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Intelligent alarm processor for the control centre of Chilgener

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This paper presents an expert system for intelligent processing of the alarms that the SCADA system located at the Chilgener control centre receives from the Alfalfal hydroelectrical station. Its objective is to reduce the number of events entering the SCADA with the purpose of obtaining a quicker reaction from the dispatchers when facing emergency situations. The system emphasizes the dependency of the knowledge base in connection with the SCADA system in which it is applied and in connection with the dispatchers, whose basic criterion the expert system emulates.

Keywords: intelligent alarm, expert system, SCADA

1. INTRODUCTION

One of the main functions of a SCADA system is to allow the dispatcher to react to events that affect the operation of the electric system, generating alarms and displaying messages that help the operator in their task of detecting anomalies, as well as locating them and taking corrective actions that will lead the system to a normal state. Among the different states of a power system, the state of emergency is the most destructive and is characterized by serious violations of the operational restrictions defined by the upper and lower limits of the analogue variables [5]. In emergency states, both the number of alarms and the number of generated messages per unit of time increase significantly, making difficult the operator to adequately distinguish between the events that cause the situation and the events that are a consequence of it.

An intelligent alarm processor emulates the criterions of the dispatchers, having the ability to consistently manage a great number of alarms, and therefore becoming an important support in emergency situations.

In those control centres where an intelligent alarm processor has been installed, it has been welcomed due to the growing complexity of the SCADA systems that have surpassed the capacity of the dispatchers to process the events [9]. A European study of the main application areas of expert systems in the electrical sector determines that the intelligent processor has – with a total of 20 % – the largest share of projects developed.

References [1] [3] [4] [6] [7] [8] present specific alarm processors, based on expert systems, that differ in key factors like software platform, knowledge base and inference methods.

This work presents the design, implementation and test of an alarm processing system based on expert systems applicable to hydroelectric power plants. The system has been developed in C language on a personal computer and receives data in real time that the Landys & Gyr SCADA system of the generating company Chilgener delivers by printer. The knowledge base is adapted to SCADA events generated at Alfalfal hydroelectric station. The rules utilize forward chaining as inference method in order to form hypotheses about states of importance to the plant, which upon validation, through the SCADA events, produces a summarized message which is added to the processor's list of events and includes the hypotheses, and the causes (activated protections).

2. ALFALFAL ELECTRIC CIRCUIT

Figure 1 presents the display in a SCADA monitor of the unilinear diagram of Alfalfal station. There are 42 SCADA points in the plant which include analogue values, state of breakers and isolators (underlined in parenthesis in the figure and energized if filled) and defined relay and alarm messages for the bars, generators, lines, transformers and RTU.

The station has two generators which deliver energy to the main bar, divided into bar 1 and bar 2 through a disconnector (11 in the diagram). Each bar is connected to a generator and to a line that feeds the Los Almendros substation.

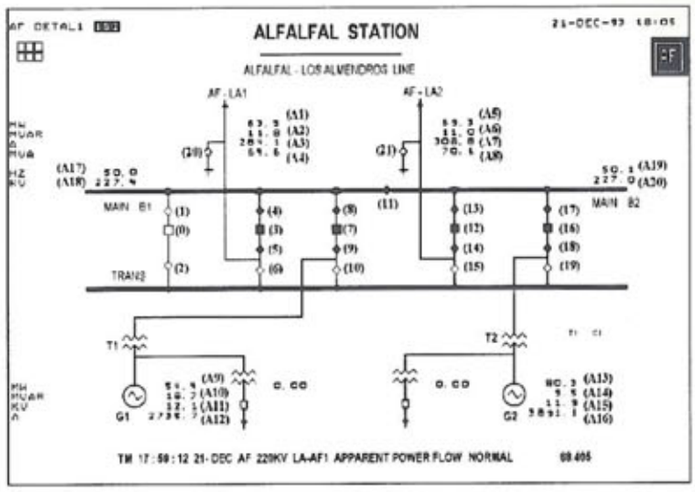

Figure 1 SCADA display of Alfalfal station

Format of input events

The following is an example of a registered event in the SCADA's event printer. Therefore, it is an example of an event entering the processor.

