Real Intelligent Alarm Processing Implementations in Power Control Centers

Carlos H. V. de Moraes, Maurilio P. Coutinho, Germano Lambert-Torres, and Luiz Eduardo Borges da Silva

***Abstract*—This paper presents two implementations of alarm processing programs in CTEEP and CPFL control centers, in Brazil. This program aims to establish a correlation between the existing alarms within an event history, allowing the creation of rules that group alarms. This grouping allows defining the origin of an alarm in relation to other existing at a given time. The tool uses three interlocking techniques for the extraction of associative rules between the alarms: data warehouse and data mining, implementing in a multi-agent structure.**

***Index Terms*—Alarm processing, data mining, intelligent systems, multi-agent systems, power system operation, control centers.**

I. Introduction

The operation of a power system is intrinsically complex due to the high degree of uncertainty and the large number of variables involved [1]. The various supervision and control actions require the presence of an operator, who must be capable of efficiently responding to the most diverse requests, by handling various types of data and information [2]. These data and information come from measurements of the system or from computational processes [3], [4].

The size of the current database in a power control center has increased a lot in the last years due to the use of telecommunication. The system operator needs to know the current state of the system and some forecasted position, such as load forecasting, maintenance scheduling, and so on in order to take a control action (switching, changing taps and voltage levels, and so on).

This paper presents a computational tool based on the intelligent multi-agent techniques. This tool executes several independent analyses, producing a logical ordination of the most important alarms and creating several levels of alarms and their processing. An intelligent agent is a program with intelligent nucleus that she integrates into a modular society, following standardized premises of communication and tends specific function inside of that society.

The agent can be seen as a structure that notices the atmosphere through sensor and it acts in that environment through some functions. The agent consists of a computational system that possesses the following properties: autonomy, social ability, reactivity and own initiative.

II. CTEEP Control Center

A. Features of CTEEP System and Control Center

The CTEEP Transmission System is the most important transmission system in Brazil. Their transmission lines and substations are located at San Paulo State, which is the most important state in Brazil, responsible for more than 40% of the Brazilian economy and energy consumers.

These system is composed by more than 11,780 kilometers of transmission (included 440 and 750 kV lines), crossing 18,266 kilometers of circuits, and 102 substations with a transformation capacity above 38, 500 MVA.

The biggest problem that occurs in the CTEEP control center is the cascade effect, it means, when an event occurs in the system, it generates an alarm, but many others secondary events also occur, and also generate alarms. Fig. 1 shows an example of this problem, where the main event (opening of circuit-breaker, located in position A) occurs generating the main alarm, many other events located in other positions shown in figure also generate alarms.

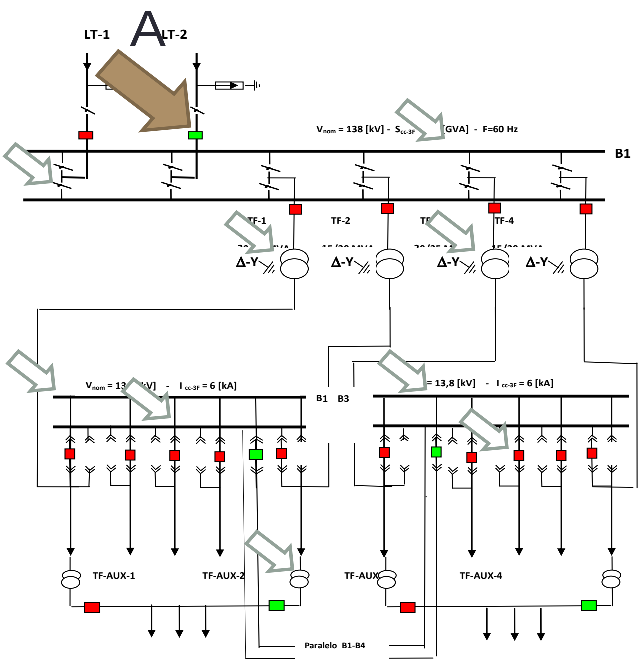

Fig. 1. Cascade effect of alarms.

