Distribution Reliability Analysis Program

O.H.S. Vicentini, H.R.P.M. de Oliveira, R.Oling, AES Sul
M. L. B. Martinez, M. A. Saran, R. J. Bachega, UNIFEI
A. Violin, C. Lefort, FUPAI

Abstract **– The objective of this paper is to present a computer program developed for Windows to compute reliability indices for different customers and set of customers supplied by a same distribution feeder. This program deals with information obtained directly from utility database to create an equivalent network modeling and carry out contingency analytical simulations. The system's average failure rates must be informed by the user, based on historical utility data, manufacturer test data or typical values.**

The program enables to compute penalties and annual costs of energy interruptions and compare the obtained indices with the reliability index targets set by the national regulatory agency (ANEEL) for the different sets of customers and distribution feeders under analysis

The program allows to analyze the influence the variation of the system rates and also modifications of the topology of the network and, thus, to carry out a sensitive study to verify the effect of some different protection equipment and modifications in the topology of the systems, justifying investments that can improve the reliability, the power quality, and reduce costs of energy interruption and other related costs.

Index Terms **– reliability indices, set of customers, distribution feeder, contingency analytical simulations, system rates, index targets, penalties.**

I. INTRODUCTION

DESPITE the fact that around 80% of the power interruptions occur in the distribution systems, the reliability analysis of these systems had never received much attention until a few years ago. However, with the restructuring of the Brazilian electric sector and the privatization of the power distribution utilities, this situation has changed. In 1996, ANEEL – National Agency of Electric Power (regulatory agency) – was established to inspect the electric sector companies and, in 2000, it created the resolutions (laws) RES 024 and RES 522, introducing new indicators and reliability index targets for each set of customers and expressions for the calculation of penalties in the event of violations of these targets.

In order to meet the targets set by the regulatory agency, most distribution utilities began to digitally record their lines, equipment and history of interruptions, thus making it easier to develop computational programs and tools for analysis of power flow, short circuit and reliability of the distribution systems.

Two different analyses are used to assess the reliability of the distribution systems: Historic and Predictive. Through the historic analysis, one can obtain the indices referring to the interruptions occurred in the system for a given period of time, generating diagnoses of the system's past behavior. While the predictive analysis calculates the future expectation of the system's behavior in the medium and long terms, combining the components failure rates, the repair duration, switching time for restoring the reliability for different equipment and distribution line sections. Considering that these factors are random, by nature, it is necessary to use average values computed from a database of interruptions and occurred failures. This way, it is possible to compute reliability indices for the whole electric system or set of customers, like the SAIFI (System Average Interruption Frequency Index and SAIDI (System Average Interruption Duration Index), as well as the reliability indices for each consumer. The method used in the predictive reliability analysis is the Analytical Method, faster and more accurate.

II. PROGRAM DESCRIPTION

The PCA (Feeder Reliability Program) is a computational tool for distribution feeder reliability analysis (systems supplied by a rated voltage equal or lower to 34.5 kV) that enables the calculation of the reliability indices for each customer or set of customers considering the penalties due to violations of the reliability index targets as set by the Brazilian National Agency of Electric Power - ANEEL.

To do these calculations, the program uses information obtained directly from the company's relational database or information that should be entered by the program's user.

This way, one can foresee the system's future behavior for different operating conditions and different protection equipment and configuration, evaluating their respective results in terms of reliability indices and the attached penalties.

Figure 1 shows the main steps and modules of the program.

III. DATA INPUT

In step (1), the program accesses information on equipment and sections of a distribution feeder (or every feeder belonging to a given set of customers) in the company's relational database management system (SGBD). For that, queries in SQL (structured query language) and a standard interface, called ODBC (open data base connectivity) for connection with Oracle databases or other types of relational databases are used. The information

This work was developed by the project "Reliability Analysis", making part of the program of Research & Development of the Brazilian Electric Sector, driven by the National Agency of Electric Power (ANEEL), and financed by AES Sul - Distribuidora Gaúcha de Energia S/A.

