Toward a Distributed Network of Intelligent Substation Alarm Processors

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Report LSI-93-15-R

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ABSTRACT

Nowadays, in domains with a uniform hierarchical structure, like power system networks domain, the advantages of the introduction of knowledge based systems to automate information processing are well known. In the specific case of alarm processing, the majority of studies have been focused on alarms in central energy management systems, in which only one system is required. The still unsolved problem appears when one tries to automate a task at all local nodes (in our case, at the substations level), i.e., when a distributed solution must be found. To go one step further, the solution method must be capable of the automatic generation of similar expert systems, taking into account not only conceptual similarities, but also physical differences, different topologies and different tasks. With the purpose to identify the reusable points of an intelligent substation alarm processor, in order to be modified and reconfigured to correspond to any particular real substation, a prototypical hybrid rule-based object oriented expert system for the treatment of alarm messages in power substation plants has been developed. This work would lead to state the necessary features of a distributed network of intelligent substation alarm processors, installed at each substation of a Power System network. The on-line alarm processor generates concise information about the equipment installed in the substation, for **maintenance scheduling** purposes. It generates an on command report of the substation's electric activity: it describes the operation of the protection and alarm systems, which operate to isolate faulty components and identifies disturbances caused by local equipment, telecomunications systems and the local power supply. The processor is an agenda driven expert system, relied on a hierarchical model of the electric components of the substation, as well as a hierarchical classification of the alarm messages and a causal model relating each other. This paper describes the prototype and discusses the above mentioned features.

INTRODUCTION

Alarms and Alarm Processors

Alarm messages are the media to observe the power network dynamics: they reflect the state changes of different elements which form the network (state alarms), the orders given by the dispatching operators over these elements (activity alarms) and maintenance operations.

Typical global alarms report hardware or software problems over the telecommunications systems, violation of an operating constraint, summary messages of telemetered orders, sythesis of critical distrubances, etc.[Amelink,Forte&Guberman, 86].

Typical local alarms report the operation of breakers, the removal from service of part of the equipment, the sending and execution of telemetered orders, failures in signal detection etc. Mainly, they have information about electric activity, communication protocols, aviability of telecommunication lines and disturbances. Information generated in the substations is recorded in a circular buffer called Local historic record (LHR).

Current intelligent alarm processors (IAP) are designed to process the alarm messages from a central or a local location. At central level, intelligent alarm processors are designed to present a clearer description of disturbances to the power system operator for monitoring and control purposes. At the local level, the processing objective is to present a general view of the current state of the equipment and the electric activity of the substation, basically, for maintenance purposes.

Justification

The fundamental difference between a global and a local alarm processor is the model of the network on which each one relies for its analysis of the alarm: on the central view, a substation is just a couple of bays, connected by lines, relays and breakers. From the local view, a substation represents a network itself. Then, to be effective, the maintenance task of substation supervisors should be unified over all the substations. We propose to do it via the introduction of local I.A.Ps. This means the (ideally parallel) development of dozens of IAP, one for each substation. Even when substations have similar structures, each one has particular features that make it impossible to develop one for the first substation and make a copy for the rest.

Even when, actually, every central location has at least a conventional alarm processor, at the local level, this task is performed manually by the substation supervisor,whose work is to analize day by day the alarm messages of various substations and to establish, for each one, a general view of the state of the equipment, almost all the time, under normal conditions. As local alarm processing at the present time is performed mostly through manual operation, developing an automatic system for the analysis is a challenging subject.

Antecedents

Studies on Artificial Intelligence applications on Power Systems were first proposed in [DyLiacco, 83][Brand & Kopainsky, 84], but the first references of intelligent alarm processors were presented only seven years ago [Wollemberg,86] [Amelink, Forte & Guberman,86], the first along with alarm cathegories and rule cathegories. The on-line analysis linked to a distributed hardware architecture was first proposed in [Cardozo, Talukdar,86,87]. For substations, preliminar studies can be found in [Don Russell& Watson,86] and local alarm filtering is reported in [Brezillon & Fauquembergue, 88]. A local day-by-day view for maintenance purposes was presented by [Avila, Casals & Corbella,90]. Finally, [Kirschen&Wollemberg, 92] present a very detailed study on intelligent central alarm processors and discusse the feasibility of a similar distributed approach, and [Holen, Botnen & Stoa, 92] present a study about hybrid knowledge-based and algorithmic methods.