10/DEC/93 14:36:53: 34C03705055 5 TM 14:36:53 AF 220KV LA-AF1 APPARENT POWER FLOW DANGER 70.38

The processor takes only the relevant part of the data, converting the event into the following:

10/DEC/93 14:36:53 AF 220KV LA-AF1 APPARENT POWER FLOW DANGER 70.38

The sequential fields are: date (10/DEC/93), hour (14:36:53), station (AF: Alfalfal), voltage level (220KV), zone (LA-AF1: Los Almendros-Alfalfal 1 line), object (APPARENT POWER FLOW), initial state (ZERO VALUE) and measure (70.38). The zone field delivers information about the physical element, like line, generator, bar. The zone field plus the object field identify the SCADA point. The initial state corresponds to one of the following situations: ZERO VALUE, NORMAL, ALERT and DANGER.

3. KNOWLEDGE BASE

The knowledge base is formed by ten rules following the same structure in a text file plus two rules internal to the program that filter events when an improper operation of Alfalfal's RTU is detected or there are consecutive changes of the state of communications variable, both problems specific to Alfalfal.

Each rule of the knowledge base postulates a hypothesis of the Alfalfal's electrical circuit situation. This could be validated through the events received from the plant in the SCADA, and then the events related to the hypothesis are replaced by the "summarized message" (validated hypothesis), that describes the station's condition and, eventually, the activated protections.

3.1 Information that defines the rule's structure

The following aspects allow to form the rule's structure based on dispatcher's criteria and SCADA characteristics.

Fault diagnosis

When facing concurrent faults, the dispatcher attempts to determine the origin of the faults. For this, he first searches all the faulty elements following a one-fault/one-element scheme, making a list of them. Subsequently, he analyzes the relationships between the faulty elements based on the current topology, which generally corresponds to the normal operation of the plant, and considers the time of failure of each element to end with the causality of each fault and then takes actions.

Therefore, based on the one-fault/one-element scheme, a single faulted element will be associated to each hypothesis.

Topology

Electric systems dynamically change their topology due to breaker and disconnector states. Because of the great number of possible states, the faults have many forms of spreading. When facing a fault's spreading, an option for an alarm processor is to carry out a sweep in the electric network and consider the time of each fault in order to display only the hypothesis of the first faulty element. But the dispatchers prefer to make a list of all the faulty elements. This is a small list, because although there are many possible states at the Main Power Station, there are only few situations with meaning to the operator. Therefore, the processor will not eliminate any validated hypothesis.

Contradictory events to hypotheses
An electric fault with transient effects could produce events that contradict a validated hypothesis. So the processor must display the validated hypotheses as well as the contradictory events, without deciding to suppress or not the hypothesis, leaving that decision to the dispatcher.

Protections
The connections of protections to elements will be included in the rules, considering their direct influence in any element.

There must be a clear distinction between the protections (physical) and the SCADA messages of protections (software), since there could be specific protections that do not have an event expression. An example is the single relay message defined for transformer one: TRANF1 MASTER RELAY, produced by activation of any of the six transformer's protections.

Event's time assignment
Events transmitted by the Alfalfal RTU to the SCADA do not account for time. These events are stored in a buffer at the SCADA Master Station which processes them every two seconds, transforming them into SCADA events with text format, which includes date and hour, both assigned by the SCADA.

Necessary events
In a fault, all the hypotheses include the operation of protections, or the automatic tripping of one or more breakers. These openings imply that there will be "necessary" events within a rule, that must be completed in order to validate the hypothesis that the rule proposes. This will also be the case for the Alfalfal situations where no protections act, like for example stopping a generator, that just needs an event to enter: the opening of the generator's breaker.

Simultaneous events
Because of event's time assignment, two events that reach 'simultaneously' the SCADA Master Station, that is to say, that have a negligible time difference, so one will follow the other in the buffer, could be arbitrarily separated if the extraction flow of data from the buffer is interrupted. So it is necessary to consider that a simultaneous condition between two events is met if the time differential in reaching the SCADA is small, for instance two seconds apart.