And more, the main event can generate other indirect events, sometimes harder to be related to the main event, and in large amount.

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Besides that, other problem that occurs in this control center is the chronological errors. It means that doesn't guarantee the main event arrives in the first place for the operator at the control center. Due to the structure of the communication system, the main alarm (caused by the main event) can arrive after many secondary or indirect events. The time-tag of each event can help the operator and the alarm processing program to define the main event, however sometimes there is no correlation among the time-tags. Fig. 2 shows a pictorial scheme where an existing correlated time-tags of each event. In this case, a secondary arrives before the main event in the control center.

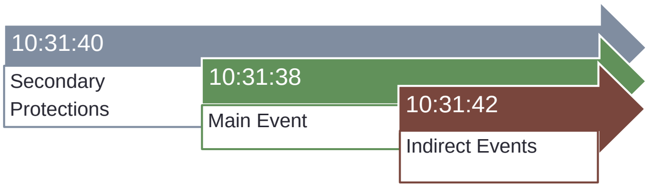


Fig. 2. Chronological errors.

B. *CTEEP DC Ranger System*

DC Ranger System is the CTEEP Control Center support computational program. This system is supply by information from many different remote communication devices located in its substations and some point of its transmission lines. These data arrives in different format and are translated to a single format used by DC Ranger System in its analysis. The developed and implemented alarm processing program also uses the same data and alarm structure, which is the following:

III. Date Time Cat Subst Point Name State Text

Where, DATE is day/month/year of event, TIME is the hour, minute, and second of the event, CAT is the category of alarm, SUBST is the name of the substation, POINT NAME is an identifier into the substation, STATE is the current state of the point, and TEXT is an optional information description. An example of the DCRanger alarm is:

17/NOV/06 05:07:12 COT2 BAURU BAU 138BA-1 KV alarm uninhibited ANALOG

This alarm occurred in November 17, 2006 at 5:07:12 a.m. The category of alarm is COT2AI (inhibited/uninhibited action), the substation name is BAURU, the point name is BAU 138BA-1, and the current state of the point for this alarm is KV (meaning voltage problem). Finally, the text is "alarm uninhibited ANALOG", meaning the done action.

A. *The CTEEP Alarm Processing Program*

The CTEEP alarm processing program starts with the definition of the trigger event. Each event has a different treatment by the program. For each type of event, the trigger time must be defined. It composed by the definition of two times: one defines how much time before the event the alarms need to be analyzed, and the second time, how much time after the event need is composed by two different parts: elimination of superfluous alarms and classification of the processing alarms.

The elimination of superfluous alarms is also divided in two parts. The first part is made by the use of a grammar. There is a list of alarms that are superfluous, it means the operator knows those alarms never are important in his/her interpretation of the main event. A typical event (it means a small problem) produces in 3 minutes around 700 alarm messages. This first elimination part deletes around half part of these alarms.

The second part is made by a set of rule, extracting from the historical alarm database using a rough-set based algorithm [5], [6]. Also, more experienced engineers can also write rules directly. The alarms which have passed by the first part are submitted to the elimination of a set of superfluous alarm rules. An example of this rule can be:

If CAT = 'alarm limit' then delete alarm.

This rule deletes all alarms of the 'alarm limit' category. It is expected that control center engineers run the rule extractor from the historical alarm database monthly. The number of generated rules has been around 30. Usually, in the above example of a typical event, passing the remained 350 alarms in this rule system, only 10% of the original alarm set remains. In our example, around 70 alarms. The time of this processing is only some milliseconds.

The second part of the CTEEP alarm processing program has been designed to make a classification of the remained alarms. This classification is also made in two parts. The first part is based the intervals of voltage, current, and power, which are important for the trigger event. The intervals of each measurement are pre-defined. An example is shown in Fig. 3 for a given bus voltage. In this example, 3 intervals are created by control center engineers named V1, V2, and V3, where the thresholds are 0.95 and 1.05 pu. These definitions are made for each bus and each type of measurement individually or for a set of same bus category.