Design Goals

Thinking on the distributed approach, the design strategy was based on the following premises:

- Standarization criteria of the factual data.
- Unification criteria of the observed activity in each node (with and without disturbances).
- Use of the domain´s hierarchical nature.
- Reusability.

ABOUT THE DOMAIN KNOWLEDGE

The analysis problem.

Besides the well known alarm analysis difficulties (the huge amount of mixed information,for different purposes, potencial lack of observation due to phisical problems in the equipment, diversity of equipment leading to diversity of messages, temporal reasoning, etc. [Avila, 89]), the distributed model implies new difficulties:

- diversity of topologies, which means the description of a great amount of equipment and its phisical dependencies.
- different tasks, depending on the presence or absence of generation units, and transformation levels (all possible combinations).
- similar, but not unified local signal messages, due to the intended local use.
- different experts, with local experience. This could lead to different priorities for maintenance purposes.
- very simple computational equipment, discarding possible dedicated architectures.
- different signaling even in same equipments, due to a defaced modernization of the different plants, etc.

Electric Activity Classification

Following the above mentioned premises, a unified electric activity classification, valid for any substation, was defined. The results are shown in table 1.

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ELECTRIC ACTIVITY

Normal

telecommunication protocols
state changes
telemetered orders
local orders
measures regulation activities
maintenance activities

With Disturbances

breaks
equipment disfunction
mechanical

electrical
protective actions due to external causes
orders misreception due telecommications errors
not executed orders
auxiliary power suply
undefined state of an element or set of elements

===

Table 1. Observed Electric Activity in a Substation.

THE INTELLIGENT SUBSTATION ALARM PROCESSOR

Goals of Intelligent local alarm processors.

As an extension to [Kirschen&Wollemberg,92], four main goals have been set for an intelligent processor of local alarms:

- reduce the number of alarms presented to the supervisor.
- convey a clear scheme of the global.situation of the substation.
- recommend additional preventive maintenance actions if needed.
- recommend corrective maintenance actions if needed.

The maintenance goals are intended to enhance the reliability of the substation plant, by following day by day the behaviour of the equipment to detect and prevent potential disturbances. For example, in the case of transformer removal, most of the time, signals of isolated problems can be found in previous records, some times within the two or three preceding weeks.

Conceptual Model

Following the ideas proposed by [Newell,81], and by [Chandrasekaran,86], a multilayered model for the intelligent .substation alarm processor was defined.[1]. Figure 1 shows the conceptual diagram.

Platform: At the bottom of the model there is the software level, which supports all the different languages and sw tools. In this case, the language selected was C, for the algorithmic processes and NexpertObject® for the symbolic and object oriented processes [2].

Factual Level: This level contains all the raw data needed by the system, which includes the following domain data: network hierarchy, equipment description, alarms dictionary, topology, statistical data base.

Object Level: All the class descriptions, data types and functional objects are placed at that level. The classes defined for the substation model were: ALARMS, ELECTRIC_EVENTS, EQUIPMENT, SUBSTATION and the metaclass POWER_NET.

Knowledge Level: What is found in this level is the knowledge embedded in the conceptual modules, i.e, the knowledge bases used by the expert system,

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[1] In [Sakaguchi,89], an interesting approach can be found.

[2] Commercial sw used: Microsoft C®, NexpertObject®, DBaseIII®, and Microsoft Windows®.

the object methods and the algorithms used by the I/O logical interphases and the preprocessor.

Control Level: The schedule and planning of all the activities is defined in this level.

Meta Control Level: At the top of the model there are the strategic policies, necessary to define the planning strategies.

