Alarm Processing and Reconfiguration in Power Distribution Systems*

Marie-Odile Cordier[1], Jean-Paul Krivine[2], Philippe Laborie[1] and Sylvie Thiébaux[3]

[1] IRISA, Campus universitaire de Beaulieu,
35042 Rennes cedex, France
<Firstname>.<Lastname>@irisa.fr
[2] EDF, Direction des Etudes et Recherches,
1 av. du Général de Gaulle, 92141 Clamart cedex, France
<Firstname>.<Lastname>@edfgdf.fr
[3] CSIRO Mathematical & Information Sciences,
GPO Box 664, Canberra ACT 2601, Australia
<Firstname>.<Lastname>@cmis.csiro.au

Abstract. Supervision of power distribution systems is a major concern for electricity distributors. It consists in analysing alarms emitted by the devices, detecting permanent faults, locating these faults and reconfiguring the network to maintain the optimal quality of service. EDF is developing the AUSTRAL platform which provide distribution control centers with a set of advanced real-time functions for alarm processing, diagnosis and power supply restoration. After an overview of the general architecture of AUSTRAL, this paper focuses on the alarm processing and restoration functions, which both use model-based approaches.

1 Introduction

Supervision of power distribution systems is a major concern for electricity distributors. It consists in analysing alarms emitted by the devices, detecting permanent faults, locating these faults and reconfiguring the network to maintain the optimal quality of service. EDF (Electricité de France) is developing the AUSTRAL platform which provide distribution control centers with a set of advanced real-time functions for alarm processing, diagnosis and power supply restoration. It is currently under experimentation on two distribution centers (Lyon and Versailles).

After a brief description of the French distribution networks (Section 2) and an overview of the general architecture of AUSTRAL (Section 3), this paper focuses on the alarm processing and supply restoration functions. Both use model-based approaches. ESF, the alarm processing or Event Synthesis Function is in charge of the synthesis of events and the detection of permanent faults (Section 4). ESF relies on an efficient chronicle recognition approach. Chronicles are automatically generated from a model of behaviour and misbehaviour of the devices by our GEMO system. When permanent faults are detected, the tasks of LRF, the fault Location and supply Restoration Function, are to locate the

* Work supported by contract R34-1H9487 and contract R37-1K4619 between IRISA and EDF.
[3] Work done while the author was at IRISA.

faulty lines, and to undertake reconfiguration actions so as to isolate the faults and restore the power to non-faulty lines (Section 5). This requires coping with numerous sources of uncertainty. The SyDRe experimental prototype described in this paper is able to successfully implement LRF by deeply intertwining the location and restoration tasks. A number of related works on power distribution systems exist (Section 6), which we discuss before presenting actual results and forecasted developments (Section 7).

2 The EDF power distribution system

The French medium voltage (MV) power distribution system is a three-phase network operating mainly at 20 kilo-volts. It is fed by the power transport and repartition networks (more than 60 kilo-volts), and supplies loads (MV/LV substations, industrial customers ...). In a primary substation, as in Figure 1, the MV produced by HV/MV transformers feeds a busbar via an incoming feeder. Each incoming feeder is protected by a circuit-breaker. The busbar supplies with MV a set of outgoing feeders, each of them being also protected by a circuit-breaker. The distribution network itself functions with a radial structure from the outgoing feeders of the HV/MV substations to the loads. (see Figure 1). Nevertheless this structure is meshable thanks to a set of remote-controlled or manually-operated switching devices. This allows a reconfiguration of the system to resupply a maximum of loads after a permanent fault occurs.