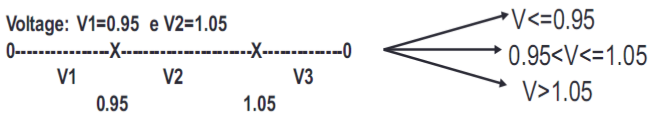


Fig. 3. Definition of voltage intervals.

Each trigger event has its trigger time and important intervals in a specific file, named Criteria.txt. This file, shown in Fig. 4, contains the trigger event description, the trigger times, the voltage, current, and power limits, and then the important intervals for the trigger event. In this example, the trigger event is 'TAUBATE TAU ISOLT440 ILS1 14.4GRO-8 AMP', a voltage event in Taubate Substation, the trigger time are 5 and 10 seconds (time before and after of the trigger event, respectively), the voltage is divided in 3 intervals, with the limits in 0.95 and 1.05, the current in 2 intervals in 200 A, the real power in 4 intervals with the following thresholds: 50, 100, and 300 MVA; and finally the important intervals in the order: V3, P4, V1, and I2.

When the passed remained alarms are treated by the Criteria.txt file, usually, 40 to 50% of alarms are not classified, and then they are deleted. In our example, the number of alarms decreases to around 40 real important alarms. The processing time of this part depends of the number of intervals and criteria; in a current used file is around 2 to 3 seconds.

```
⋮
TAUBATE   TAU  ISOLT440 ILS1 14.4GRO-8 AMP
5 10
⋮
V3
0.95
1.05
I2
200
P4
50
100
300
V3
P4
V1
I2
⋮
```

Fig. 4. Example of part of Criteria.txt.

Finally, another rough-set based program [7], [8] is the second part of the classification of remained alarms. This program which the rules have been extracted from the historical alarm database provides some sets of alarms selecting the most representative alarm for each set. In our example, usually only 2 to 5 representative alarms are displayed to operators. Also, the operator can visualized the other alarms the same set selecting the most representative alarm. The processing time is included in the 2 to 3 seconds above.

B. *Some Illustrative Results*

The CTEEP alarm processing program was implemented in 2007 and has been used in different situations. The reduction of amount of alarms depends on the type of Criteria.txt file. Fig. 5 shows an illustrative example for a real processing. The original amount of alarms is 1818.

Number of original alarms = 1818
Number of select alarms = 316
Reduction Percentage = 82.61%

Classification according the Criteria File:

	Criteria 1.txt	Criteria 2.txt
Number of KV alarms =	17	5
Number of MW alarms =	4	2
Number of MVA alarms =	1	1
Number of MVAr alarms =	2	1
Number of AMPS alarms =	13	2
Number of TAP alarms =	1	0
Number of Hz alarms =	4	0
Other alarms =	6	0
Total number of alarms =	48	11
Number of alarm sets =	3	2
Reduction Percentage =	97.35%	99.85%

Fig. 5. Illustrative example of the CTEEP alarm processing program.

With the first part of the alarm processing program only 316 alarms remained. It means the other 1502 alarms are superfluous to identify the main event, with a reduction of 82.61% in the original amount of alarms. And then, using the Criteria1.txt, 48 alarms are selected and 3 representative alarms are displayed to operator. If the operator uses the file Criteria2.txt, 11 alarms are selected and 2 representative alarms are displayed.

Finally, Fig. 6 shows some results for different sizes of alarm set and its typical used Criteria.txt file. This figure shows the amount of original alarm set and the remained alarms after the Criteria.txt file. The typical reduction is bigger than 97%.

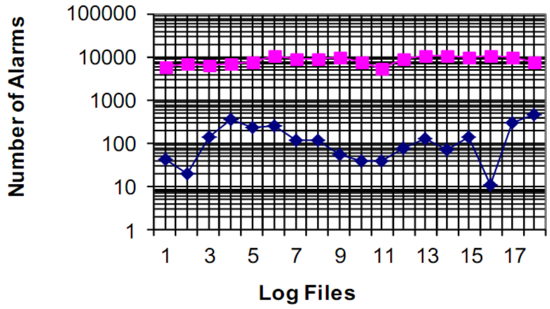


Fig. 6. Original amount of alarms (supper data) versus the remained amount of alarms (lower data).