Knowledge Representation

The system uses an hybrid rule-based object oriented approach. The choise responds to conceptual structuring needs and to our reusability target. Instantiation is the most basic reusability mechanism. Besides, objects may be dynamically instantiated. Inheritance provides a powerfull mechanism for defining new classes that inherit properties from existing classes. In this case, it serves not only as a reusability mechanism, but also as a conceptual structuring mechanism. Furthermore, polimorphism enhaces software reusabiity by making it possible to implement generic software that will work not only for a range of existing objects but also for objects to be added later. This is very important, because we are working under the close word assumption by defining, for each class, a subclass of "other" objects. In the specific case of electric activity, it is a neccessary feature, having in mind that a power system is dynamic in terms of new technologies and equipment acquisition..

Control Strategy

Following the object orientation, the control strategy was defined in a modular way, with the following global algorithm, implemented in C language:

```
USE ALARMS, STATISTICS, LHR

begin
  read(alarms)
  run(preprocessor)
  run(expert_system)
  show_results(expert_system)
end
```

System Description.

Figure 2 shows a block diagram of the intelligent alarm processor. The expert system is embedded into the hole system. The rest of modules were designed and implemented in an algorithmic fashion.

Filtering: The Preprocessor.

The preprocessor acts as the logic interface beetween the IAP and the power network signaling system. As we are concerned only with local electric activities, two filtering levels where defined. The first obvious filtering is to eliminate those signals not related with the electric tarjet. The second filtering level is intended to detect the communication protocol of teleordered messages, between each local RTU and the central dispatching center. The efect of this filtering is the following:

- detect the complete secuence
- replace all messages involved in each secuence with a synthesis message, without loosing information.

To do this, a general grammatical expression was defined as :

S X* N X* A X* R

where

t - time stamp
o - order, $o \in O$ class
e - element , $e \in E$ class
a - alarm description, $a \in A$ class

N(t1,oi,ej,ak) RTU acknowledge
A(t2,oi,ej,ak) actuation order
R(t3,oi) teleorder reception acknowledge

$t0 < t1 < t2 < t3 < 15$ seconds

X^*, $X \in$ LHR.

S(t0,oi,ej,ak) order selection

and was rewritten as:

T(t0,oi,ej,ak), where T means teleorder

This module was implemented using a hybrid C - DBMS language approach. To observe the filtering effects, files from 10 different days, ramdomly choosen, were filtered. The total volume reduction (measured in bytes) was around 77%. [Avila, Casals & Corbella, 90]

THE EXPERT SYSTEM

Once the alarms volume is reduced, the expert system is used to make the finner processing work. It was designed so each conceptual event could be encapsulated and implemented in a separate knowledge base. This action also facilitates the testing and validation tasks. Its strategy is data-driven and follows a forward chaining ingerence. The knowledge diagram is shown in figure 3.

Supervisor. It acts as a manager, controlling inputs/outputs and applying meta-control strategies for each module. It works in an on-command fashion. When connected on-line, it is called from the general algorithm.

Input. Input module accepts the files from the preprocessor and creates the ALARMS class.

Zeros. From the ALARMS class , this module creates the ZERO subclass of undefined messages, i.e., those from elements in undefined electric state, caused by observation loose or transition states. In the former case, these signals are deleted. Besides, it looks for active state alarms during less than 2 minutes, by detecting Initial/Final pairs and transforming them in a unique condensated message.

Detection For each electric event in the ELECTRIC_EVENTS class, it calls to the specific detection knowledge base. Every detection knowledge base follow the next metacontrol strategy:

Create_subclass($E_i \subseteq$ ALARMS)
if $E_i \neq \emptyset \Rightarrow \forall e_{ij} \in E_i$

search_classification(e_{ij},LHR)
search_topologic_links(e_{ij},EQUIPMENT)
interpret_cause(e_{ij})
interpret_effects(e_{ij})
define_status(e_{ij})

endif

for example, if there is a break in a three-wind transformer breaker, the expert system first creates the subclass BREAKS $\subseteq$ ALARMS, then identifies it as a TRANSFORMER BREAKER FAULT, looks for the posterior desconnection and for the related equipment, in this case, for the transformer and the other breakers' status, defines whether it was caused by some transformer disturbance or by other causes, and defines if it is recovered or not (in the first case, the mentioned breaker would be closed), via a manual or an automatic action.

