On-line Fault Diagnosis with Incomplete Information in a Power Transmission Network

Nuno Malheiro[1], Zita Vale[1], Carlos Ramos[1], Albino Marques[2], Vieira Couto[2]

[1] GECAD - Knowledge Engineering and Decision Support Group
Instituto Superior de Engenharia do Porto
Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal
ntm@dei.isep.ipp.pt; zav@dee.isep.ipp.pt ; csr@dei.isep.ipp.pt

[2] REN - Rede Eléctrica Nacional,S.A
Portuguese Electricity Transmission
Rua Casal dos Mogos-Vermoim, 4470-259 Maia, Portugal
Albino.Marques@ren.pt; VieiraCouto@ren.pt

***Abstract*—Nowadays, Power Transmission Networks are operated through Supervisory Control and Data Acquisition (SCADA) systems. In incident situations, SCADA systems are prone to accumulate huge amounts of information potentially with temporal, non-monotonic and incompleteness information problems. To support operator's decisions, on-line fault diagnosis is needed due to the critical nature of their work. In this paper a system – SPARSE II – is presented. Is has the ability to perform on-line fault diagnosis despite the information problems of having a SCADA system as an information source.**

***Index Terms*—Power Systems, SCADA Systems, Network Fault Diagnosis, Temporal Reasoning, Incomplete Information**

I. INTRODUCTION

NOWADAYS, Power Transmission Networks are operated in Control Centers (CC) through Supervisory Control and Data Acquisition (SCADA) systems. SCADA are distributed systems which provide means for the acquisition of temporal information (alarms, sampled voltage, current and power, etc) and the (local or remote) control of the active devices in the network, like circuit breakers for instance. SCADA systems are operated in Control Centers (CC), where Control Center Operators (CCOps), maintain the stability of the power network in every aspect it requires. The temporal information acquired though a SCADA system is subject to several problems which will be discussed in section III.

To help CCOps, there have been developed some sophisticated applications for load flow, state estimation, etc. which are designated by Energy Management System (EMS) and are usually integrated in the SCADA system, helping CCOps in the operation of the network. The whole system usually available to CCOps includes: a SCADA system; a set of applications of EMS and visual human machine interface to present the relevant information. The operation of a power transmission network in a normal situation is therefore well handled by CCOps since they receive small amounts of information and have time to both analyze it and act accordingly.

In an incident situation, such as actuation of a protection device (due to the failure of a line for instance), a SCADA system produces huge amounts of information, because every device which changed state produces an alarm. Since there is an interconnection between several devices, and there are automatic operations (performed by automatisms) which occur in these situations, the state of the devices involved in the incident can be altered several times before the network reaches a new stationary state.

In incident situations CCOps are required to perform correct fault diagnosis in the presence of huge amounts of information containing some problems. CCOps are required to perform this task as swiftly as they can to allow them to elaborate a plan for power restoration. In incident situations and contrary to normal situations, CCOps cannot depend on standard applications to help them to perform their duty. In [1] a survey concerning the excessive production of alarms in SCADA systems is presented and even though this survey has been conveyed over a decade and a half ago, only few of the problems it presents have been addressed by SCADA developers in order to provide standard applications for fault diagnosis. In several power transmission networks, CCOps are prepared for the hard job of fault diagnosis through theoretical learning and incident simulation, without any help from decision support applications.

This paper presents a system which can diagnose faults and provide decision support for CCOps in the Portuguese Power Transmission Network, based on information with possible temporal and incompleteness problems.

II. RELATED WORK

Several groups have been working on the production of decision support systems for fault diagnosis in incident situations. One of the systems developed for that purpose was the SPARSE (Expert System for Incident Analysis and Service Restoration) system [2], which is an ancestor of the work presented in this paper. The SPARSE system is constituted at its core by a production rule inference mechanism, which uses temporally tagged facts. It handles temporal reasoning on two levels, either using temporal metaknowledge for the triggering of rules as well as including temporal constraints as premises of rules.