IV. CPFL Control Center

A. *Features of CPFL System and Control Center*

The Paulista Light &Power Company (CPFL) is the second most important power distribution company in Brazil. It feeds 560 cities, with an area of 175,237 km², with a feeder extension equal to 210,491 km, 276,561 transformers and more than 7 million of clients (for a population around 17,7 million of people).

The two biggest problems had been reported by operators before the implementation of CPFL alarm processing program, these are: the huge number of alarms in normal operation and the large amount of number of alarms in contingencies.

The second problem is common in major part of the control center; however, the first problem is not very common. It occurs because the warning level of a measurement. Fig. 7 shows this problem. When a measurement goes out (in the case of figure goes down, could be up) of the normal range of operation described by the warning lines, an alarm is displayed to operator. And more, when this measurement returns to the normal range another alarm is also displayed. It means each time this fact occurs 2 alarms are displayed to operators. It occurs with at least 6 types of existing alarms (ALISUP, LIRSUP, ALIINF, LIRINF, UTRNR, and UTRRES) in all types of measurements. For instance, in a heavy load period, when the system operates very close to its limits, the measurements also are very close the upper (or lower) warning lines, and the number of these alarms could be bigger than 200 in each minute. With this amount of alarms is impossible to run the system normally.

To solve this situation the operators tend to delete all alarm with this label; however this action is not good, because some of these alarms are important, mainly when some relevant measurements are outside of range during a long period of time.

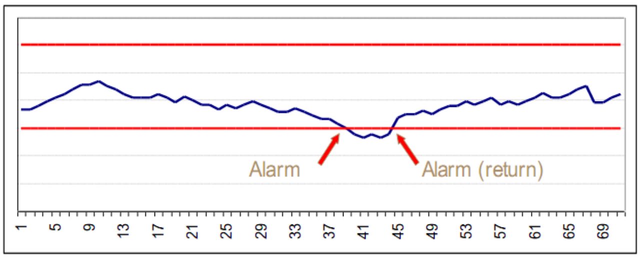
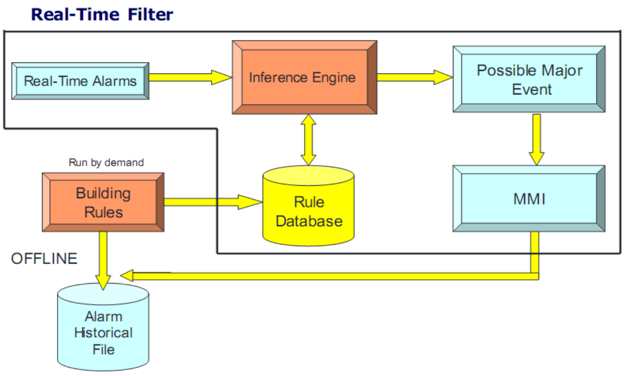


Fig. 7. Example when a measurement goes out and returns to the normal range operation.

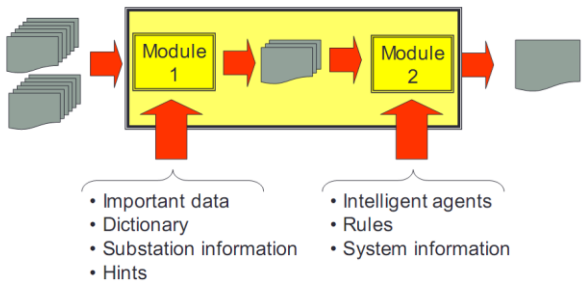
B. *The CPFL Alarm Processing Program*

The CPFL alarm processing program is called PAESE (Program for Event and Alarm Analysis), and has its operation shown in Fig. 8 (a). The alarms arrive to CPFL control center and passes by an inference engine to find the ‘possible’ major event, which is displayed to operators. The rules of the inference engine are built in an offline process from an alarm historical database.