Diagnosis. The synthesis task is performed via the diagnosis module. It relates each event detected previously to determine if they are independent or not, cuased by a unique big fault (for example, by a local supply fault) or by different ones, etc.

Output As output, a statistic summary of the events observed in each subclass is shown, indicating also the pending state alarms. Finally, for each alarm subclass, it makes a specific detailed report, stamping priority flags for maintenance actions. Both are sent to a local printer and stored in the statistics data base.

Implementation Details.

The expert system was implemented in a 386PC-like computer, using the NexpertObject tool from Neuron Data, which runs under Microsoft's Windows V.2.0. The data base was implemented in the DBaseIII package, preferred by ENHER. The system works on-line and is completely operational.

DISCUSSION

The following are discussions on the more general difficulties encountered at each phase of the system development:

Domain Knowledge Acquisition. The present methodologies known in this phase cannot automate the process of knowledge acquistion, thus leaving much essencial work to the system developers and to the domain expert participation. Actually this task is expert dependent almost at each construction stage. In the specific case of local alarm processing, we observed some expert knowledge deficiencies: expert were able to explain common disturbances, but couldn't quantify their occurrence, even in a qualitative way. This information is necessary to define preventive maintenance programs for the electric elements. Moreover, due to its local intended use, new disturbances in the telecommunications system were ignored, even when they appeared in the historical register (local experts make an implicit filtering of not interesting alarms). Exhaustive analysis of historical records let the experts identify unusual disturbances, even to discover new ones. Based in this strategy, the development of a statistical study of historical records let the developers clarify those dashed points. It would be desirable to integrate in the knowledge-based software tool different decision making strategies and methods (for example, logistic analysis or discriminant analysis or a simple statistical tool) for the analysis of data banks when dealing with domains where there is not enough experience available. For the distributed approach, the acquisiton of particular knowledge would not imply the same scene each time a particular local expert system is being developed. Based in a kernel of domain concepts, only the very particular features of a node would be acquired, following the same strategy .

Design Phase.When a distributed approach is thought, once the conceptual model is defined, there are not important design differences between one particular system and another, but specific data related to specific tasks. The best would be to construct some kind of specialized libraries, which describe the common design points, in standard modules, so one can easily visualize those similarities and latter use them in the implementation phase.
For example, associated with a specific conceptual task, the specific inference strategy; with a specific disturbance, the specific set of detection rules and causal rules, etc. (better if these libraries were implemented in a portable conventional language like C or C++, for example).

Implementation Phase. The most important difficulties found in trying to implement this system, also valid for a distributed network are perhaps those due to final implementation and installation constraints. By one side, there are the following hw and sw constraints:

- compatibility with the equipment installed in the substation to facilitate the on-line installation ,
- very extended use, to avoid the additional training cost (discarding AI dedicated hw), and
- low acquisition cost (multiplicative factor) .
- host independent interfaces with other languages and data base management systems

Validation and verification of a very complex system as in our case, is nowaday a handcrafted task. Due to the diversity of nature of the final system modules, very different testing methods are needed. For the distributed approach, the task has added updating and consistency preserving difficulties. Nevertheless, with the object orientation, this task is easier.

RESULTS

Once the intelligent local alarm processor has been finished, we distinguish the following reusable features:

Conceptual Model: The conceptual model fits the modelling definition of any particular substation.

System Model: In general terms, the system is independent from the particular features of the substation, so it could be applied to all substations who fit the same or less complicated tasks, taking in mind the particular factual data.

Preprocessor: It has been standardized in terms of alarm signals syntaxis, so it accepts any particular LHR from any substation. 100% reusable.

