CORRELATION BETWEEN EVENTS AND THEIR CAUSES IN ELECTRICITY DISTRIBUTION SYSTEMS

C. C. B. de OLIVEIRA A. MÉFFE C. A. S. PENIN H. P. SCHMIDT
Universidade de São Paulo - Brazil
barioni@pea.usp.br

J. J. dos S. OLIVEIRA I. T. DOMINGUES
AES Eletropaulo - Brazil
joaosantos@eletropaulo.com.br

ABSTRACT - *This paper presents a methodology and a software implementation for studying events in the operation of a large-scale distribution system and the identification of their most probable causes. In this work, the term "event" refers to any action against the electrical system that in most cases leads to a supply interruption (for instance, lightning strokes, protective equipment failure, aging components, effect of air pollution and so on). The methodology also allows for the quick identification of system critical points, as well as an economic analysis of different corrective actions and the corresponding payback periods. Preliminary results from the application of the proposed methodology are also presented and discussed.*

INTRODUCTION

AES Eletropaulo is the electricity distribution utility operating in the city of São Paulo, Brazil. It supplies electricity to over 4,500,000 customers through approximately 1,500 medium voltage (MV) primary feeders and 100,000 low voltage (LV) circuits.

At present, the number of events per month is approximately 30,000, most of them involving supply interruptions. An existing corporate system called GOD is responsible for managing all events. It keeps on-line records of events of the past 3 years. Although the system allows storing detailed information on every event, the identification of the most probable causes for each event is not an easy task, for a number of reasons. First, the information collected directly on the field is sometimes incomplete or inadequate. Second, the system was not designed to easily integrate information provided by external sources. This includes information on lightning, rain, wind and air pollution that is nowadays available from various state-level agencies. Finally, the system does not have a built-in statistical methodology for establishing relationships between the events and parameters that can affect the electrical network at particular points.

The main objectives of the proposed methodology can then be summarized as follows: (*i*) to provide an efficient and error-checking procedure to collect event data directly on the field, (*ii*) to integrate event data and external-source information (such as lightning strokes and rain) in the same computational framework, and (*iii*) to provide statistical analysis tools so as to identify the underlying causes of events. The software implementation is called *SisCorrela*, and the expected benefits of its application include the possibility of assessing current maintenance plans, network project criteria and materials performance, so inadequacies can be identified and corrected accordingly.

The paper is organized as follows. Initially, the methodology is presented in a way as detailed as possible. This includes the description of external information sources and the software functional capabilities. A successful example on the application of the methodology to a real-world problem is also presented. Finally, the conclusions of the paper and topics for further development are presented and discussed.

METHODOLOGY

Data Sources

Input data for the proposed methodology come from various independent sources. Relevant data for the problem at hand have been extracted from each data source and integrated in a single database, which is part of the computational implementation. In the following subsections, the sources of information are briefly presented.

Event management system (GOD). This is the system responsible for collecting and managing event information, from the initial steps to the generation of consolidate reports at various detail levels. As it runs on a mainframe platform, there is no direct interaction between the field personnel and the system - this communication was formerly performed through specific paper forms.

Electrical network management system (GRADE). This system contains all data regarding the electrical network: MV and LV circuits, pole locations, network section cables, protective and switching equipment location and state (open/closed), consumer location and demand, results from loadflow calculations and so on. It also runs on a mainframe platform and lacks a graphical user interface, but all entities are georeferenced (i.e., possess a corresponding pair of UTM coordinates), so the geographical information is already in the database. GOD system normally issues various queries to the GRADE system in order to find out circuit topology, state of protective/switching equipment and demand levels at specific locations.

Wind data. In São Paulo state, wind and air pollution data are collected and processed by a state agency called CETESB [1], which operates 23 local stations spread over São Paulo city's metropolitan area. As for the wind, available data consists of maximum wind speed (m/s) in 1-hour intervals. For each recorded event, the software identifies the station closest to the event location and retrieves the maximum wind speed in the hour prior to the event and the maximum wind speed in the 24 hours prior to the event.

Air pollution data. As mentioned earlier, CETESB is also responsible for collecting and processing air pollution data in São Paulo city. Among others, available data consists of hourly values of inhalable particles, measured in $\mu g/m^3$. For each recorded event, the software identifies the station closest to the event location and computes the annual average value and the 30-day average value of inhalable particles prior to the event. These values are then mapped onto the following categories: low (below 50 $\mu g/m^3$), medium (between 50 and 100 $\mu g/m^3$), and high (above 100 $\mu g/m^3$).

Rain data. The agency responsible for collecting rain data is called CTH [2], and it makes available rainfall values at 5-minute intervals in various ranges (0-5 mm/h, 5-7 mm/h, etc.). For each recorded event, the software identifies the corresponding square on the rain grid and computes the accumulated rainfall in the preceding 60 minutes and 24 hours.