H.R.P.M. de Oliveira works with AES Sul - Distribuidora Gaúcha de Energia S/A, São Leopoldo, RS, Brazil (e-mail: hermes.oliveira@aes.com)

R. Oling works with AES Sul - Distribuidora Gaúcha de Energia S/A, São Leopoldo, RS, Brazil (e-mail: renato.oling@aes.com)

O.H.S. Vicentini works with AES Sul - Distribuidora Gaúcha de Energia S/A, São Leopoldo, RS, Brazil (e-mail: Otavio.vicentini@aes.com)

M.L.B. Martinez works with Universidade Federal de Itajubá - Unifei, MG, Brazil (e-mail:martinez@iee.unfinei.org)

A.Violin works with FUPAI – Fundação de Pesquisa e Assessoramento a Indústria, MG, Brazil (e-mail:aviolin@sulminal.com.br)

obtained in this process is a bond of geographic information and different alphanumeric records that are stored in a local file with the name of the feeder under analysis in the station where the program is installed.

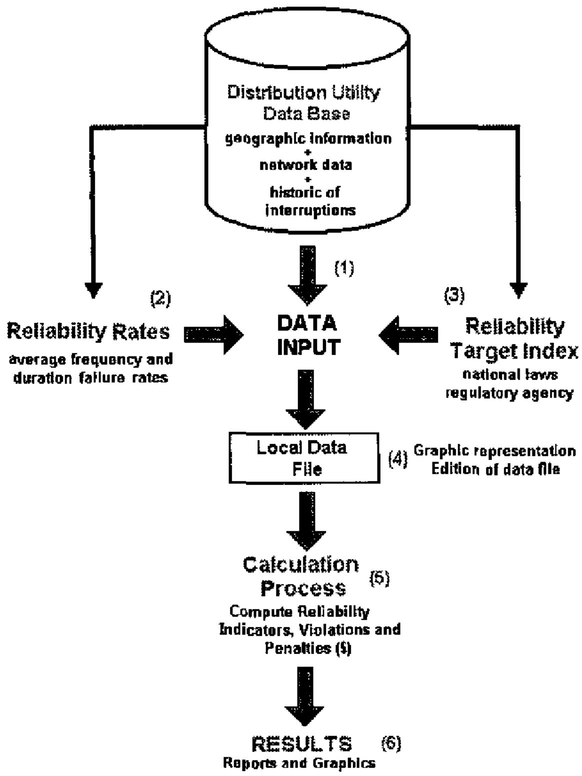

Fig. 1 PCA Program Functioning Diagram.

By opening this local file, the program displays general information and a chart with the feeder's topology, through which one can view, with different zoom levels, the distribution substation, primary sections and equipment, like transformers, switches, reclosers, fuses, capacitor banks, etc. Besides the georeferenced representation of all components, one can also see their main information and features. This kind of computational resource, linked to other tools, is called automated mapping and facilities management.

Figure 2 shows the initial screen after a local file of the program's data was opened.

In step (2), the user should inform the system's average failure rates. This information should include failure rates of the system's components and average interruption frequency and duration, replacements and maintenance of the existing different equipment and lines recognized by the program, such as type of primary lines, protection equipment, switches, voltage regulators, capacitor banks and distribution transformers. This information is stored in a local file and should be obtained from the technical reading, with typical values, or based on the utility's interruption history, which is more recommended, considering that these values have a direct influence on the indices to be calculated.

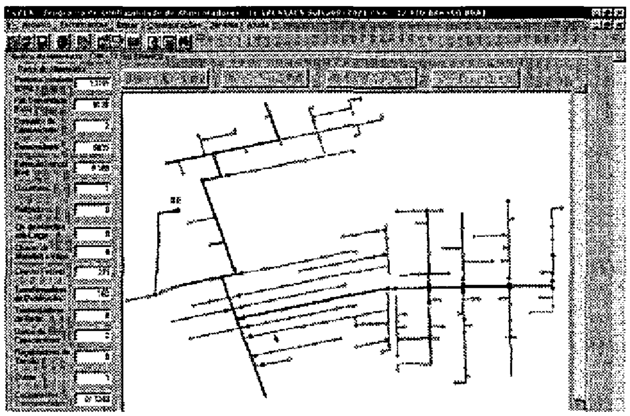

Fig. 2 Initial Screen of the Program.

In step (3), the reading of the reliability index targets for the sets of customers and the calculation of the customer index targets based on ANEEL Resolution 024 are performed.

As a result, the program has all the input data necessary for the calculation of the reliability indicators of the feeder and of the set of supplied customers. However, before starting the calculations, one should perform an identification process that divides the circuit's components in buses and branches, with the geographic coordinates being related to the buses, while the main reliability information, such as average failure rates and interruption duration, are related to the branches, in which contingency simulations are performed during the calculation process, observing the results of momentary interruptions, sustained interruptions, planned maintenance and protection failures for each existing load bus, which, in this case, are the buses referring to the distribution transformers.