Expert System: The particular expert system is based in the hierarchical description of a 220/160/120HV substation, without generation and an auxiliary 25kV power supply. It covers almost 40% of the total number of susbtations of ENHER. To be applied to any substation, it is necessary to add an additional learning module, (it may be learning by examples) able to extend the actual model by generalization, and, for simpler substations, to prune the actual model by specification tasks. What is needed is to extend the classes to cover the hole network model. A big part of this work can be done by the statistical analysis of LHRs for each substation. Furthermore, the control and meta-control strategies are already generic, so they can be applied to any future substation model.

Topological Dependency: The final output depends of the particular topological data of the substation. Nevertheless, it is relatively simple to relate topologies with the expert system, by adding two lines to the global algorithm: USE TOPOLOGY and read(topology_descriptor$_k$). The former could be a logical vector.

CONCLUSIONS

Standardization of I/O data is reached by the definition of a standard alarm message syntaxis, first through the preprocessor module and later with the inclusion of relational data base files and objects. Finally, in form of standard final reports.

Unification criteria for the electric activity was done by abstracting the particular electric activity in a generic class, able to be extended if needed. By the other hand, the hardware choise enables the introduction of the model with a relative low cost. Finally, the class inheritance and instantiation, polimorphism and encapsulation features of object orientation facilitate reusability via the definition of specialized libraries.

Looking the results and the reasons commented in this paper, it seems that the implementation of a distributed network of intelligent local alarm processors is not just the right choise when dealing with similar local problems but also reachable, in a feasible time period. Nevertheless, domain-specific libraries and intelligent tools for the development would be very helpfull.

References

[Amelink,Forte&Guberman, 86] Amelink, H., Forte, A and Guberman, R.P. "Dispatcher alarm and messages processing", IEEE Trans. Power Syst., Vol. PWRS-1 No.3, Aug. 1986, pp. 188-194.

[Avila,89] Avila, P. "Expert Systems For Alarm Treatment",Invited Tutorial, Fourth IASTED Int.Conf. High Technology in the Power Industry, Power High Tech'89.

[Avila, Casals &Corbella, 90] Avila, P., Casals, A. and Corbella, X. "An expert system for local alarm treatment in ENHER substation", tech. rep. ENHER, 1990.

[Bijoch et al.91] Bijoch, R. W. et al., "Development and implementation of the NSP intelligent alarm processor", IEEE Trans. Power Syst, Vol. PWRS-6, May, 1991. pp. 806-812.

[Brezillon&Fauquembergue,88] P.Brezillon, P. and Fauquembergue, P. "Sept, an expert system approach for the monitoring of EHV Substation Control Equipment", Symposium on Expert Systems Application to Power Systems, Stockholm-Helsinki, Aug. 1988. pp. 6.9-6.13.

[Cardozo&Talukdar,88] S.Cardozo, E. and Talukdar, S. "A distributed Expert System for fault diagnosis", IEEE Trans. Power Syst., vol. 3, No. 2, May, 1988. pp. 641-646.[] Germond, A. J. and Niebur, D., "Survey of Knowledge-Based Systems in Power Systems: Europe", Proc. IEEE, Vol. 80, No. 5, May, 1992, pp. 732-744.

[Chandrasekaran,86] Chandrasekaran, B. "Generic Tasks in Knowledge Based Reasoning: High level building blocks for Expert System design", IEEE Expert, vol. 1, No. 3, fall 1986. pp. 23-30.

[de Montravel, G.&Arrieta,89]de Montravel, G.and Arrieta, D. "Alarm processing in power systems operation at EdF", Proc. Intern. Working Conf. Expert Systems in Electrical & Power Systems", No. 4.1 Avignon, may, 1989

[Don Russell&Watson,86]Don Russell,B and Watson, K., "Power Substation automation using a knowledge based system- Justification and preliminary field experiments", IEEE Trans. and Distr. Conf., Anaheim, Cal. 1986. pp. 1090-1097.

[Holen,Botnen&Stoa,92] Holen, A. T., Botnen, A. and Stoa, P.,"Coupling between knowledge-based and algorithmic methods", Proc. IEEE, Vol. 80, No. 5, may, 1992. pp. 745-757.