Lightning data. In this case, data is provided by a regional system called SIMEPAR [3]. For each detected lightning stroke, the following information is made available, among others: GMT time of stroke, stroke intensity and parameters of the ellipse that most likely contains the stroke location. For each recorded event, the software determines if the event location belongs to the ellipse of any recorded stroke, both at the time of the event and in the preceding 24 hours. GMT time conversion to local time is automatically performed by the software, accounting for energy-saving summer time corrections if applicable.

Functional main aspects

In the following subsections, the main methodological features of the proposed approach are presented.

Field data acquisition. Improving the quality of the information acquired on the field was one of the first aspects to be tackled in the current research project. The former data-acquisition procedure, based on paper forms, allowed for incomplete and/or inconsistent data to be generated. This step has been enhanced by introducing a handheld personal computer, which is equipped with a friendly, simple-to-use interface software that automatically guides the user in the filling-in process. Also, a number of consistency checks are performed before accepting the information provided by the field technician. Figure 1 shows the screen for starting the event recording procedure.

Figure 1 - Event recording initial screen

Platforms, applications and data transfers. At the end of its shift, each maintenance/emergency team connects the handheld computer to the desktop computer located in the team's regional maintenance center. All data is then transferred to the desktop computer. After executing a local information processing routine, data is sent over to a central database in a remote location (the central database is connected to all maintenance centers).

The core of the *SisCorrela* software runs locally on the desktop computers in each maintenance center. Whenever a user opens a new study session, the relevant data is transferred back from the central database, making it available for the local application. The functionality of the software will be described in the following subsections.

Failure rate evaluation. Given the nature of the data associated with events, incorporating functions for evaluating failure rates into the software was relatively simple [4]. The software can compute failure rate values considering a single MV circuit or any set of MV circuits defined by the user (including the special case of all MV circuits), in any period of time. Failure rate for cables can be obtained for the whole cable population, or segregated by cable type (bare conductor, protected cable, insulated cable or multiplex cable). The general expression for evaluating failure rate of cables is as follows:

$$FR_{cable} = \frac{N_e}{L_{tot} \cdot \Delta t} \ , \qquad (1)$$

where FR_{cable} is the failure rate of a cable (failures per year per km), N_e is the number of events of which the component was identified as being a cable, L_{tot} is the total cable length (km) and Δt is the period for which the failure rate is being estimated (year).

Components for which failure rates can be computed include poles, insulators, transformers, voltage regulators, capacitor banks, arresters, switches, fuse links, automatic reclosers, automatic seccionalizers, energy meters, current transformers, voltage transformers, spacers and connections. Each one of these components can be divided into subtypes according to the type of equipment existing in the distribution network (for instance, the item "arresters" has subtypes "ceramic" and "polymeric"). The general expression for evaluating failure rate of a given component is as follows:

$$FR_{comp} = \frac{N_e}{N_{tot} \cdot \Delta t} \ , \qquad (2)$$

where FR_{comp} is the failure rate of the component (failures per year), N_e is the number of events involving the component, N_{tot} is the total number of components of the type being considered, and Δt is the period for which the failure rate is being estimated (year).

Failure rate for components can also be computed taking the total network length as reference; in this case, a formula similar to Eq. (1) is employed. Figure 2 shows an example of failure rate evaluation per network length, in this case 700.274 km. Events occurred in the whole MV network in the year of 1999 were used in this example.

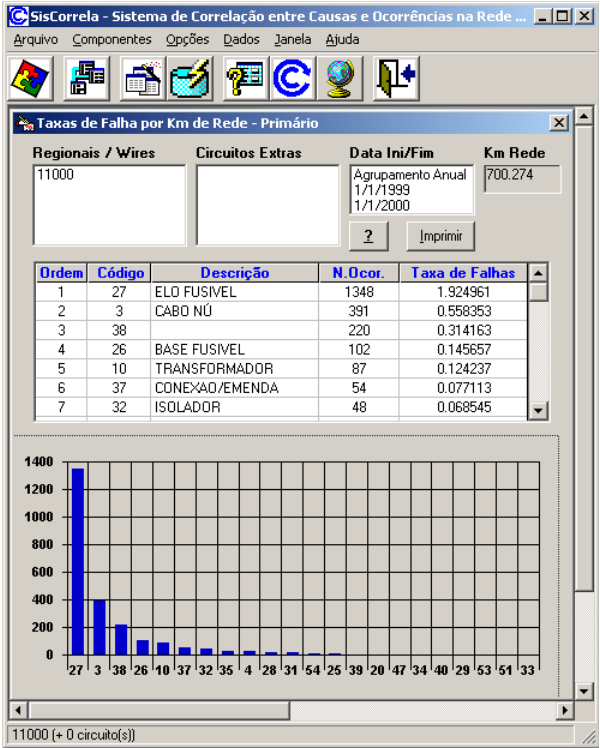

Figure 2 - Example of failure rate evaluation

Number of service operations. The software also allows for analyzing the number of service operations executed in the network, grouped by component type. Figure 3 shows the results for 1999.