One other relevant approach was the GAAM (Generalized Alarm Analysis Module) [3] system which uses logic and logic resolution as an automatic theorem proving method to perform inference of new knowledge. One interesting feature of this work is its ability to handle missing information. In the absence of minor information particles this system assumes the existence of that information, filling the incident with the information it expected associated with a typical time instant.

There are some multi-agent approaches to the problem of fault diagnosis, namely an application of DESIRE (DEsign and Specification of Interacting REasoning components) [4] and PEDA (Protection Engineering Diagnostic Agents) [5]. Both these systems use legacy (previously developed) systems to perform fault diagnosis.

The application of DESIRE to fault diagnosis uses a fault diagnosis system developed in [6]. It is one of the earlier works in fault diagnosis and very simple compared to recent developments.

In the PEDA system fault diagnosis is performed by a sequential application of a Knowledge-Based System (KBS), which inclusion as an agent is described in [7], followed by a Model-Based System (MBS) described in [8]. The KBS and MBS were developed to perform independent tasks. The KBS performs the task of incident identification while the MBS analyses the actuation of protection devices to verify its correctness.

All the described systems receive temporal information but none of them uses a temporal paradigm to perform inference. Instead, they use non temporal paradigms such as logic or production rules and try to include temporal reasoning into the non temporal paradigms.

There is a consensus that since MBR is based on deep knowledge it is more robust than KBR which is based on shallow (often heuristic) knowledge. It is also a fact that the MBR technique is more prone to computational complexity than the KBR which means that KBR is better for an on-line real-time application.

An on-line system built using a temporal reasoning paradigm and which can symbiotically use the best features of KBR and MBR has been presented in [9]. This paper shows the developments in the previous work and its increasing ability to handle incompleteness in information.

III. Problems in the information

The production, acquisition and presentation of alarms using SCADA systems are subject to some problems which will be addressed in the following subsections.

A. Temporal Problems

The geographical distribution of power transmission networks dictates the use of Wide Area Networks (WANs) to transport the temporal information from the devices which produced it into the CC. This fact along with possible topological differences in the attribution of time tags to information produced in different devices, originates the following temporal problems in the information which arrives to a CC:

1) Different chronological order in information production and its reception in the CC, due to different information paths;
2) Attribution of time tags to alarms different from their instant of production, due to a distributed topology of the attribution of temporal tags in some installations;
3) Attribution of equal time tags to different alarms from different devices, due to a centralized topology of the attribution of temporal tags in some installations.

The identified temporal problems in information are very relevant to the choice of a paradigm, for knowledge inference, based on this type of information.

B. Non-Monotonic Problems

There are some issues regarding non-monotonic reasoning which must be taken into account when using a SCADA system as an information source. The problems are:

1) Semantics of the integration of information particles in incorrect chronological order. For instance the opening and closing of a circuit breaker has a different interpretation than a closing followed by the opening;
2) Alteration of the state of a device to the same state in which it was before. This alarm is a signaled alteration without the alteration itself and must initiate a process of truth maintenance;
3) A delay in the arrival of some of the information might detect a non existing incident situation which must be handled when more complete information becomes gradually available.

The non-monotonic problems described in this subsection are very relevant to the real use of an application for decision support based on a SCADA system as an information source. Failure to comply with a resolution to these problems can render an application useless.

C. Incompleteness Problems

There are two kinds of incompleteness which can be identified using a SCADA as an information source:

1) **Incomplete Information with Expectation:** this information can be incomplete at a certain instant in time but there must be an expectation of its arrival.
2) **Manifestly Incomplete Information:** in this case there is an assumption that information will not be know or that the cost of its knowledge (e. g. in time) is too great.

There is a temporal incompleteness dynamic implicit in the above definitions, which is presented in Fig. 1, raising questions as to what is expectation and when to draw the line on this expectation. An information particle can be in expectation in a determined point in time in which its appearance is still viable, to become its absence cataloged as manifestly incomplete due to the elapse of a certain amount of time. This very particle which was expected and afterwards cataloged as manifestly incomplete can arrive and truth maintenance must be performed. Each possible situation in the domain of fault diagnosis must be modeled in terms of expectation.