[Kirschen&Wollemberg,92]Kirschen,D. and Wollemberg,B."Intelligent Alarm Processing in Power Systems", Proc. IEEE, Vol. 80, No.5, May, 1992.

[Newell, 81] Newell, A. "The knowledge level", AI Mag. Vol. 2, No. 2, 1981, pp. 1-20.

[Sakaguchi,89] Sakaguchi, T."Task and domain specific Expert System Tool", Int. Symp for Demons. of Exp. Syst. Appl. to Pow. Syst., Montreal, may, 1989, pp. 101-106

[Schulte, et al 87] Schulte, R.P. et.al. "Artificial Intelligence solutions to Power System operating problems", IEEE Trans. Power Syst., Vol. PWRS-2 No. 4, Nov. 1987, pp. 920-926.

[Talukdar,Cardozo&Leáo,86].Talukdar, S, Cardozo, E. and Leáo. L. V. "The operator's assistant- An intelligent, expandable program for power system trouble analysis", IEEE Trans. Power Syst, Vol. PWRS-1, No. 3, Aug. 1986 pp.53-60.

[Wollenberg,86] Wollemberg, B., "Feasibility study for an energy management system intelligent alarm processor", IEEE Trans. Power Syst., Vol. PWRS-1, No.2, May, 1986 pp. 241-247.