Each rule will incorporate relay and alarm protections. Considering the protections act 'simultaneously' when facing a fault, these will be part of the summarized message if there is a greatest difference of time equal to the event's time assignment (two seconds) between the relay or alarm signal and the necessary opening of the breaker or disconnector.

Review of the element's state
The state of the elements is checked by a small SCADA located in Alfalfal which operates by sequentially interrogating the PLC's ('polling').

Communication between components
Any communication problem in the route sensor-PLC-small SCADA-RTU-SCADA could produce loss of events. So the processor can not expect to receive all the events associated to a fault. Therefore the expected events will have a 'symptom' status, that is to say, they agree with the hypothesis, but they can be received or not.

Events asynchrony
Due to possible loss of events or to the polling mechanism it could happen that two events are stored in the buffer in an inverted order to which they were generated. The first form of altering the order of events corresponds to the situation in which the first event generated is lost and reported immediately after the second generated event. The second form happens when in two elements, yet to be incorporated to the interrogation sequence, events are generated in an inverted order to that of the interrogation.

As a result, strict sequentiality of events can not be demanded and they can be found in loose order within the rule.

Restorative delay
Considering the great quantity of energy that the elements of the electric circuit manage, the fault's diagnosis process should be extensive. Therefore, there will normally be a delay in the restoration of element's operation, especially if there is telephone verification of the fault. So, an interval of time has to be defined, small enough to allow the confirmation that the events keep relation with the summarized message. This interval will be a variable of the program with an initial value of five minutes proposed by dispatchers. So, the hypothesis of a rule will be valid for five minutes, counted from the first detected event. After the five minutes, the hypothesis is disabled, and the related events will not be eliminated.

Measurement errors
The analogue values carry a measurement error produced by the use of transformers destined to protections, that have a wider margin of error. For that reason, an analogue value will not be exactly zero, but will be considered 'small', if it is less than the lower limit defined in the SCADA for the danger state.

In a situation in which the opening of a breaker occurs it is expected that the values of the energy delivered will diminish: the power, current and, eventually, also the voltage. Therefore, in the situation described, the processor is satisfied with 'small' values to associate them to the breaker's opening.

3.2 Rule's structure

The knowledge base is a set of rules contained in a modifiable text file. Each rule is composed of a summarized message and SCADA events. The processor filters, among the events that are received by the SCADA, only the events coming from the Alfalfal station and Los Almendros substation.

The summarized message corresponds to a hypothesis that describes one of the emergency situations at the Alfalfal station, and it is associated to a single faulty element (one rule-one element scheme). Examples of emergency are the shutting down of *one generator* and activation of *one bar* protections. In the processing of messages the hypotheses are concurrently generated by forward chaining, so several hypotheses search for validation in order to explain the situation at Alfalfal. The reception of an event part of a rule activates it like a hypothesis. After activating, the Intelligent Alarm Processor waits for the arrival of other events related with it.

The component events of a rule (expected events) are divided into 'necessary' and 'symptoms'. The hypothesis is considered true only when all the necessary events are completed within an interval of time preset at five minutes (according to 'restorative delay' in section 3.1). It is expected that the symptom events occur in a situation in which the hypothesis is true and, unlike the necessary events, they don't determinantly support the hypotheses validation. When a rule is valid, all the corresponding events are removed, generating a single event, the summarized message, that describes the emergency situation and replaces the first detected event of the rule.

Table 1 presents an example of a rule that manages the different situations that causes the shutting down of generator one at Alfalfal, whether it happens because of a local operation or by a relay or alarm activation.

The first line informs if the rule is activated or not. The second contains the summarized message, and the others the necessary events and symptoms in random order. The fields are detailed below.