This work presents a notion of expectation in information incompleteness. This allows the modeling of expectations and the inclusion of an expectation model to deal with information incompleteness.

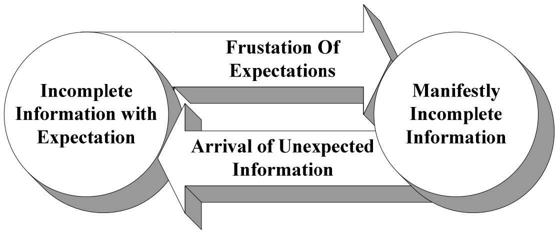

Fig. 1. States of Incomplete Temporal information

There is some *a priori* manifestly incomplete information in SCADA systems due to the fact that the SCADA does not possess all the information about the power network. If, for instance, a circuit breaker which usually protects a line has to be deactivated so that maintenance can be performed, the CCOp must ensure that this line will still be protected, usually by the use of an inter-bus circuit breaker. This change in the protection scheme is not explicit in the SCADA. It is implicit in the topology of operation. If the protections of the initial circuit breaker become active during its maintenance, the opening breaker will be the inter-bus circuit breaker. In these situations, the correlation between the actuation of the protections and the opening of the device is impossible without an updated model of the power network's topology.

IV. On-line Fault Diagnosis

A. Problem Statement

From what has been already been exposed in this paper, a problem statement is now able to emerge. What was sought was an application which was able to: diagnose faults in real-time in the Portuguese Power Transmission Network, with the ability to handle temporal, non-monotonic and incompleteness problems.

The application must be able to receive huge amounts of temporal information subject to the referred problems and reason with it in some form that it can arrive at the same conclusions that a CCOp would draw.

In order to develop such an application, and based on previous work several guidelines have been pointed:

1) The information used in the SCADA is temporal hence any paradigm which reasons with it must also be temporal;
2) The use of the KBR paradigm allows real-time performance;
3) The use of the MBR paradigm allows the robustness to information incompleteness;
4) Interaction between KBR and MBR techniques during fault diagnosis is an asset to correct reasoning because the combination of deep and shallow knowledge preserves both real-time operation and the robustness to incompleteness;

Based on these guidelines, an architecture for a solution will be presented in the next subsection. This architecture has been used in the development of a real system operation in the Portuguese Transmission Network.

B. Architecture of the Solution

In order to follow the guidelines presented in the previous subsection, a set of directives have been followed to ensure their application. The directives are:

1) As a temporal reasoning paradigm use the Event Calculus with Timeouts (ECT), initially presented in [10];
2) Develop a KBR module using the ECT as a paradigm and the knowledge about network operation previously acquired in the SPARSE project. This module has been presented in [9];
3) Develop a MBR module using the ECT as a paradigm and the knowledge about network topology and dynamics extracted from the SCADA. This module has been presented in [11];
4) Join the KBR and MBR modules in a multi-component distributed application. Enhance each of these modules with interconnection knowledge so that each of their inferences can upgrade the whole set.

The joint use of a KBR module and a MBR reasoning module independent and interconnected preserves the best features of each one, which is real-time response in the KBR and increased robustness in the MBR but allows any inference performed by any of the modules to complete the other module's knowledge.

C. Event Calculus with Timeouts

A brief presentation of the Event Calculus with timeouts will be made in this section.

The Event Calculus (EC) [12] is based on a set of axioms which can assign a truth value to a fluent property. A fluent property is some property which truth value can change over time. The EC knowledge base is composed of fluent property initiation and termination conditions. The occurrence of an event in a particularly defined state can be defined, in the knowledge base, to cause fluent property initiation or termination.

