducing costs and the time associated with those elaboration tasks. Finally a case study illustrates the applicability of the method.

INTRODUCTION

Designing distribution networks is a hard task, which demands the meeting of diverse abilities and knowledge. It makes use of technical norms, empirical procedures, judgment, common sense, calculations and a considerable mass of data to result in an executive project. For this reason, a complex and delayed task is characterized. Technical norms and standards, technical procedures and basic criteria must be assumed to ensure minimal operational conditions of distribution systems and to adequate the quality of power supply enforced by regulatory agencies. Moreover, they establish security levels compatible with the network operational requirements. The set of technical norms adds great amount of information used, studied and interpreted by the designers.

The local or region load growth involves distribution network projects so that esthetic, ecological and social aspects must be considered, without affect the quality of power supply. These factors, with greater or minor degree, compete between themselves, demanding a complex job from designers to achieve reasonable solutions.

When looking for approaches to provide project details and technical requirements related to the network planning and construction, we come across with total scarcity of contributions, thus suggesting a new and potential research field in electric distribution networks area.

This paper describes a decision support system model (DSS) to aid designers in the task of elaborating distribution network projects, using optimization and artificial intelligence techniques involved in a unique and innovative approach. The following section defines the project automation problem and the architecture of the developed DSS will be presented next, including a description of all involved modules. Elaborated case study will be introduced to illustrate the proposed methodology. Finally, some considerations will be presented.

PROJECT AUTOMATION

Distribution network projects are elaborated according to technical norms and standards, defining basic criteria and technical procedures to guarantee the operational conditions and the quality of power supply, defined by regulatory agencies. However, the accomplishment of such requirements does not guarantee good technical solutions or even low cost solutions. There will be a set of engineering practices that can be considered as directions to have good projects. Hence, the project elaboration demands from designers proper criteria to identify appropriate project engineering solutions. This conclusion makes suitable an automation model, due to the inherent complexity of this project elaboration task.

Two well-defined phases arise when elaborating distribution network projects: Project Classification and Project Specification. Whichever project, these same phases occur even if we are facing with a new consumer simple connection or a more sophisticated network expansion. The Project Classification distinguishes some types of projects, considering the basic project characteristics, results of projects previously elaborated, designer experience as well as company norms and standards. Frequently, the designer uses his common sense in cases where commitment solutions are necessary.

The following phase, Project Specification, includes the execution of adequate procedures to each type of project. All the procedures are summarized to the chaining of the activities in such a way that project specifications, materials and manpower needed have been defined.

The main objective is the creation of alternative engineering solutions for, later, selects the solution that adjusts better to

the project requirements.
This work considers the automation of the Project Specification phase, leaving to the designer the responsibility to carry out the Project Classification phase. A brief description of each project type is presented as follows:

• *Customers connection* are extensions of network to connect new loads in low (residential consumer) and high voltage levels (commercial and industrial consumer).

• *New residential areas* comprise the definition of the number and location of the transformers to be installed as well as electric network routing.

• *Improvement* in the distribution network consists of modifying significantly the existing network, including its actual physical and/or electric configuration in order to meet the load growth scenario. The main purposes are eliminate technical deficiencies to maintain quality levels, construct structural reinforcements to support additional efforts due to the occupation of cable TV and telephone companies, for instance.

DSS ARCHITECTURE

Considering the practical issues, requirements and circumstances involved in the design of electric distribution networks, a Decision Support System (DSS) model [3] becomes suitable and appropriated to the problem approached in this paper.
Conceptually, the general architecture of the DSS can be represented by the relationship between the user, Interface, Database, and Models Base. The Interface establishes the interaction protocol between the user and the DSS. The Database is the data repository needed for the problem solution, including literal, numerical and graphical data. In the Models Base are stored the procedures, techniques and algorithms that can be used in interactive and recursive way, to find adequate solutions to the problem.
This general architecture can be applied to the task of automate the energy distribution network projects, as showed in Figure 1.

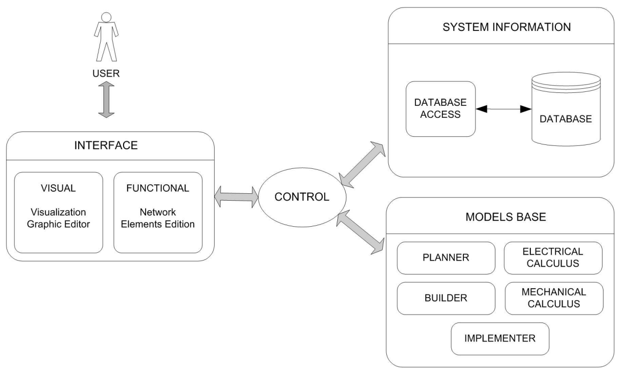


Figure 1: DSS Architecture.