Table 1 Example of a rule

```
+OFF

GENER1 <relay> <alarm> GENER1 EXIT

AFOFF<nec><open>GENER1 BREAKER

AFOFF<alarm?>GENER1  HIGH FREQUENCY ALARM
AFOFF<alarm?>GENER1  QUICK STOP
AFOFF<alarm?>GENER1  ELECTRIC STOP
AFOFF<alarm?>GENER1  MECHANIC STOP
AFOFF<alarm?>GENER1  LOW FREQUENCY ALARM
AFOFF<relay?>GENER1  MASTER RELAY
AFOFF<relay?>TRANF1 MASTER RELAY
AFOFF<relay?>BAR 1   MASTER RELAY
AFOFF<open>GENER1  DISC ENTRANCE LINE/MAIN BAR
AFOFF<open>GENER1  DISC ENTR GENRATOR SIDE
AFOFF<symptom?><small>GENER1  ACTIVE POWER
AFOFF<symptom?><small>GENER1  REACTIVE POWER
AFOFF<symptom?><small>GENER1  VOLTAGE
AFOFF<symptom?><small>GENER1  GENERATOR
                              CURRENT
```

Rule heading

A '+' in the rule's file denotes the start of a rule. '+OFF' indicates a disabled rule and '+ON' an activated one.

Events

In each event the station is identified: Alfalfal ('AF') or Los Almendros substation ('LA'); in Table 1 all the events are of Alfalfal. The condition of the event is registered ('OFF': not active or 'ON': active).

All the events in the rule have on their right side and in capital letters a single description of the defined SCADA point, combining the zone and object code. An example is 'GENER1 BREAKER' in the rule's third line (zone: 'GENER1' and object: 'BREAKER').

The opening and closing of breakers and disconnectors, and presence of small analogue values are events that matter in a fault. So, if the received point (in a SCADA event) is a breaker or a disconnector, their final state is of interest: OPENED or CLOSED. The expressions '<open>' and '<close>' in the rule are interpreted by the processor as matching the final state of the event received with the values OPENED and CLOSED respectively. '<small>' is also interpreted, but on points of measuring like 'GENER1 GENERATOR CURRENT'; the numerical final state is compared with the limit defined in the processor. If it is minor, the value is considered to be 'small'.

The expressions '<relay?>' and '<alarm?>' identify the point as a relay and alarm type respectively. On the other hand, '<nec>' and '<symptom?>' give the status of necessary or just symptom to the event in the rule.

Summarized message

The summarized message in the example is 'GENER1 <relay> <alarm> GENER1 EXIT'.

If signals of relay or alarm are not received but the signal of the necessary event: ('AFOFF <nec><open> GENER1 BREAKER') is received, the hypothesis is validated remaining as summarized message 'GENER1 GENER1 EXIT', which denotes the shutting off of Alfalfal's generator one by on-site operation, a situation which is generally scheduled.

But if besides receiving the necessary event, a relay or alarm as GENER1 MASTER RELAY (relay) or GENER1 LOW FREQUENCY ALARM (alarm) is also received, and it happens with a maximum of two seconds of time difference with the necessary event GENER1 BREAKER XXXXX OPENED (final state opened), it should validate any of the previous texts, and at least one of the expressions of the summarized message <relay> or <alarm> should be replaced by the corresponding text. So, if both are validated, the summarized message should be: 'GENER1 GENER1 MASTER RELAY GENER1 LOW FREQUENCY ALARM GENER1 EXIT'. The two seconds value is due to 'simultaneous events' in section 3.1 .

In Table 1 it is possible to verify that the rule covers a great number of situations with the possible combinations of relay and alarm messages ('<relay?>' and ' <alarm?>' in the rule), all synthesized in the summarized message. The existence of the master relay of generator one, bar one and transformer one indicates that any of them produce the situation of the summarized message (they determine that all the necessary events are completed). The defined alarms

in generator one also activate its master relay. So, the rules reveal the protections and connections of these to the elements.

From the knowledge base, it is concluded that it is important to represent correctly the behavior of the dispatchers, even if only for simple cases. Besides, it must be adapted to the characteristics of the Landys & Gyr SCADA system to which it is applied, since it influences heavily the form events are received.

4. IMPLEMENTATION AND TEST

The processor has been implemented on an IBM compatible PC. It is connected to the SCADA printer that registers all the events at a rate of 4800 bps and without error correction. The PC is connected in parallel to the link of the SCADA to the printer, extracting data through hardware interrupts of the PC's serial port. This type of connection was selected because the SCADA is in its capacity limit, that is exceeded especially in emergency states of the electric system.

The program has been tested with prepared and historical listings of SCADA events, introduced at a rate of events per time unit much higher than normal, reaching the 4800 bps maximum.