The EC has been considered a valid approach to temporal reasoning but it has the drawback of being unable to represent the flow of time. In this calculus, only events can alter the knowledge base and the flow of time is not considered an event. In order to maintain the low computational complexity of the EC and still be able to represent the flow of time in some form, an extension to the EC has been created: the Event Calculus with Timeouts (ECT). This extension adds the possibility of variable temporal persistence to every event in the ECT. The temporal persistence of an event is obtained by introducing a timeout event in the ECT knowledge base along with the original event. The temporal persistence is variable because the timeout event is based on the type of event which arrived.

The need of variable temporal persistence can be justified with an example: if a circuit breaker opens at a particular instant in time, this information might be important to correlate this event with some other event in its temporal neighborhood. However, the neighborhood must be limited so that the correlation is meaningful. The previous states that the opening of the breaker has limited temporal persistence for alarm correlation.

The axioms of the ECT are presented in ECT1 through 4:

$$holdsAt(F,T) :- \; iniciallyValid(F), \; not(broken(0,F,T)). \qquad \text{ECT1}$$

$$holdsAt(F,T2) :- happens(A,T1), starts(A,F,T1), \; T1 < T2, not(broken(T1,F,T2)), \; not(timedout(T1,A,F,T2)). \qquad \text{ECT2}$$

$$broken(T1,F,T2) :- happens(A,T), T1 < T < T2, \; ends(A,F,T). \qquad \text{ECT3}$$

$$timedout(T1,A,F,T2) :- \; isTimedout(A,F), \; happens(timeout(A),T), \; T1 < T < T2. \qquad \text{ECT4}$$

The ontology of the formulas used in the axioms of the ECT can be found in Table I.

TABLE I
ONTOLOGY OF THE EVENT CALCULUS WITH TIMEOUTS

Formula	Meaning
holdsAt(F,T)	Fluent F is valid at instant T
initiallyValid(F)	Fluent F is valid from the beginning of time
broken(T1,F,T2)	Fluent F has been invalidated in the interval]T1;T2[
happens(A,T)	Action (event) A happens at instant T
starts(A,F,T)	Action A starts fluent F at instant T
ends(A,F,T	Action A ends fluent F at instant T
timedout(T1,A,F,T2)	The persistence of action A times out and ends fluent F in the interval]T1;T2[
timeout(A)	Action of timing out action A
isTimedout(A,F)	Action A can end fluent F by timeout

The use of the ECT as a paradigm for temporal reasoning, using the variable temporal persistence to perform robust correlation between fluent properties can solve the temporal and non-monotonic problems respectively depicted in sub sections III.A and III.B.

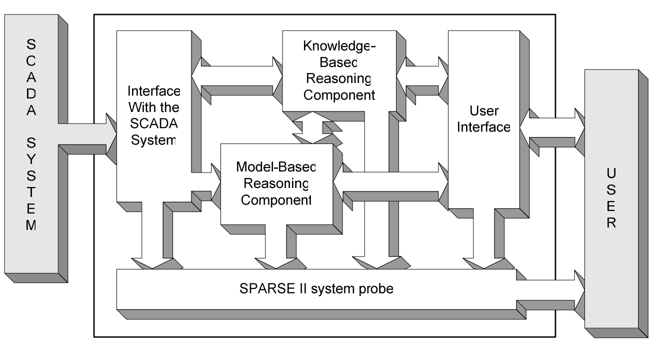

Fig. 2. Block Diagram of the SPARSE II Components

V. SPARSE II Decision Support System

SPARSE II stands for "Expert System for Incident Analysis and Service Restoration with Incomplete Information" and it is the designation of the system developed in this paper, which block diagram is presented in Fig. 2.

The interface with the SCADA used in the Portuguese Power Transmission Network (Siemens SINAUT Spectrum) has been built based on a open protocol called TASE.2 (Telecontrol Application Service Element) [13] and also referred to as ICCP (Inter Control Center Protocol). The system probe can collect the status of every component thus making available their functioning and intercommunication.