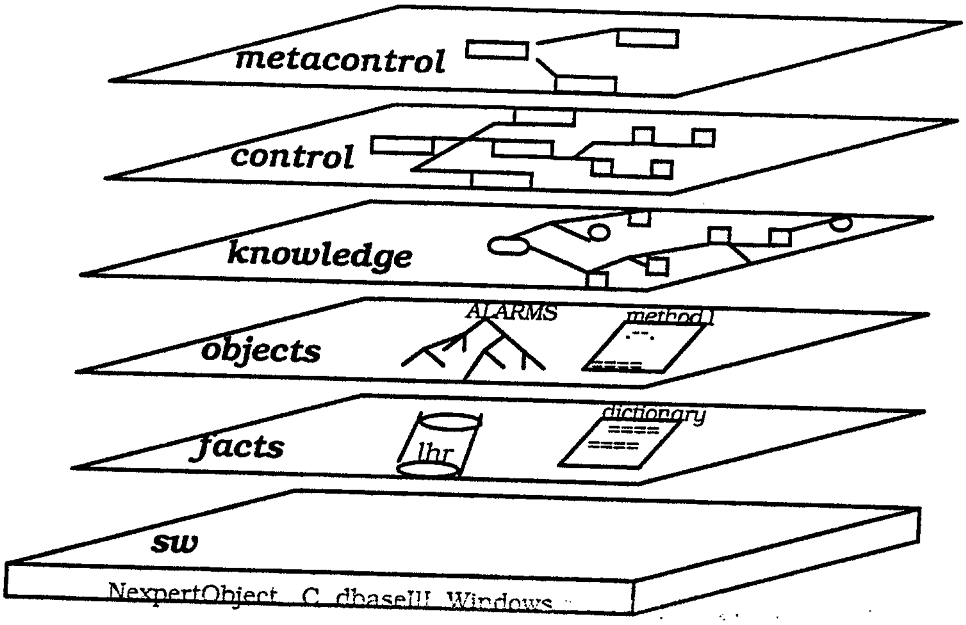

Fig. 1 The conceptual model

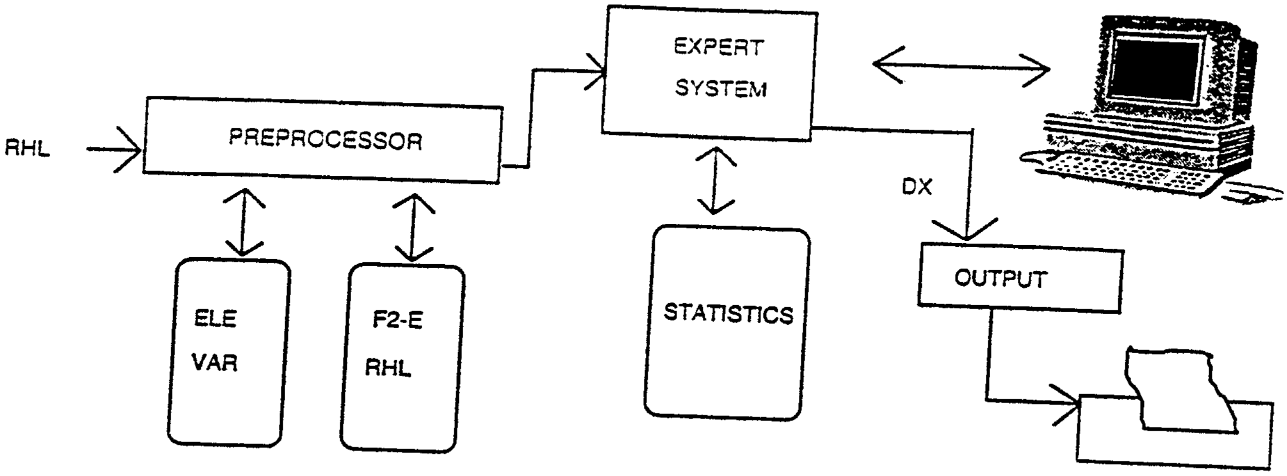

FIG 2 THE INTELLIGENT LOCAL ALARM PROCESSOR.

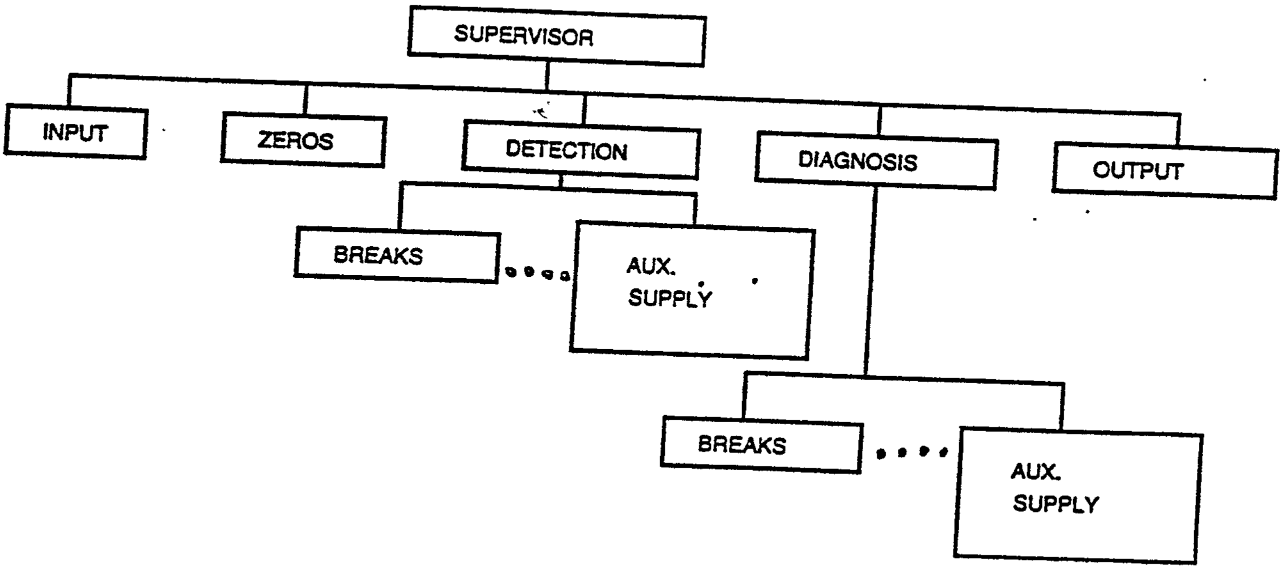

FIG. 3 KNOWLEDGE BASES

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