The Interface provides interaction between the user and the DSS by graphical visualization and editing functions, both pertaining to the Visual module. The Functional module includes basic functions used in the preparation of system input data - pole allocation, transformers, primary segments, secondary segments, and consumer loads.
The Database stores information about the projects that will be specified, while the Access module is responsible for the data transactions. The Planner, Builder, Electrical Calculus, Mechanical Calculus, and Implementer compose the Models Base. Each module has its specific function in the project development task, and can interact between them. The next subsections will describe all modules.

Planner Module

The Planner module aims to elaborate alternative projects for the network with the minimum possible cost, defining the position and capacity for the distribution street transformers and the route of the primary segments (15 kV) and secondary distribution circuits (127/220V). The primary segments define the path between the transformer and the main distribution feeder. The model adopted for the Planner considers the electrical limits of the conductors and transformers, as well as the voltage levels that better match standards determined for the Brazilian regulatory agency.
The complexity of this problem leads to a hierarchical approach of three sub-problems: localization and sizing of distribution transformers, primary segments routing and secondary distribution circuit routing. The allocation of distribution transformers corresponds to solve an uncapacitated *p-median* problem, characterizing a combinatorial optimization problem to find the best places for installing *p* transformers, connecting each load unit to the nearest transformer that minimizes the sum of the electric moments (distance x demand). Each transformer has its capacity defined by the sum of demands resulting from the consumers allocated to the transformer unit.
The design of secondary distribution circuits is obtained using a matrix of shortest paths between all the points of the network, and is obtained using the Dijkstra algorithm [1]. The choice of which cable type will be proposed in the arc depends on the cable costs and its current limits. The Planner module activates the Electric Calculus Module to compute the power flow in the secondary distribution circuit.
To find the route of primary segments is necessary to decide the arcs that will be used to create a path between each street transformer and the nearest point in main distribution feeder. This problem is formulated as a Steiner problem [2], which corresponds to connect a set of graph nodes at minimum cost.

Builder Module

The objective of this module is to detail each element of the network proposal in its physical components (primary structure, secondary structure, settings, and poles, among others). For accomplishing that, engineering rules based on technical standards as well as practical knowledge of designers are used. These rules have been formulated as production rules and stored in a knowledge base of the expert system.

During the definition process of the network elements, free interactions between designer and system will be possible, giving the chance of using the designer choices when the expert system is not able to make its own decision (exceptions of rules).

Implementer Module

The final solution for a giving project is a list with the materials and manpower defined by operations of addition, removal and substitution of networks elements. The Implementer makes the association between the network elements, materials and manpower for the corresponding construction.

Electrical Calculus Module

This module is used to validate the electrical parameters of giving project. It checks voltage limits and line currents through the execution of a power flow algorithm.

The input data for this module are: the reference node (street transformer), the set of nodes with loads and the arcs with respective cables.

Mechanical Calculus Module

This module checks the mechanical conditions of each pole, ensuring its integrity and stability through proper solutions or indicating to the user some situations that require its intervention.

CASE STUDIES

In this section, two case studies are presented to show the efficiency and the applicability of the developed system. Considering the similarities between the three types of projects presented in Section 2, it was opted for examples that evidence some important aspects in network project.

Customers connection

Figure 2 illustrates a situation where three low-voltage customers with relatively low demand request attendance (points A, B and C in the figure).

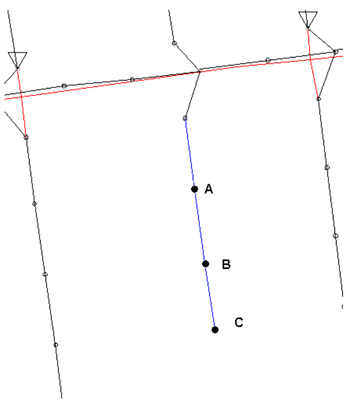


Figure 2. Customer connection.

In this simple project the system's user often proposes the conductors without aid of the Planner module. Although this example illustrates this situation, nothing prevents the user to use the Planner module to make the sizing of the conductors.

In this case, the designer decides that will not be necessary any alteration in the primary network segments or transformers insertion to supply the new loads. The user himself traces the new secondary distribution circuit (blue lines in Figure 2), selecting the conductors to be used and the points where poles will be placed (for instance, in the points A, B and C in Figure 2).

At present, the Builder module is used to make the network constructive project. The Constructor activates the Mechanical Calculus module to make the sizing of poles. The constructive elements selected by the Builder for this situation are, among others, poles, secondary structures, setting of the secondary structures, knottings. The designer can modify the Builder output, adding or removing list elements.

The Implementer module is trigged to detail the final result of the project. It uses the Builder output and information about the early state of the network. In this case there are no changes in the existing network; all projected elements will be added and any removal or substitution will not be necessary.

Network Expansion

Figure 3 illustrates a network expansion area that needs to be powered. Segments in red (primary) and black (secondary) are representing the existing network. Triangles represent transformers; in this case, we have 5 existing transformers.