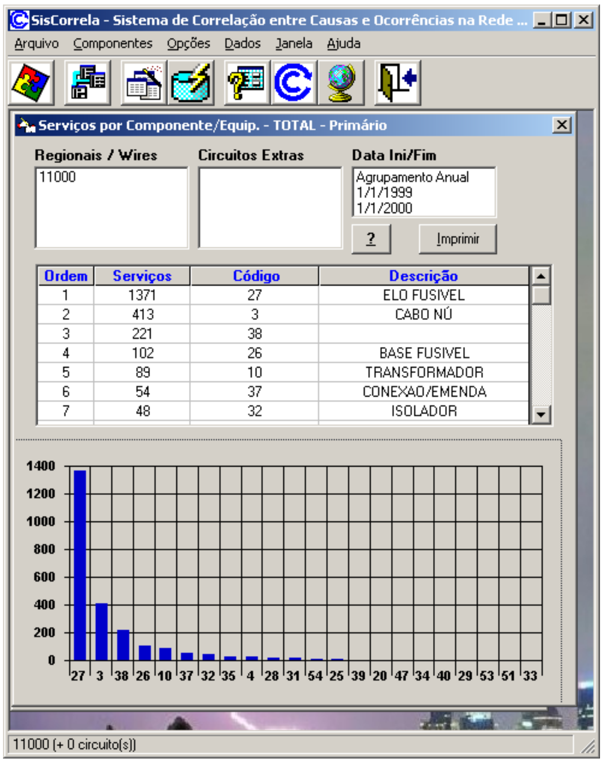

Figure 3 - Number of service operations in 1999

Reported causes. When opening a new event, the technician reports a cause based upon his assessment of the event on the field. The software allows a quantitative analysis of events based on the reported causes, as shown in Figure 4. It should be noted that, for displaying purposes, causes can be grouped in various ways (Environment, Maintenance, etc.).

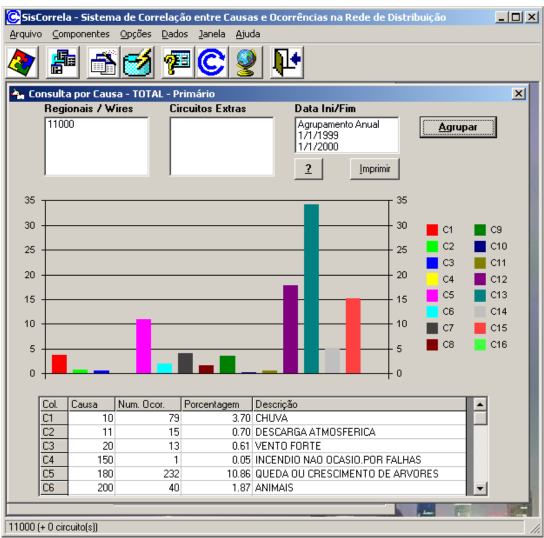

Figure 4 - Events grouped by reported cause

Cost estimates. Events have always associated an initial time and a final time. The duration of the event multiplied by the corresponding non-supplied demand (available from the network management system once the operated switches during the event are known), yields the event's non-supplied energy. The software computes this value and multiplies it by a user-defined unit cost, thus yielding the event's total cost of the non-supplied energy. The software also computes, based on average unit costs for labor and replaced components, the total cost associated with the two items. Figure 5 shows an example of these calculations.

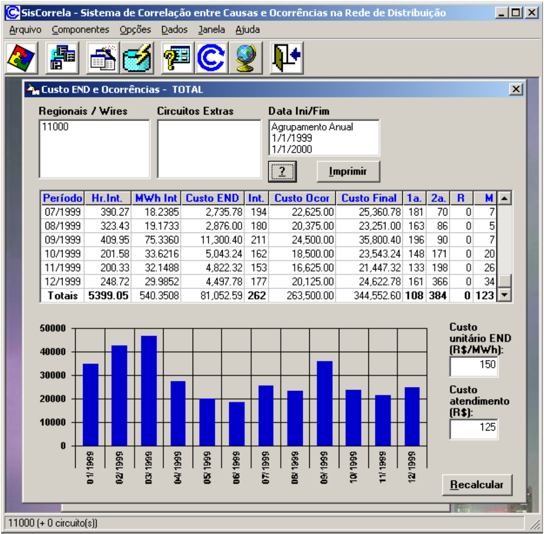

Figure 5 - Cost of non-supplied energy, labor and materials

Estimation of Mean Time Between Failures (MTBF). For a given period of time, the MTBF is simply computed by dividing the period (in hours or days) by the total number of events. Figure 6 shows the MTBF evaluation for the whole MV network during the year of 1999.