In fact, the inference process occurs in two steps of processing made by modules 1 and 2, shown in Fig. 8 (b). The program reads two types of databases: one is the alarms in a pre-defined period of time (usually, 30 seconds), and other is the current electric structure of the system (with the open/close positions of each circuit-breaker).



(a)



(b)

Fig. 8. PAESE - CPFL alarm processing program.

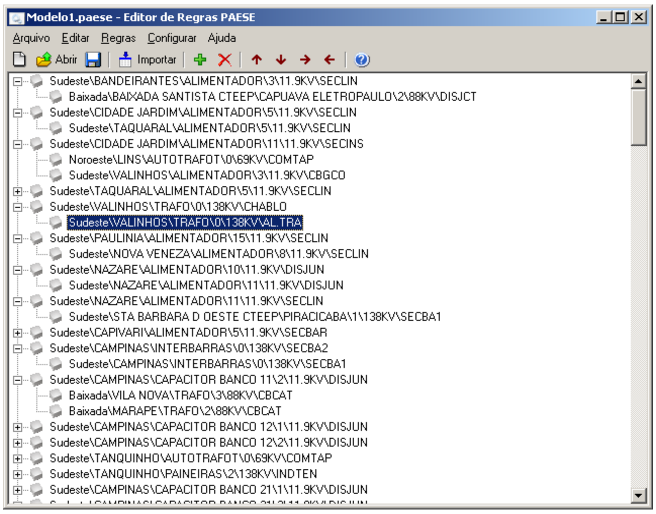
The Module 1 contains the set of information to reduce the number of alarms, mainly the superfluous alarms. This module has: (a) a dictionary to understand each alarm and its function in the system; (b) some practical information about the substations and feeders according their importance for the system; (c) some hints about alarm processing and operation of the system; and (d) some important data about the status of the system, about contingencies or about some special demands and supplies to consumers.

All alarms pass by the Module 1, and only a reduce part of alarms pass to the Module 2. Usually, around 70% of alarms are deleted by Module 1 processing, including the major part of the first type of reported alarms described above.

The Module 2 contains a set of rules grouping in a multi-agent structure. Basically, each agent has a part of the knowledge about the alarm structure and the relation amount the alarms and amount alarms and the level of system load. These rules can be incorporated in two different ways: The first incorporation of rules is by a data mining process in the historical alarm database, which contains information about alarms and status of the system (system load and system structure) when the alarms occur. The second possibility of incorporate rules is by a rule editor, in which an engineer can write rule for the system. A set of windows have been developed to this purpose. Fig. 9(a) gives an idea about the structure of the rule written directly by engineers. This structure contains information about the rule: data, the main event (Evento) by its code (ALESTC), the name of substation (BAURU), its location (AUTOTRAFOT), the voltage (69 kV), the equipment (DISJUN, meaning circuit-breaker in Portuguese), and the action (LIGOU, meaning ‘turn on’). Related to this information are associated many facts listed below this line. It means all these other events can be erased when the first part of the rule is presented. Fig. 9(b) shows the window developed to this end.

Data	Evento	Subestação	Local	Índ	Tensão	Equip.	Ação	
28/05/2008 10:00	ALESTC	BAURU	AUTOTRAFOT		69KV	DISJUN	LIGOU	
	+	ALESTS	BAURU	AUTOTRAFOT		138/69	CHABLO	DESBLOQUEOU
	+	ALESTS	BAURU	TRAFO	2	69KV	CHABLO	DESBLOQUEOU
	+	ALESTS	BAURU	BAURU CTEEP		138KV	INDTEN	COM TENSAO
	+	ALESTS	BAURU	TRAFO	1	69KV	SECTRA	FECHOU
	+	ALESTS	BAURU	TRAFO	2	69KV	SECTRA	FECHOU
	+	ALESTS	BAURU	TERRA BRANCA		138KV	INDTEN	COM TENSAO
	+	ALESTS	BAURU	TRAFO		138KV	CHABLO	DESBLOQUEOU
	+	ALESTS	BAURU	PRESIDENTE ALVES		69KV	INDTEN	COM TENSAO
	+	ALESTS	BAURU	USINA GAVIAO PEIXOTO		69KV	INDTEN	COM TENSAO
	+	ALESTS	BAURU	REGULADOR DE TENSAO	1	13.8KV	AL.REG	NORMAL

(a)



(b)

Fig. 9. Structure of the rule editor.