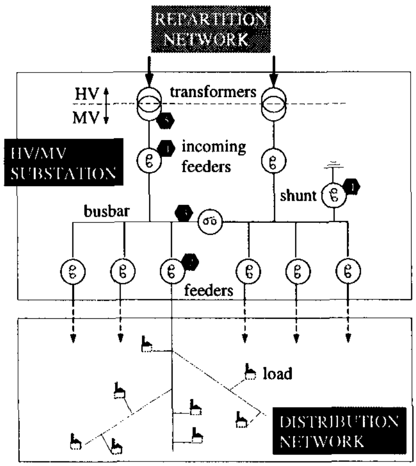

Fig. 1. Substation and part of distribution network downstream one feeder

Faults may occur on the lines of the network, or anywhere in the substation (transformers, incoming feeders, busbars). The equipment of the system is designed to reduce the impact that these faults could have on the quality of the service. In particular, fault detectors positioned on the lines and in the substations can detect faults that are situated downstream. In the substations, fault detectors are integrated into protections relays. When a fault is detected by a protection relay, this relay can fire some automatic devices in order to isolate or eliminate the fault. To clear transient faults, MV feeders are fitted with two kinds of automatic devices: a shunt circuit-breaker and an automatic recloser.

A fault is said to be *permanent* when it cannot be cleared by these automatic devices, in which case the circuit-breaker remains open. Fault detectors and automatic devices indicate their behaviour (fault detection, opening or closing of a circuit breaker, etc.) to the telecontrol system in the supervision center, by generating a flow of time stamped remote signals (called *events*).

The French distribution system is controlled by about a hundred control centers. Each center covers in general a big city and its region, and is responsible for several tens of substations. The equipment configuration may differ from one center to another.

3 Overview of AUSTRAL

When a fault occurs, the operator should react with a minimum delay. He has to interpret the flow of incoming events and alarms in order to make an accurate diagnosis: what has happened, where is the fault located and which customers are de-energized? On the basis of this diagnosis, action is then taken: remote switching orders are sent to isolate the fault and restore power for the maximum number of customers. Then, a team is sent into the field for fault repair. During the early steps of this procedure, time is critical. Unfortunately, the large amount of events and alarms coming from the network during an outage may make the diagnosis task rather difficult. Moreover, reconstruction of a coherent explanation from remote events may require a fairly good knowledge of automata to link it to the actual state of network topology. AUSTRAL attempts to assist the operator throughout this procedure (see figure 2).

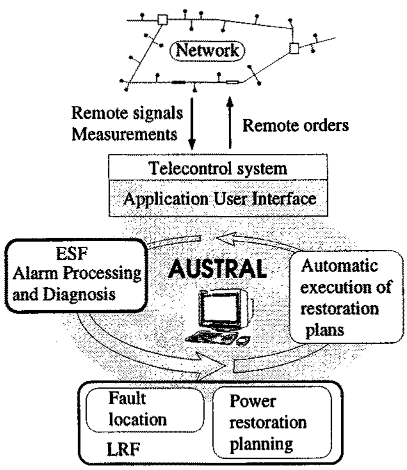

Fig. 2. AUSTRAL platform

The alarm processing function of AUSTRAL (ESF) is the first function triggered after a fault occurs. The first objective of ESF is therefore to reduce the total amount of data presented to the operator. To achieve this, sets of coherent remote signals are combined to form a single synthetic data entity. The second objective of ESF is to provide a full analysis of incoming events, in terms of outage diagnosis. Around 20 types of diagnosis have been identified. They correspond to a synthesis of correct behaviour or misbehaviour of automata and protection devices.

According to the diagnosis produced by ESF, other AUSTRAL functions may be launched. In particular, when a permanent fault on an outgoing feeder is diagnosed, the fault location and power restoration function LRF is triggered. Its tasks are to locate the faulty lines on the basis of information transmitted by the fault detectors, and to reconfigure the network so as to restore power to the maximum number of customers.

4 Fault detection: the ESF module

4.1 Events emitted by the automatic devices of the substation

Except for some mechanical faults in the HV/MV transformers, most of the faults are electrical short circuits (more or less resistive) that may occur in the different components of a substation (transformers, incoming feeders, busbars) and on the lines of the network. Short circuits are traditionally cataloged with respect to the number of phases they affect: phase-to-earth, phase-to-phase, two-phase-to-earth, three-phase. Phase-to-earth faults are the most common; on a line, they can for instance be due to the fall of a body on a line or to the appearance of an electrical arc between one phase and its support after a thunderbolt.