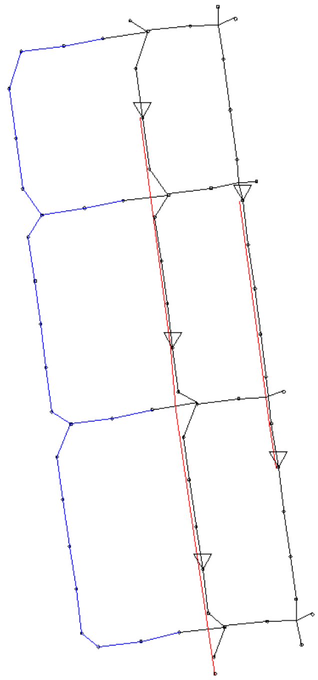
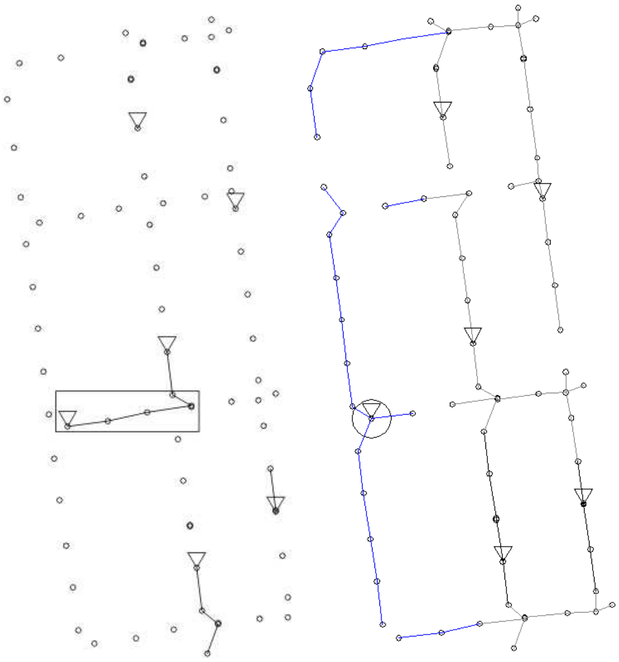


Figure 3. Network expansion.

The system user needs to inform to DSS the possible locals to install poles and paths for cables (in blue in Figure 3).
Figure 4 shows the solution suggested by the Planner module. It shows primary segments and secondary circuits proposed by the DSS, considering the expansion introduced in Figure 3. The main goal is to expand the network causing the minimum intervention in the existing network, considering operational conditions. As observed a new secondary circuit was created to supply energy to the new loads, not necessarily implying changes on the existing circuits. In Figure 4a the added transformer (inside the rectangle) is connected to the main distribution feeder through a small extension.



a) b)

Figure 4. Primary segments and secondary circuits.

Note in Figure 4b that the resulting expansion added a new secondary circuit, bringing a new transformer to the network. However, this new circuit was not able to incorporate all load points; some of them were allocated to adjacent existing secondary circuits.
Next, the Builder module is trigged to determine which constructive elements must be placed in the project. The output of this module is a list of constructive elements for each pole. Among these elements, we can cite poles, primary and secondary structures, knotting of the conductors in the structures and settings of the structures. To illustrate this procedure, we take as example the pole where the new transformer is installed, highlighted with a circle in Figure 4b. Firstly, the pole type is chosen, through the determination of its height and the traction effort necessary to support it. After that primary and secondary structures to support the conductors in the pole are selected. At this stage the type of conductors and angles created between them are also considered. Other elements are selected in similar ways, where normally a choice depends on early selections

CONCLUSIONS

A Decision Support System was described in this paper to aid the elaboration of electric distribution networks projects. Through a simple architecture, several techniques and algorithms are used in interrelated specific modules, each one performing a different function in the system.
As illustrated in case studies, the proposed system is an efficient tool for projecting over-head electric distribution networks. The following benefits can be achieved using the DSS:
• *Dispersion reduction in project solutions*- the use of the tool set for optimizing and conducting the different choices among a large number of alternatives limits the subjectivity inherent to the project design tasks, improving the standardization of procedures and criteria in power distribution companies.
• *Reduction in design errors*- the project automation causes a considerable reduction of possible mistakes, since the consistency checking during the application of engineering rules is among the system functionalities.
• *Lower cost solutions* - the use of computational intelligence algorithms leads to solutions with lower execution cost and better customer satisfaction.
• *Lower time in project execution* – automating the main tasks of project elaboration, including the use of graphical interface, databases interconnection, fast optimization algorithms, mechanical and electric computing, will result in important reduction of the project execution time.

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Acknowledgments

The authors are indebted to support from CNPq (Brazilian National Research Council), CAPES and CPFL (Power Company of São Paulo). However, they emphasize that opinions expressed in the paper are their own responsibility; they are not necessarily endorsed by these institutions which have been kindly supporting their research.