When the engineer finishes writing the rule, the program translates the current structure to a internal format of rules to be treat with the other existing rules

The passed alarms of Module 1 are submitted to Module 2, which tries to detect the main event (or events or the most important alarm or alarms), which is displayed to operator. Fig. 10 shows a window with an example of a system uses by engineers to verify the quality of the existing set of rules. The superior part of the window is presented all passed alarms of Module 1, and the inferior part of the window the main events (or the most important alarms). In this example, the main event was an opening of a circuit-breaker, in a feeder of 23 kV in Itu location.

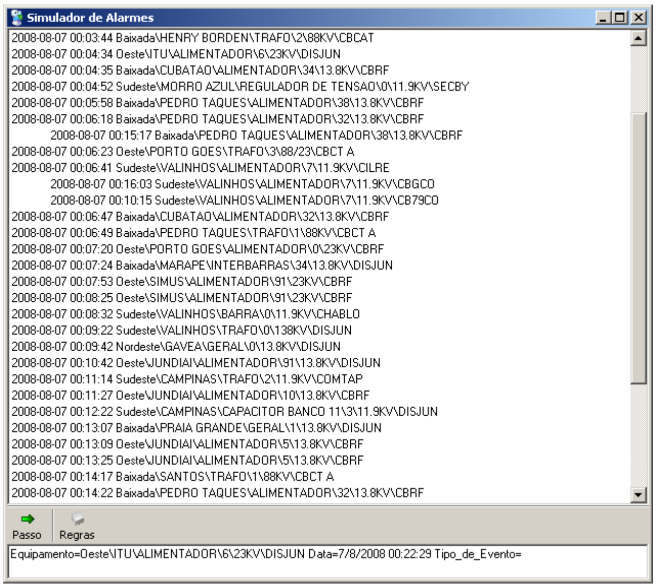


Fig. 10. Window of the rule simulations.

C. Some Illustrative Results

Fig. 11 shows the operator display, where he/she can verify the alarms in each substation of the CPFL power system. The color of each substation gives to operator an idea about the amount of alarms in this substation. In the case of this figure, Carioba Substation has been selected, and in the right part of the screen, the operator has the equipment of the substation, and below the list of existent alarms.

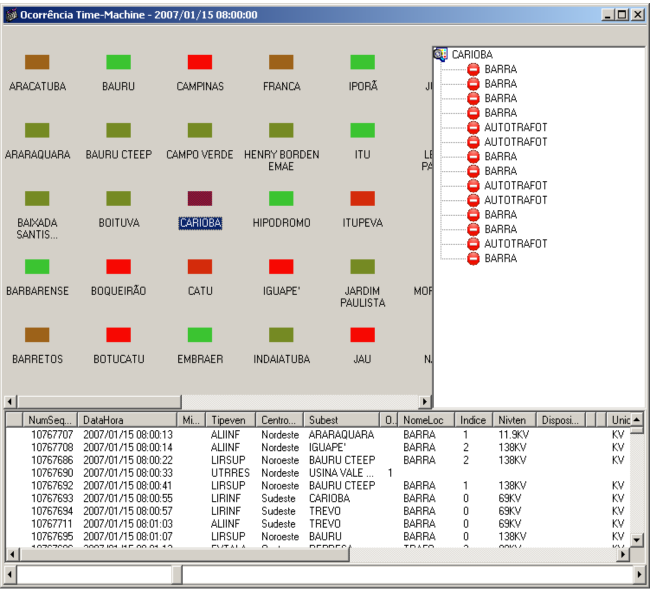


Fig. 10. Window of the PAESE to operators.