When a fault is detected by a protection relay in a substations, this relay can fire some automatic devices in order to isolate or eliminate the fault.The main automatic devices in a substation are described below (the numbers of the items refer to figure 1). As the same fault is detected by all the protections upstream, the functioning of the automatic devices is coordinated, through their specified times, so that they react in the following order:

1. some outgoing feeders are protected by a *shunt* that react to a phase-to-earth line fault by short-cutting the faulty phase during some hundred milliseconds in order to eliminate transient faults,
2. on some outgoing feeders (in general aerial feeders), an *automatic recloser* tries to eliminate some transient and semi-permanent faults by applying one or several circuit opening cycles depending on the recloser configuration. If the fault is not eliminated after these cycles the feeder circuit breaker definitely opens,
3. on the busbar an automatic device opens the surrounding circuit breakers (incoming and outgoing feeders, switched busbar circuit breaker) in case of an internal fault,
4. incoming feeder circuit breaker opens when a fault is detected by its associated protection,
5. when a fault occurs in an HV/MV transformer, the surrounding circuit breakers (incoming feeder, HV transformer feeder) are automatically opened.

Each of these automatic devices is fired by one or several protection relays. The relays and automatic devices send remote signal (called *events*) to the telecontrol system in the center with respect to their behaviour (fault detection, opening or closing of a circuit breaker, etc.). Automatic devices can be affected by outages, for instance, a circuit breaker may not open when asked to do so.

4.2 A chronicle recognition approach

ESF inputs a stream of incoming time-stamped events. A set of events, occurring in a given temporal pattern, could develop into what we call a chronicle. ESF manages a set of predefined chronicles and tries to match them against the incoming stream of events [10].

A chronicle is described as a sequence of the expected presence or absence of events associated with time constraints. A specific event in a chronicle serves as a trigger event. The chronicle becomes active when this event is detected. ESF does not try to recognize the chronicle as it develops: a specific length of time is associated with each chronicle. This delay corresponds to the minimum length of time required for receiving all relevant events. The recognition process waits for expiration of this period. Then the sequence of registered events is compared with the chronicle. If the chronicle is partially or completely recognized, a message is sent to the operator, and if the chronicle corresponds to a diagnosis that calls for reconfiguring the network, the location and restoration function (LRF) is called up.

The following table describes, in an IxTeT-like formalism [5], a chronicle corresponding to the elimination of a phase-to-earth fault on an outgoing feeder ?fd by a shunt cycle.

```
 1. chronicle fault_eliminated_by_shunt()() {
 2.    event(FAULT_DETECT(?fd):(false,true), t0);
 3.      when recognized {
 4.        check_configuration(?fd,''+SH'');
 5.      };
 6.    PROTECTS(?sh,?fd);
 7.    event(SHUNT(?sh):(opened,closed),t1);
 8.    event(FAULT_DETECT(?fd):(true,false), t1);
 9.    event(SHUNT(?sh):(closed,opened),t2);
10.    hold(FAULT_DETECT(?fd):false, (t2,t3));
11.    t1-t0 = duration_fault_confirmation(?sh);
12.    t2-t1 = duration_shunt_cycle(?sh);
13.    t3-t2 in [100,100];
14.    when recognized {
15.      display "Fault on feeder ?fd eliminated by shunt.";
16.    }
17. }
```

This chronicle states that a diagnosis `Fault on feeder ?fd eliminated by shunt` will be generated (line 15-16) as soon as the following scenario is recognized: A feeder protected by a shunt (line 4) send a fault detection event (line 2). The shunt that protects this feeder (line 6) closes (line 7) after a given delay (line 11). At the same moment, the fault image disappears (line 8). The shunt opens (line 9) after a delay corresponding to the cycle (line 12) and the fault does not reappear (line 10) during 100ms (line 13).