IV. DATA EDITION

The program also enables the editing of components (Step 4), allowing entering, removing or just changing the type of circuit component through the chart or through menus and lists of the existing different element types. These changes can be saved in different local files generating study alternatives. As a result, one can compare the results for different equipment and network topology, assessing investments and improvements in the system.

V. CALCULATION PROCESS

The computation of the reliability indicators for each customer and set of customers are carried out in step (5), through an interactive analytical process, based on the simulation of simple contingencies in every component of a feeder.

Equations (1) and (2) are used in the calculation of average duration and frequency indicators for each customer. In Brazil, these indicators are named DIC (duration of interruption by customer) and FIC (frequency of interruption by customer).

$$DIC = DIC_{interruptions} + DIC_{maintenance} + DIC_{replacements} + DIC_{protection\_failure} \quad (1)$$

$$FIC = FIC_{interruptions} + FIC_{maintenance} + FIC_{replacements} +$$

$$FIC_{protection\,failure} \quad (2)$$

Once the individual indicators (DIC and FIC) are computed for each bus load and supplied customers, the average duration and frequency indices are calculated for the sets of customers and feeders under analysis, indicators that, in Brazil, are named DEC (equivalent duration by set of customers or system)and FEC (equivalent frequency by set of customers or system), and that can be calculated by equations (3), (4), (5) and (6).

$$FEC_{(Set\_of\_Customers)} = \sum_{i=1}^{k} \frac{FIC(i) \times Ca(i)}{Cc} \quad (3)$$

$$FEC_{(Feeder)} = \sum_{j=1}^{nc} \frac{FEC(j) \times Cc(j)_{(Set\_of\_Customers)}}{Cal} \quad (4)$$

$$DEC_{(Set\_of\_Customers)} = \sum_{i=1}^{k} \frac{DIC(i) \times Ca(i)}{Cc} \quad (5)$$

$$DEC_{(Feeder)} = \sum_{j=1}^{nc} \frac{DEC(j) \times Ca(j)_{(Set\_of\_Customers)}}{Cal} \quad (6)$$

Where:

DIC i = DIC calculated for a given load bus i;
FIC i = FIC calculated for a given load bus i;
Ca i = Number of customer supplied at load bus i;
i = Number of load buses where FIC and DIC are calculated;
j = Number of served sets of customers under analysis;
k = Total number of load buses (transformers) of the feeder belonging to a given set of customers;
Cc = Total number of customers of the feeder belonging to a given set of customers;
Cal = Total number of customers of the feeder;
nc = Total number of sets of customers in the feeder.

After the calculation of the indicators (actual values – DICv, FICv, DECv and FECv), their respective penalties for occasional violations of the set targets (forecast values – DICp, FICp, DECp and FECp) are calculated.

Equations (7) and (8) show the expressions valid for the computation of the average yearly FIC and DIC penalties, as issued by ANEEL Resolution 24, whereas equations (9), (10) and (11) show the expressions used in the program for the computation of the average yearly FEC and DEC penalties for each set of customers and for the feeder.

For DIC:

$$Penalties = \left(\frac{DIC_c}{DIC_t} - 1 \right) \cdot DIC_t \cdot \frac{CM}{8760} \cdot k \quad (7)$$

For FIC:

$$Penalties = \left(\frac{FIC_c}{FIC_t} - 1 \right) \cdot DIC_t \cdot \frac{CM}{8760} \cdot k \quad (8)$$

Where:

DICc = Average duration index calculated by load bus and supplied customers, in hours per year.
DICt = Reliability target set by load bus and served customers, in hours per year;
FICc = Average interruption frequency calculated by load bus and served customers, in number of interruptions per year;
FICt = Reliability target set by load bus and served customers, in number of interruptions per year;
CM = Average yearly billings (without taxes) by load bus and supplied customers, in Brazilian Currency - Reais (R$);
8760 = Average number of hours in a year;
k = Increase ratio fixed at 10 (ten).