To illustrate the PAESE performance, CPFL's electrical system real occurrences were provided corresponding alarms from September 2007 until August 2008. In total there were more than 1,867,928 of alarms provided involving 22,392 different types of equipment, and comprising measures and status change at critical points. Table I exemplifies a small portion of alarms present to be analyzed to PAESE.

Where: Data: day/month/year, hour: minutes: seconds; Event: types of alarms; Equipment: Area – Substation Name [type of equipment]; Action – status changed.

TABLE I: EXAMPLE OF THE ALARM DATABASE

Data	Event	Equipment	Action
14/4/08/ 22:07:40	CEXEC	Northeast - ITAMBE [Capacitor Bank (2) 138KV Circuit-Breaker]	TURN OFF
14/4/08/ 22:07:44	LIRSUP	Northeast - ITAMBE [Capacitor Bank (0) 138KV KV]	
14/4/08/ 22:08:48	COREG	Southeast - CAMPINAS [Capacitor Bank 11 (4) 11.9KV Circuit-Breaker]	
14/4/08/ 22:08:49	CEXEC	Southeast - CAMPINAS [Capacitor Bank 11 (4) 11.9KV Circuit-Breaker]	TURN OFF
14/4/08/ 22:10:08	ALISUP	Southeast - CAMPINAS [Bus (2) 11.9KV KV]	
14/4/08/ 22:11:11	LIRSUP	Northeast - IPORA [Bus (0) 11.9KV KV]	
14/4/08/ 22:13:46	LIRSUP	Northeast - ARARAQUARA [Bus (1) 138KV KV]	
14/4/08/ 22:13:50	CEXEC	Southeast - MORRO AZUL [Feeder (6) 11.9KV Circuit-Breaker]	TURN OFF
14/4/08/ 22:13:50	ALESTC	Southeast - MORRO AZUL [Feeder (6) 11.9KV CBRF]	BLOCKED

Due to the large amount of data involved in the process of extraction of rules and scarce computational time of analysis, a statistical analysis were incorporated to PAESE to the identification of serious occurrences with points or large production rules. These moments of disorder or disconnections that need more attention, because these are the most important moments for the performance of the alarm processing program with the rules obtained from the system, not only for rapid identification of the anomaly, but also ease the operator to obtain faster responses and efficient operation of the electric system. Table II shows some cases (data and number of analyzed alarms) where the PAESE was able to treat the alarms and give to operator a good answer (the main event of the occurrence). It is possible to verify that PAESE is able to manage a large amount of alarm in few seconds.

TABLE II: EXAMPLES OF THE SIZE OF TREATED ALARMS

Data (d/m/y)	Number of Alarms
12/2/2008	7.716
13/2/2008	8.420
14/2/2008	9.352
20/2/2008	6.785
16/3/2008	8.273
26/3/2008	6.807
10/4/2008	8.231
11/4/2008	6.850
23/7/2008	6.555
7/8/2008	6.729
21/8/2008	10.011
26/8/2008	6.591
29/8/2008	7.118

V. CONCLUSION

During the normal operation of a power system, many measurements and events arrive to control centers. The number of these measurements and events are increased in the last times due to the decrease of the price of the measurement devices and the telecommunication system. With this the observability of power system has increased and also the number of alarms that need to be interpreted by operators. Usually, the amount of these alarms is very huge and quite impossible to be analyzed, in special during the contingencies in the system, where this amount can attend some hundreds of alarms in few seconds.

This paper presents two real implementations of alarm processing in two different types of power companies. The first presented implementation was in CTEEP, a power transmission company, operating 138 to 750 kV transmission lines and its substations. The second presented implementation was in CPFL, a power distribution company, operating feeders and its substation, closer to the industrial and residential consumers.

Each program was developed using the grammar of each SCADA control center system and their operational characteristics, which are included in the programs by a set of rules extracted directly from the historical alarm database and from rules written by their engineers.

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