The important features of our chronicle formalism are listed below:

- A chronicle is generic. Thanks to variables, a chronicle represents a set of possible behaviours.
- A chronicle is always associated with a subset of equipment configurations. A chronicle can be recognized only if the configuration of the equipments sending the events belongs to those specified in the chronicle.
- In the chronicle, it is possible to express the non-occurrence of event.
- Some events can be labeled as optional events; this means that they do not need to be actually recognized in order to recognize the chronicle. According to the optional events that have been collected, the main diagnosis associated with the chronicle will be complemented.
- It is possible to represent implicit sets of events through collectors. A collector refers to a set of events with a common property. These sets are made

explicit during the recognition process by querying a database to establish the current topology of the distribution system at the adequate time-point.

In order to avoid the simultaneous recognition of redundant or incoherent chronicles, the set of chronicles is split into several exclusive sets. An exclusive set is an ordered set of chronicles with the same trigger event. For a given event that triggers an exclusive set, one chronicle at most from this exclusive set can be recognized: the first one, according to the order, that matches the registered stream of events.

4.3 Chronicle acquisition

The current knowledge base of ESF has been developed by acquiring every chronicle. For the recognition of a specific fault, the set of expected events should be entered manually. For a single fault, it may often happen that several chronicles have to be designed. They correspond to various configurations of protection devices and automata that may be found on the actual network. The present knowledge base of ESF contains 66 chronicles gathered into 13 exclusive sets. On average, a chronicle involves 7 events, but some of them may have more than 20 events.

The writing of such a knowledge base by an expert raises several problems:

- It is a long and costly activity: it took about two experts a year to write the knowledge base for the centers of Lyon and Versailles.
- We cannot prove that the chronicles are correct.
- We cannot prove that we have described the complete set of relevant chronicles: for instance, due to the combinatory of possible configurations, some chronicles may have been forgotten.
- As distribution system devices evolve, it is very difficult to propagate these evolutions on the knowledge base. Indeed, certain local changes of the devices (for example the use of a new type of protection) make it necessary to re-examine the whole set of chronicles where this equipment occurs.

These are great limitations on the display of AUSTRAL to a larger number of centers and on its maintainability.

To overcome these difficulties, we have developed GEMO[4], a model-based application for automatic chronicle generation[12, 11]. The basic assumption is that it is easier to provide a description of behaviour and misbehaviour of network components when a fault occurs, instead of describing the event-signature for a specific fault. GEMO will automatically produce the event-signature after a computation from specified normal and abnormal components behaviour.

In GEMO, we represent the generic components of the power distribution system using a finite state automata formalism. This representation seems very natural because the individual behaviours of each component are well known (we define as behaviours both normal and characteristic abnormal behaviours). Furthermore, as the schemas of most of the components have already been described as automata during the component conception stage, the expert can be inspired by or even reuse these existing models.

Once the system has been modeled, GEMO performs an automatic exhaustive simulation of the model in order to generate a base of chronicle skeletons. Chronicle skeletons are chronicles that do not contain any non-occurrence of event. Because the simulation is exhaustive, we can prove that the set of generated chronicle skeletons is complete with respect to the model.

A post-treatment of these chronicle skeletons is then performed to complete them with some non-occurrences of events and divide them into exclusive sets

[4] GEMO stands, in French, for *generator of chronicles*

in order to avoid redundancy. This step ensures the correctness and the non-redundancy of the chronicle base.

4.4 Results

The ESF implemented on the AUSTRAL platform has been validated on a realistic distribution network. With a knowledge base containing 66 chronicles, the average response time of the ESF is lower than 5s which is considered sufficiently fast for real time deployment. As far as now, ESF was using a knowledge base hand-written by experts. A knowledge base automatically generated by GEMO is currently being tested.