For DEC:

$$Penalties = \sum_{j=1}^{nc} \left(\frac{INDc(j)}{INDs(j)} - 1 \right) * DECs(j) * \left(\frac{NCC(j)}{NCE} \right) * \frac{CB}{8760} * K1 * K2 * K3 * K4 \quad (9)$$

Where:

INDc(j) = (FEC or DEC) Calculated average duration index by set of customers (j) in the period;
INDs(j) = Standard indicator of the set of customers (j) in the period;
DECs(j) = Standard DEC of the set of customers (j) in the period;
NCC(j) = Average number of customers of the set of customers (j) in the period;
NCE = Average Number of Customers of the Company in the period;
CB = Company Bill;
nc = Total sets of customers exceeding the DEC or FEC reliability indicator;
K1 = Increase ratio (considering k1= 5);
K2 = Reincidence ratio for violations of the indicator of the set of customers (according to Art. 10 of ANEEL Resolution no. 318/1998, k2 = 1 or 1.5);
K3 = Ratio of existence of a previous sanction over the last four years (according to Art. 9, of ANEEL Resolution no. 318/1998; considering the application of the additional 2% for each sanction);
K4 – Worsening ratio (considering k4 = 1.20)
8760 – Number of hours in the year.

Note: The (FEC or DEC) indicator with the largest deviation is considered.

After finishing the calculations, the user can also make linear changes in the billing and in the number of customers of the feeder, and recalculate the penalty amounts, thus being able to foresee results for an expected load growth.

VI. RESULTS

The reports with the reliability indices of each set of customers and of each customer grouped by the distribution transformer through which they are served are shown in the program's data output. Besides these reports, one can view a diagnosis chart, which displays the topology of the feeder where the load buses are represented in three different colors according to the violation of the target of each transformer and respective supplied customers: green for the buses without violation, yellow for the buses with violation equal to or lower than 10%, and red for the buses with violation higher than 10%. Below, figure 3 illustrates it.

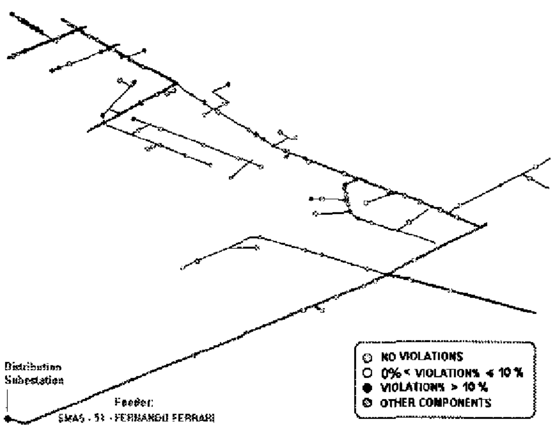

Fig. 3 Chart of Individual Reliability Indicator Diagnosis.

Next, it is discussed the results of two feeders analysis, where just the index of the set of customers was violated.

Figure 4 shows the feeder 5 of Substation Santa Maria 4, called Fernando Ferrari, with about 3,500 customers, 100 load buses, 6,000 kVA Peak Feeder Demand and 5.0 km overhead Primary Trunk.

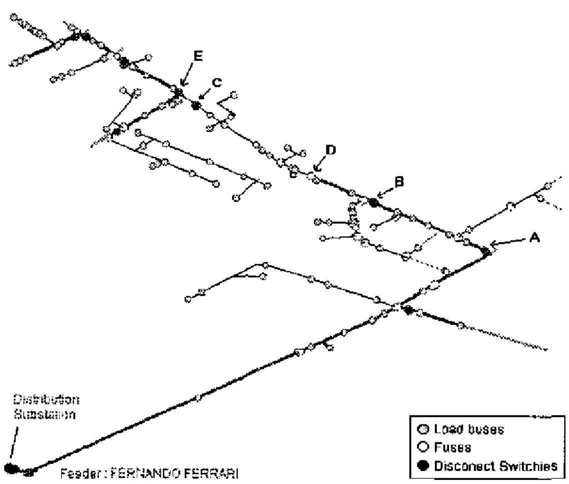

Fig. 4 Feeder Fernando Ferrari Toplogy.

Table I shows the penalties costs and DEC indicator of total interruptions effects: planned maintenance, sustained and temporary interruptions, where the calculations used typical values, as in [2]. Case 1 is the Base (existing feeder). Case 2 was improved replacing three disconnecting switches by fuses (points A, B and C) and Case 3 was improved by replacing one fuse and one disconnecting switch (points D and E) by one recloser and one sectionalizer, both in the primary trunk. It is possible to see that penalties costs was reduced, but in the Case 2 it is easier to justify investment than in the Case 3.