A. Knowledge-Based Reasoning Component

The Knowledge-Based Reasoning Component (KBRC) uses knowledge about incident diagnosis on power transmission networks mapped in fluent properties which are:

1) State of the network's active devices. Each active device is assigned a fluent property which represents its state;
2) Correlation possibility. Each alarm which can be possibly correlated with others and its corresponding timeout are assigned a fluent property. The pairs (event, timeout) define temporal windows in which the fluent property is true;
3) Basic incident situation. Basic incidents are considered to be incidents which inference is based on correlation fluents. Several fluent properties regarding the several types of basic incidents which can occur in the network are implicitly defined for each active component of the network;
4) Complex incident situation. Complex incidents are considered to be incidents which inference is based on basic incident fluents or in other complex incident fluents. As in the basic incident situation, several fluent properties regarding the several types of basic incidents are implicitly defined.

The KBRC maps all the knowledge acquired in the SPARSE project, being able to represent the knowledge in a way which resembles more the reasoning of the CCOps. The ECT is a non-monotonic paradigm, which means that, unlike other approaches, an historic of consistent changes can be kept within the database.

This component is used for the detection of incidents in power lines, which can be the following:

1) Simple Trip: it is an incident where a protective device triggers, actuating a circuit breaker. This is done when the electrical parameters on the line rise above or sink below normal parameters.
2) Simple Trip with Reclosure: after the occurrence of a simple trip, some devices have the ability to try to reconnect to perform a swift restoration of service. This is particularly useful in fugitive (very short duration) incidents.
3) Simple Trip with Successful Reclosure: after a simple trip with reclosure, the existence of a temporal long enough interval without the occurrence of a simple trip indicates a successful reclosure.
4) Simple Trip with Unsuccessful Reclosure: after a simple trip with reclosure, the existence of a new simple trip in

its temporal neighborhood indicates an unsuccessful reclosure.

This component is an "executive" component, with the ability to respond in real-time with some explanation for a particular incident. It provides nearly the same heuristic knowledge that an experienced CCOp could provide.

B. Model-Based Reasoning Component

The Model-Based Reasoning Component (MBRC) uses a model of the Portuguese Power Transmission Network. Every device included in the SCADA system is also mapped on this component. The interaction with the SCADA can assign states and electrical values to each of the devices mapped by this component. This component is, in fact a representation of the SCADA and hence of the electrical power network.

Based on the representation of the SCADA, the MBRC possesses expected behaviours for the active components of the network. This is a way to model knowledge about the network's dynamics and also a way to detect incompleteness in the information. For instance, if a tripping alarm is detected, it is expected that a circuit breaker will open. This expectation can trigger a search for this device or, given sufficient time without the detection of the expected behaviour, proactively alert the user of the problem.

The main function of the MBRC is to detect state changes and to be robust to incomplete information. The problems it detects are:

1) Disconnected Line: a line which is disconnected from the network by either actuation or expected actuation of some device;
2) Disconnected Bus: a bus which is disconnected from its every connection by either actuation or expected actuation of some device;
3) Isolated Installation: an installation with no possible contact with the remaining network;
4) Island Creation: the existence of at least two subsets of installations each of which includes generation ability.

This is a deep reasoning component since models both the actuation of the network and the expected actuation of the network.

In what concerns the actuation of the network, the SCADA system used in SPARSE II, the Siemens SINAUT Spectrum can provide electrical measures for each component of the power network and, if it cannot acquire them in real-time, an on-line simulation model fills the measures with deep knowledge calculations.

Expected actuation of devices through the actuation of protections or automatic operators is not taken into account by the SCADA. The MBRC enhances the SCADA with an additional deep knowledge layer which allows robustness to increase even further.

C. Inter-Component Interaction

The interaction between components is performed by proactive communication of relevant inferences and the ability to inter-communicate in a query-reply form.

For instance, when one of the modules arrives to a conclusion about a line, it proactively communicates its inference to the other module so that it can internally update its knowledge.

If a module requires some specific knowledge from the other it can also query it and receive a reply. This is usually done by the KBRC when it is trying to robustly prove something. In this case, the KBRC starts a reasoning process which waits for a reply even though other reasoning processes in execution coexist. When a reply comes, the waiting reasoning process is awakened and it continues.