5 Fault location and power restoration: the LRF module

5.1 Permanent faults on outgoing feeders

Figure 3 describes in detail part of the distribution network downstream several feeders outgoing the HV/MV substation (see Figure 1). Each feeder is a tree of electric lines rooted at the feeder's circuit-breaker (CB, represented by a large square in the figure). These lines are connected by remote-controlled *switching devices* (SDs, represented by small squares), with the help of which the network can be reconfigured. Switching devices have two possible positions: at the leaves of the feeders, *open* devices (white ones) stop the power propagation; the other devices (black ones) are *closed*. Consumers (loads) may be located on any line, and are then only supplied when this line is fed.

LRF is activated when permanent faults are diagnosed by ESF on one or more outgoing feeders (since these faults are mainly short circuits to due to bad weather conditions, multiple faults are not rare). Let us recall from Section 4 that the circuit-breakers feeding the faulty lines have definitely opened in order to protect the rest of their feeder from damaging overloads. As a result, all customers located on these feeders are left without power. Using the sensors and actuators described below, LRF must locate the faulty lines and reconfigure the network so as to isolate faults and restore the supply to the non-faulty lines. This must be completed within a few minutes.

5.2 Sensors and actuators

As shown in figure 4, devices are equipped with a remote-controlled *actuator* (AC) used to change their position, a *position detector* (PD) sensing this position, and a *fault detector* (FD) sensing the presence of faults.

Fault detectors are the basis on which to locate faults. They indicate whether whether or not a fault is downstream on the feeder. Then ideally, a fault is located on the line between a sequence of devices whose detectors indicate that it is downstream and a sequence of devices whose detectors indicate that it is not. Unfortunately, fault detectors are not always correct and can be in one of the following two permanent abnormal modes: broken (i.e., they do not return any information), or even liar (i.e., they return erroneous information).

Actuators enable us to switch devices so as to reconfigure the network. An actuator is not always reliable and can be in one of the following permanent abnormal modes: broken (it fails in executing the switching operation and sends a negative notification), or liar (it fails in executing the operation but sends a positive notification).

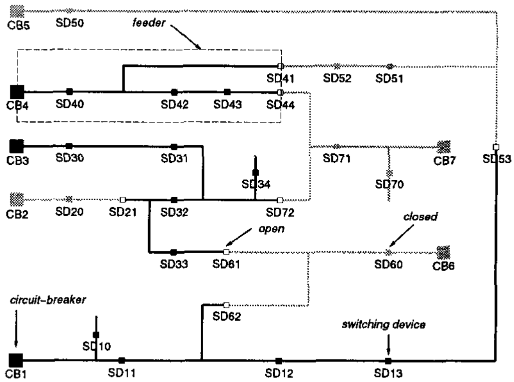

Fig. 3. Network downstream several outgoing feeders

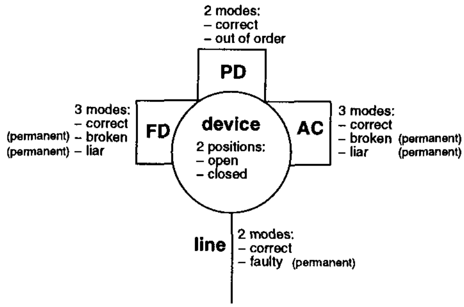

Fig. 4. Behaviour modes

Position detectors can be consulted in order to reduce uncertainty about the success of switching operations positively notified by actuators. However, position detectors can be out of order (they do not return any information) for an indeterminate time, in which case the configuration of the network remains uncertain.

5.3 The problem facing LRF

Supply restoration The problem of supply restoration is that of reconfiguring the network in view of resupplying the customers following the loss of one or more feeders. It amounts to building a restoration plan consisting of switching (opening/closing) operations. This plan must enable the isolation of the faulty lines by prescribing to open the switching devices surrounding them, as well as the restoration of the supply to the non-faulty areas of the lost feeders, by prescribing to operate devices so as to direct the power towards these areas.