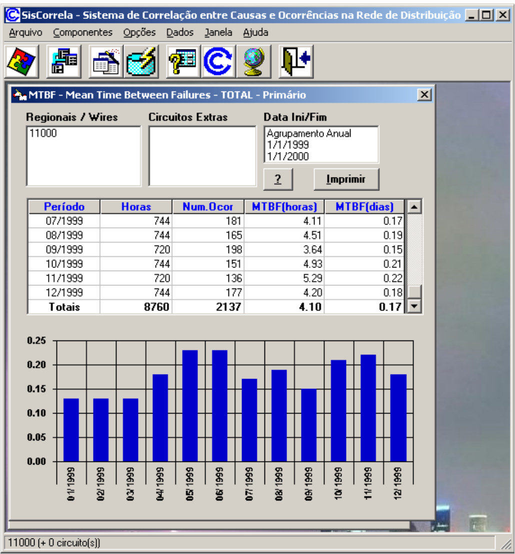

Figure 6 - MTBF evaluation

STUDY CASE

Figure 7 shows another analysis tool, in which each MV circuit appears along its failure rate (circuits are sorted in descending order of the failure rate).

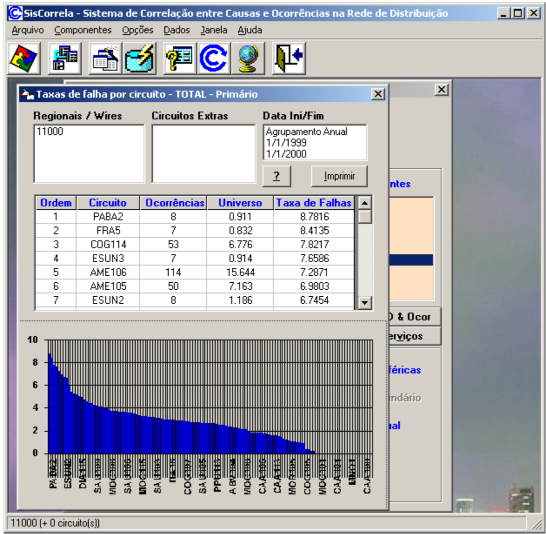

Figure 7 - MV circuits and failure rate

One of the circuits with a relatively high failure rate showed an unusual fraction of events (24%) with reported cause "animals". One of these events was described in detail by the technician in charge, who said that in a certain location there was a fly-tap with insufficient distance among phases, Figure 8 (this information was stored using the handheld computer). An on-site visit confirmed that information and also revealed that a passer-by used to feed pigeons close to the fly-tap. It was concluded that when the pigeons opened their wings, they caused a short-circuit between two phases, causing the disconnection of the entire circuit. Phase separation was then increased. Considering the circuit's average maintenance cost and the cost of modifying the fly-tap, and supposing that the modification would bring about a 20% economy on the maintenance cost, the payback period for this operation was estimated at 131 days.

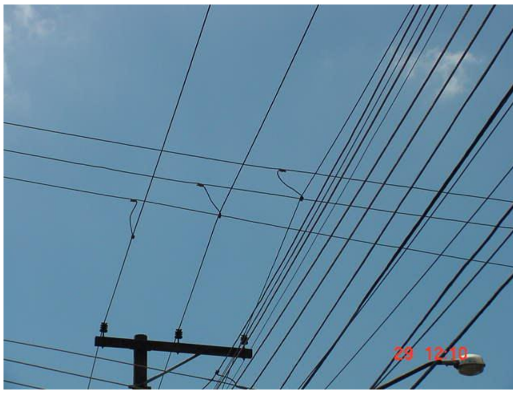

Figure 8 - Flay-tap with insufficient phase separation

CONCLUSION

This paper has presented a methodology and a software implementation of a computational system that attempts to establish cause-effect relationships of events in the operation of a large distribution system. The implementation also allows for a number of different analyses that can be valuable for optimizing financial resources associated with the maintenance of a large distribution system, including costs of labor and materials. Preliminary results show that there is a great potential for revealing chronic problems that could otherwise remain undetected. A natural topic for future development is the evaluation of other reliability indices, such as DEC and FEC, since the relevant information is already stored in the system's central database.

REFERENCES

[1] CETESB - Companhia de Tecnologia de Saneamento Ambiental (São Paulo, Brazil).

[2] CTH - Centro Tecnológico de Hidráulica - Escola Politécnica da Universidade de São Paulo (Brazil).

[3] SIMEPAR - Sistema Meteorológico do Paraná (Paraná, Brazil).

[4] R. Billinton, R. N. Allan, 1996, *Reliability evaluation of power systems*, 2nd ed., Plenum Press, New York.