VI. Incomplete Information Incident

The incident presented in this example is the simple tripping of a line with the particularity that the information available in the CC is incomplete. It is an incident which occurs when a line is being operated with protection from the installation's inter-bus circuit breaker rather than its usual circuit breaker. It is shown in Fig. 3 a scheme of the installation in which this incident has occurred, namely line LBLRM2.

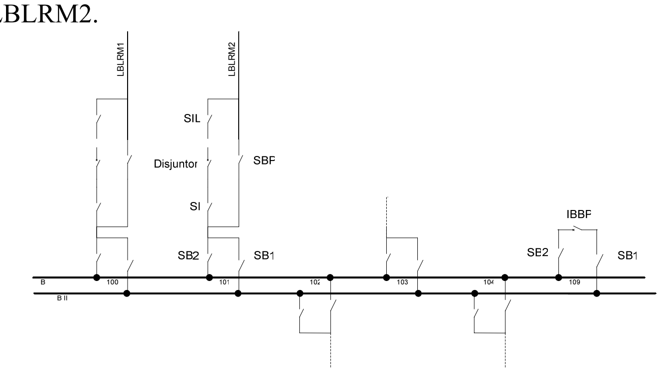

Fig. 3. Installation Scheme for the Incomplete Information Example

A. Incident Explanation

In normal operation a circuit breaker must protect a power line at all times. Usually a line has a dedicated circuit breaker but if for some reason this breaker cannot protect the line, an alternative protection scheme must be set up. Normally the alternative scheme involves the inter-bus circuit breaker.

Associated with a power line there are detection devices which measure voltage and current and send a tripping signal when some abnormal condition occurs. The signal is usually sent to the line's circuit breaker unless it has been assigned other target. The SCADA system is not aware of these changes and they can only be noticed by topological analysis of an incident.

In a situation in which the line is being operated with an alternative protection scheme, no correlation can be found between the tripping signal and the opening of the device unless the protection scheme is known.

In these cases, given the occurrence of an incident, the MBRC can find out the protection scheme an correlate the events.

B. Incident Analysis

The alarms that compose the incident are depicted in Table II.

No date information has been supplied due to its redundancy.