The following constraint determines which restoration plans are admissible: circuit-breakers and lines can only support a certain maximal power. This might prevent directing the power through certain paths and resupplying all the non-faulty areas. Ideally, restoration should optimize certain parameters under this constraint, such as minimizing breakdown costs (i.e., resupplying as many consumers as possible, as fast as possible, giving priority to critical consumers like hospitals), minimizing the number of switching operations so as to stay close to the configuration in which the network is normally exploited, and balancing power margins of circuit-breakers in anticipation of the next load peak.

Fault location Being able to isolate faulty lines requires locating these lines. This is done by looking at the information transmitted by the fault detectors. It follows from possible fault detectors failures that these might disagree, and more generally that several hypotheses of fault location exist, each of which correspond to an hypothesis concerning the behaviour mode of the fault detectors.

There exist preferences between these hypotheses (the probability of multiple faults is much smaller than that of a fault detector lying, and this latter is higher when the fault detector indicates a fault downstream than when it does not because detectors do not detect all types of faults). But in fact, only the reconfiguration phase may enable us to discriminate, especially when this one goes wrong.

Uncertainty Uncertainty is the primary cause making LRF's task difficult. Firstly, switching operations are undeterministic: since actuators are unreliable, predictions concerning the actual configuration of the network cannot be made with certainty. More importantly, the state of the network is only partially observable: information gained from existing sensors is not sufficient and reliable enough to provide an accurate picture either (location of the faults, configuration).

A consequence is that the space of possible state hypotheses to be dealt with is huge. For instance the network in Figure 3 has about 2.10^{56} possible states. The space of admissible restoration plans is huge as well, which makes the selection of the "best" or even a "good" reconfiguration action problematic.

Intertwining fault location and reconfiguration This (and to a smaller extent the fact that the primary purpose of LRF is not to identify the faulty lines but to minimize breakdown costs by reconfiguring the network appropriately) explains why a successful approach needs to closely intertwin fault location and reconfiguration:

- Indeed, the only possibility for acquiring new measurements and discriminating between fault location hypotheses, is to perform reconfiguration actions and to confront the resulting sensing information to predictions. Hence accurate fault location requires reconfiguration.
- Reciprocally, since each candidate location (even highly unlikely) should ideally be taken into account for the selection of a restoration plan of high expected utility, it is best if the huge set of candidates has been reduced to a minimum before reconfiguration. Pruning this set is problematic since it may spoil the evaluation by forgetting unlikely but risky (costly) states. Hence, a good reconfiguration requires an accurate fault location.

5.4 The SyDRe prototype

In a first step, a prototype was developed by EDF ([2]) which couples a special-purpose model-based simulator and an expert system; it is able to locate the most probable faulty line and to select among prestored restoration plans the best suited ones and to check their admissibility. These plans are displayed to the operators who rely on them to undertake actions. This prototype is the one which is currently integrated in the AUSTRAL platform. Its main limits are that it is unable to follow the execution of a plan and to revise it adequately in case of failure; also it cannot deal with multiple faults.

In the framework of our collaboration between IRISA and EDF, a way of overcoming some of these limits was investigated. It results in the SyDRe [5] experimental prototype which intertwins phases of discrimination between fault location hypotheses (or more generally state hypotheses) and phases of reconfiguration. SyDRe is entirely model-based, and handles hypotheses about the state of the network in a systematic way, including multiple fault hypotheses.

As shown in Figure 5, SyDRe's architecture is composed of a domain-specific model which accounts for both the logical and quantitative aspects of distribution networks, of a diagnostic reasoner which is in charge of maintaining hypotheses about the state of the system throughout the location/reconfiguration process, and of a domain specific planner which returns restoration plans for given state hypotheses.