TABLE I
RESULTS OF SENSITIVE ANALYSIS OF FIGURE 4

Case	Penalties (US$ / year)		DEC (hours / year)	
	Total	Transients	Standard	Calculated
1	7,551	1,990	16	33.9
2	6,286	1,284	16	30.5
3	5,572	317	16	28.7

Table I also shows part of the penalties costs refering to temporary interruptions due to transients failures (less than one minute) in the overhead primary feeder. If a fuse blows when a transient failure occurs, an hour or more is necessary to reclose the costumers and a temporary interruption is taking into account. The severity of this depends on the response the protection system. In the Case 3, the effect on the penalties costs was strongly reduced, although it is difficult to justify the recloser and sectionalizer, unless the feeder is longer than it is.

Figure 5 shows the feeder 6 of Substation Cidade Industrial, called Harmonia, with about 3,100 customers, 88 load buses, 4,400 kVA Peak Feeder Demand and 8.2 km overhead Primary Trunk.

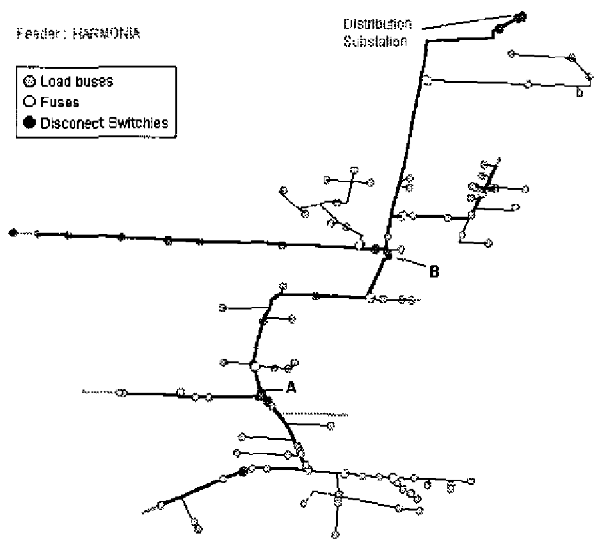

Fig. 5 Feeder Harmonia Toplogy.

As above, Table II shows the results of sensitive analysis for the feeder.

TABLE II
RESULTS OF SENSITIVE ANALYSIS OF FIGURE 5

Case	Penalties (US$ / year)		DEC (hours / year)	
	Total	Transients	Standard	Calculated
1	6,788	434	14.0	27.0
2	6,000	1,317	14.0	25.5
3	3,781	269	14.0	21.2

Case 1 is the Base. Case 2 was improved with replaced one disconnect switch (point A) by a fuse and Case 3 was improved with a recloser installed on point B and a sectionalizer installed on point A (disconnect switch repalced).

In the Case 3 the total of penalties costs was reduced to 56% and the costs due transients failures was also reduced. Maybe, some years of feeder operation can justify the investment. In the Case 2 the total of penalties costs was reduced to 88%, but the costs due transients failures was increased.

The fuses have an positive effect when they reduce the temporaries interruptions due actives failures on the feeder, but if transients failures occur and the fuses blow the advantage will go down.

So, statistics reports about fuses's behavior and the protection schemes used are very important to make good choises.

In addition, part of the total penalties costs showed on Table I and Table II refers to sustained interruptions on the transmission system that must be reduced by maintenance actions.

VII. CONCLUSIONS

The PCA program enables the reliability analysis of distribution feeders and systems, reducing costs, increasing the power quality and making the planning and analysis of different improvement alternatives in cost-benefit terms easier. The main advantages provided by this software include: the direct and simple access to different types of databases, through queries in SQL (structured query language) and the OBDC interface; and also the man-machine interface offered by the Windows environment and by the graphic resources, thus facilitating the display of reliability results, the editing of improvement alternatives and assessment of the return on the investment (pay-back).

VIII. REFERENCES

[1] ANEEL – Agência Nacional de Energia Elétrica, Resolução 24 / 2000, Brasil, 2000.

[2] Brown, R. E., "Electric Power Distribution Reliability", ABB Inc., Raleigh, North Carolina, 2002.

[3] Bilington, R. & Allan R. N.,"Reliability Evaluation of Power System", Pitman, N. Y,.1984.

[4] Lewis, E. E., "Introduction to Reliability Engineering", J. Wiley & Songs, Inc., N. Y., 1994.