TABLE II
SCADA ALARMS FOR THE INCOMPLETE INFORMATION INCIDENT

10:30:20,526	SBL		Command	Local
10:30:21,947	SBL		Command	Manual
10:30:56,824	SBL	240 IB 220kV	SB2	Closed
10:31:04,764	SBL	240 IB 220kV	SB1	Closed
10:35:26,870	SBL	240 IB 220kV	Breaker	Closed
10:35:26,870	SBL	240 IB 220kV	Fault Breaker	Start
10:35:26,870	SBL	240 IB 220kV	Alarm Not urgent	Start
10:35:35,526	SBL	240 IB 220kV	Fault Breaker	End
10:35:35,526	SBL	240 IB 220kV	Alarm Not urgent	End
10:36:09,764	SBL	236 LBLRM2	SB2	Closed
10:45:58,596	SBL	236 LBLRM2	SB2	Open
10:48:07,353	SBL	236 LBLRM2	SBP	Closed
10:50:16,086	SBL	236 LBLRM2	Breaker	Open
11:23:48,199	SBL	236 LBLRM2	Alarm Not urgent	Start
11:23:48,199	SBL	236 LBLRM2	Alarm urgent	Start
11:23:48,509	SBL	236 LBLRM2	Protections	>>Trip
11:23:48,512	SRM	205 LBLRM2	Alarm Not urgent	Start
11:23:48,512	SRM	205 LBLRM2	Alarm urgent	Start
11:23:48,513	SBL	236 LBLRM2	Fault Breaker	Start
11:23:48,513	SBL	236 LBLRM2	Fault source	Start
11:23:48,513	SBL	236 LBLRM2	Not maneuver	Start
11:23:48,542	SRM	205 LBLRM2	Protections	>>Trip
11:23:48,542	SRM	205 LBLRM2	Not maneuver	Start
11:23:48,513	SBL	240 IB 220kV	Not maneuver	Start
11:23:48,513	SBL	240 IB 220kV	Alarm Not urgent	Start
11:23:48,546	SBL	240 IB 220kV	Breaker	dist
11:23:48,546	SBL	B1 220kV Voltage 211.7 kV	Start	V_Low 212.0
11:23:48,546	SBL	240 IB 220kV	Breaker	Open
11:23:48,550	SRM	205 LBLRM2	Breaker	Open
11:23:48,558	SBL	236 LBLRM2	Voltage zero	Start
11:23:48,558	SBL	240 IB 220kV	Alarm urgent	Start
11:23:48,659	SBL	236 LBLRM2	SBP	dist
11:23:48,689	SBL	236 LBLRM2	SB2	dist
11:23:48,703	SBL	236 LBLRM2	SB1	dist
11:49:50,859	SBL	236 LBLRM2	Breaker	Closed
11:49:50,876	SBL	B1 220kV Voltage 214.3 kV	End	V_Low 212.0
11:49:50,876	SBL	236 LBLRM2	Voltage zero	End
11:50:42,478	SRM	205 LBLRM2	Breaker	Closed
11:50:42,487	SRM	205 LBLRM2	Alarm urgent	Start
11:50:42,487	SRM	205 LBLRM2	Alarm urgent	End
11:52:13,299	SBL	236 LBLRM2	Alarm urgent	Start
11:52:13,299	SBL	236 LBLRM2	Alarm urgent	End
11:52:13,299	SBL	236 LBLRM2	Fault source	Start
11:52:13,299	SBL	236 LBLRM2	Fault source	End
11:52:19,774	SBL	236 LBLRM2	SBP	Open
11:54:41,991	SBL	236 LBLRM2	SB2	Closed
11:55:01,744	SBL	236 LBLRM2	SB1	Open
12:00:10,430	SBL	240 IB 220kV	Breaker	Open
10:30:20,526	SBL		Command	Local
10:30:21,947	SBL		Command	Manual
10:30:56,824	SBL	240 IB 220kV	SB2	Closed
10:31:04,764	SBL	240 IB 220kV	SB1	Closed
10:35:26,870	SBL	240 IB 220kV	Breaker	Closed
10:35:26,870	SBL	240 IB 220kV	Fault Breaker	Start
10:35:26,870	SBL	240 IB 220kV	Alarm Not urgent	Start
10:35:35,526	SBL	240 IB 220kV	Fault Breaker	End
10:35:35,526	SBL	240 IB 220kV	Alarm Not urgent	End
10:36:09,764	SBL	236 LBLRM2	SB2	Closed
10:45:58,596	SBL	236 LBLRM2	SB2	Open
10:48:07,353	SBL	236 LBLRM2	SBP	Closed

The compact conclusions of SPARSE II explaining this incident can be seen in Table III.

TABLE III
CONCLUSIONS OF SPARSE II FOR THE INCOMPLETE INCIDENT

11:23:48,546	SBL	Bus SBL 1 Without Voltage
11:23:48,546	SBL 236	Line LBLRM2 Without Voltage
11:23:48,550	SBL 236-SRM 205	Simple Trip on line LBLRM2

The set of alarms can be divided into three subsets:

10:30:20,526 until 10:50:16,086: devices states are altered so that the protection of the line LBLRM2 switches from its normal circuit breaker to the inter-bus circuit breaker.

11:23:48,199 until 11:23:48,703: there is an incident in line LBLRM2, which triggers a tripping alarm in panels SBL 236 and SRM 205. Shortly afterwards, the inter-bus circuit breaker opens in panel SBL 240.

11:49:50,859 until 12:00:10,430: Service is restored on line LBLRM2 through its normal protection scheme. The inter-bus circuit breaker is freed from its line protection duty.

In this case, the MBRC detects a voltage fault on the bus followed by a voltage fault on line LBLRM2.