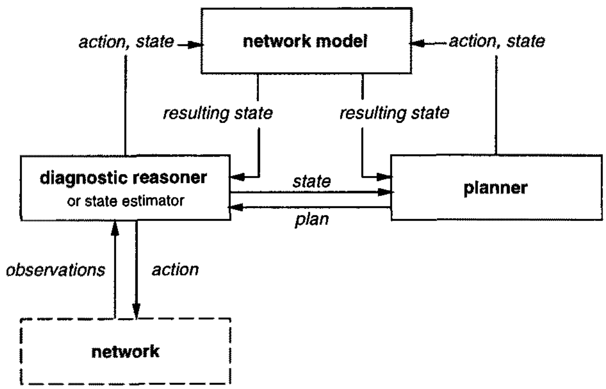

Fig. 5. Architecture of SyDRe

The main steps followed by the diagnostic reasoner are: (1) compute the possible states and their initial probability distribution from the initial observations, (2) ask the planner for a restoration plan for the most probable state, (3) if all actions in the current plan have been executed then exit the restoration process successfully, (4) otherwise execute an action in this plan, gather the resulting sensing information and update the probability distribution accordingly, (5) decide whether the current plan is still appropriate for the new most probable state of the distribution; if so go on with (3) otherwise go on with (2). In order to cope with complexity, the initial probability distribution only considers a single fault per lost feeder; states involving n+1 multiple faults are only considered after all state hypotheses involving n faults are proven inconsistent. Naturally enough, the probability distribution at any time considers that the switching devices that have not yet been operated are in their normal mode. This is not restrictive.

The planner takes as input the most probable state supplied by the diagnostic reasoner. It returns a plan (sequence of switching operations) isolating the faults and restoring the supply to the lines assumed to be non-faulty in that state. In order to cope with complexity, the search space is restricted to plans that only extend existing feeders, i.e., do not discharge any circuit-breaker of part of its load after the incident. In fact, other types of plans are rarely used in the reality,

[5] SyDRe stands, in French, for *system for diagnosis and reconfiguration of distribution networks.*

and the space of such admissible plans for the given state is small enough to be entirely explored. For our network example in Figure 3, it contains most of the time less than a hundred plans. These are all evaluated using a utility function that captures the optimization criteria mentioned above, and the best one is returned to the diagnostic reasoner. As another concession to complexity, risks due to partial observability and actuator failures are not taken into account in the evaluation. Therefore, the returned plan is optimal iff the state hypothesis provided by the diagnostic reasoner is correct and none of the actuators changes its behaviour mode during the process.

Further details on the principles underlying SyDRe, including the actual construction of plans, are out of the scope of this presentation. They can be found in [14, 3].

5.5 Results

SyDRe has been tested on a number of simulated scenarios involving multiple faults on multiple feeders of semi-rural and urban networks, and could restore the supply in real-time. It has also been successfully tested on real data issued from the distribution center of Bordeaux. The restoration sessions have been judged satisfactory by experts.

6 Related work

Power systems being economically important, several attempts at developing support tools for their supervision can be found in the literature (see e.g. [8, 9]). A majority of these tools belong to the knowledge-based systems approach, from which they inherit the well-known limitations. As far as we know, few of them are based on an explicit model of the diagnosed system and take into account the temporal behaviour of the automatic devices.

The closest work to ours is reported in [13]. In this approach, automatic devices are represented as finite state communicating machines that describe both the correct and faulty behaviour of components. This model is used on-line to perform an interpretation of the flow of incoming events with two layers : (1) a local interpretation that generates the set of all possible histories for each component according to the observed events and (2) a global interpretation that checks for the coherence between local histories and generates global histories of the model. If the representation is very similar to the one used in GEMO, the difference between the two approaches relies on the fact that our model is not used on-line but rather, compiled off-line into chronicles that efficiently maps observations to diagnostics.

[6, 1] studies diagnosis and supply restoration in power *transmission* systems. A crucial difference is that observations and actions are assumed to be reliable. This may be reasonable when considering transmission systems, but far too restrictive for power distribution systems. Moreover, this work is not concerned with the events and alarms analysis (performed by the ESF module) and does consequently not model the temporal behaviour of the automatic devices (shunts and reclosers).

[7] proposes a model-based approach to diagnosing faults in power distribution systems, identifying sensor failures and carrying out appropriate corrective action. An Intelligent Power Controller has been developed whose capabilities have been tested on a power distribution system breadboard representative of space station power systems. The diagnostic reasoning is a variation of Reiter's conflict-based approach. A brief mention is made of the fault recovery task, which includes fault isolation, and reconfiguration of the network as in [4] (in particular, the way diagnosis and recovery phases are interleaved is not specified).

7 Conclusion and perspectives

This paper describes the two main functions of AUSTRAL for alarm processing and network reconfiguration. The alarm processing function (ESF) relies on an efficient chronicle recognition approach. The ESF described in the paper is the one actually installed and tested on-site. A tool (GEMO) has been developped to automatically generate chronicles from a model. The SyDRe prototype is a promising alternative to the existing fault location and reconfiguration function (LRF). It intertwins fault location and reconfiguration tasks and can deal with multiple faults. At present, AUSTRAL is being tested in the distribution center of Lyon. Three French centers will be equipped with AUSTRAL in 1998. The potential customers are all the distribution centers in France, as well as some centers abroad.

References

1. A. Beschta, O. Dressler, H. Freitag, M. Montag, and P. Struß. A model-based approach to fault localisation in power transmission networks. *Intel. Syst. Eng.*, 1-2:190–201, 1993.
2. P. Bredillet, I. Delouis, P. Eyrolles, O. Jehl, J.-P. Krivine, and P. Thiault. The AUSTRAL expert system for power restoration on distribution systems. In *Proc. ISAP-94*, pages 295–302. EC2, 1994.
3. M.-O. Cordier, S. Thiébaux, O. Jehl, and J.-P. Krivine. Supply restoration in power distribution systems: a reference problem in diagnosis and reconfiguration. In *Proceedings of the 8th International workshop on Principles of Diagnosis (DX'97)*, pages 27–34, 1997.
4. J. Crow and J. Rushby. Model-based reconfiguration: Towards and integration with diagnosis. In *Proc. AAAI-91*, pages 836–841, 1991.
5. C. Dousson, P. Gaborit, and M. Ghallab. Situation recognition: representation and algorithms. In *Proc. 13th International Joint Conference on Artificial Intelligence (IJCAI'93)*, pages 166–172, 1993. Chambéry, France.
6. G. Friedrich and W. Nejdl. Choosing observations and actions in model-based diagnosis-repair systems. In *Proc. DX-92*, pages 76–85, 1992.
7. A. Gonzalez, R. Morris, F. McKenzie, D. Carreira, and B. Gann. Model-based, real-time control of electrical power systems. *IEEE Trans. on Systems, Man, and Cybernetics*, 26(4), 1996.
8. *Proc. International Conference on Intelligent System Application to Power Systems (ISAP-94)*, Montpellier, France, 1994.
9. *Proc. International Conference on Intelligent System Application to Power Systems (ISAP-96)*, Orlando, FL, 1996.
10. J-P. Krivine and O. Jehl. The AUSTRAL system for diagnosis and power restoration: an overview. In *Proc. of international conference on Intelligent System Application to Power Systems (ISAP'96)*, August 1996. Orlando, USA.
11. P. Laborie and J-P. Krivine. Automatic generation of chronicles and its application to alarm processing in power distribution systems. In *International Workshop on Principles of Diagnosis (DX'97)*, pages 61–68, September 1997. Mont St Michel, France.
12. P. Laborie and J-P. Krivine. GEMO: A model-based approach for an alarm processing function in power distribution networks. In *International conference on Intelligent System Application to Power Systems (ISAP'97)*, pages 135–141, July 1997. Seoul, South Corea.
13. G. Lamperti and P. Pogliano. Event-Based Reasoning for Short Circuit Diagnosis in Power Transmission Networks. In *Proc. 15th International Joint Conference on Artificial Intelligence (IJCAI'97)*, pages 446–451, 1997. Nagoya, Japan.
14. S. Thiébaux, M.-O. Cordier, O. Jehl, and J.-P. Krivine. Supply restoration in power distribution systems : A case study in integrating model-based diagnosis and repair planning. In *Proc. UAI-96*, pages 525–532, 1996.