The KBRC receives this information and correlates it with the tripping alarms to conclude a simple trip on line LRMBL2

VII. CONCLUSION

This paper stresses the importance of on-line fault diagnosis in power transmission networks. Fault diagnosis can add support for decisions of the operator for service restoration. Other addressed issues are the problems of using a real SCADA system as an information source. These problems can be temporal, non-monotonic and of incomplete information.

An architecture has been designed to provide decision support to Control Center operators, overcoming the problems of the SCADA. The SPARSE II system is presented in this paper as an implementation of the architecture and is installed in the Control Center of the Portuguese Power Transmission Network, integrated with the Siemens SINAUT Spectrum SCADA.

REFERENCES

[1] W. Prince, B. Wollenberg, D. Bertagnolli; “Survey on Excessive Alarms”; in *IEEE Transactions on Power Systems*; vol. 4(3); August, 1989; pp. 950-956

[2] Z. Vale, A. Machado e Moura, M.F. Fernandes, A. Marques, C. Rosado, C. Ramos “SPARSE: An Intelligent Alarm Processor and Operator Assistant”; *in IEEE Expert*; vol. 12(3); Special Track on AI Applications in the Electric Power Industry; 1997; pp.86-93

[3] J. Jung, C. C. Liu, M. Hong, M. Gallanti and G. Tornielli, “Multiple hypotheses and their Credibility in On-Line Fault Diagnosis,” *in IEEE Transactions on Power Delivery*, vol. 16(2), 2001, pp 225-230

[4] F. Brazier, B. Dunin-Keplicz, N. Jennings, J. Treur; “DESIRE: Modelling Multi-Agent Systems in a Compositional Formal Framework”; *in Int. Journal of Cooperative Information Systems*; vol. 6; n. 1; 1997; pp. 67-94

[5] S. McArthur, J. McDonald, J. Hossack;”A multi-agent approach to power system disturbance diagnosis”; *Book Chapter in Autonomous systems and intelligent agents in power system control and operation*; ed. Christian Rehantz, Springer Verlag; 2003

[6] J. Barandiaran, I. Laresgoiti, J. Perez, J. Corera,, J. Echavarri; “An expert system for the analysis of disturbances in electrical networks”; *in Operational expert system applications in Europe*; G.P. Zarri eds. Pergamon Press, New York; 1991

[7] J. Hossack, J. Menal, S. McArthur, J. McDonald; “A multiagent architecture for protection engineering diagnostic assistance”; *in IEEE Transactions on Power Systems*, vol. 18(2); May, 2003

[8] S. C. Bell, S. McArthur, J. McDonald, G. Burt et al; “Model Based Analysis of Protection System Performance”; *in IEE Proc. Generation, Transmission and Distribution*; vol. 145(3) ; 1998; pp. 547-552

[9] N. Malheiro, Z. Vale, C. Ramos, M. Cordeiro, A. Gomes, A. Marques, V. Couto; ”Fault diagnosis with incomplete and temporal information – an application using a knowledge and model-based architecture”; *in Proc. of Int. Conf. on Intelligent Systems Application to Power Systems (ISAP 2003)*; Lemnos, Greece; 2003

[10] N. Malheiro, Z. Vale, C. Ramos, “A Formal Expert System For Power Systems Fault Diagnosis”, *in Proc. of 20th IASTED International Multi-Conference Applied Informatics (AI 2002)*, 18-21 February, 2002, Innsbruck, Austria

[11] N. Malheiro, Z. Vale, C. Ramos, M. Cordeiro, A. Gomes, A. Marques, V. Couto; ” Decision Support For Power System Control Centers – A Model Based Reasoning Component”; *in Proc. of Int. Conf. on Knowledge Engineering and Decision Support (ICKEDS 2004)*; Porto, Portugal; 2004; pp. 331-319

[12] R. Kowalski, M. Sergot, “A Logic-Based Calculus of Events”, *in New Generation Computing*; n. 4; 1986; pp. 67–95

[13] IEC Utility Communications Specification Working Group. "TASE.2 Services and Protocol". IEC870-6-503, Version 1996-08, August 1996