Following is the analytical handling by the processor of a historical listing of events:

Input

```
10/DEC/93 15:26:35 AF —— TRANF1 MASTER RELAY
NORMAL   OPERATED
10/DEC/93 15:26:35 AF —— TRANF1 MASTER RELAY
NORMAL   OPERATED
10/DEC/93 15:26:37 AF 220KV GENER2 BREAKER
CLOSED   OPENED
10/DEC/93 15:26:37 AF 220KV GENER1 BREAKER
CLOSED   OPENED
10/DEC/93 15:26:39 AF 12 KV GENER1 ACTIVE POWER
NORMAL      0.00
10/DEC/93 15:26:39 AF 12 KV GENER1 VOLTAGE
NORMAL      13.24
10/DEC/93 15:26:39 AF 220KV LA-AF1 ACTIVE POWER
FLOW    NORMAL      0.00
10/DEC/93 15:26:39 AF 12 KV GENER2 GENERATOR
CURRENT    NORMAL    429.89
10/DEC/93 15:26:41 AF 12 KV GENER1 REACTIVE POWER
DANGER      0.00
10/DEC/93 15:26:41 AF 12 KV GENER1 VOLTAGE
ALERT       4.48
10/DEC/93 15:26:41 AF 220KV BAR 1  VOLTAGE
ALERT       207.30
10/DEC/93 15:26:41 AF 12 KV GENER2 VOLTAGE
NORMAL      3.40
10/DEC/93 15:26:43 AF 12 KV GENER1 GENERATOR
CURRENT    NORMAL    58.62
10/DEC/93 15:26:43 AF 220KV BAR 2  VOLTAGE
ALERT       207.64
10/DEC/93 15:26:45 AF 220KV LA-AF1 APPARENT POWER
FLOW    NORMAL      0.17
10/DEC/93 15:26:45 AF 220KV LA-AF1 APPARENT POWER
FLOW    ALERT       3.87
10/DEC/93 15:27:01 AF 12 KV GENER2 VOLTAGE
DANGER      0.00
10/DEC/93 15:27:33 AF 220KV BAR 2  VOLTAGE
DANGER      210.00
10/DEC/93 15:27:35 AF 220KV BAR 1  VOLTAGE
DANGER      212.36
10/DEC/93 15:27:41 AF 12 KV GENER1 VOLTAGE
DANGER      0.00
10/DEC/93 16:06:29 AF —— TRANF1 MASTER RELAY
OPERATED  NORMAL
```

Analysis of the process

The first validated hypothesis is the shutting off of the generator one by automatic operation of the master relay of transformer one. Generator two also ceases operation, but there is no evidence of intervention of protections in the entry events, so the processor must suppose an exit from operation attributable to a dispatcher.

Eight events are eliminated by the summarized message GENER1 AF TRANF1 MASTER RELAY GENER1 EXIT and GENER2 GENER2 EXIT eliminates 4.

After dynamically removing the events, the processor displays the following summarized list of events:

```
$ 10/DEC/93 15:26:35 GENER1 AF TRANF1 MASTER
RELAY  GENER1 EXIT(R01E08)
$ 10/DEC/93 15:26:37 GENER2 GENER2 EXIT(R02E04)
10/DEC/93 15:26:39 AF 12 KV GENER1 VOLTAGE
NORMAL      13.24
10/DEC/93 15:26:39 AF 220KV LA-AF1 ACTIVE POWER FLOW
NORMAL      0.00
10/DEC/93 15:26:41 AF 220KV BAR 1  VOLTAGE
ALERT       207.30
10/DEC/93 15:26:43 AF 220KV BAR 2  VOLTAGE
ALERT       207.64
10/DEC/93 15:26:45 AF 220KV LA-AF1 APPARENT POWER
FLOW    NORMAL      0.17
10/DEC/93 15:26:45 AF 220KV LA-AF1 APPARENT POWER
FLOW    ALERT       3.87
10/DEC/93 15:27:33 AF 220KV BAR 2  VOLTAGE
DANGER      210.00
10/DEC/93 15:27:35 AF 220KV BAR 1  VOLTAGE
DANGER      212.36
10/DEC/93 16:06:29 AF —— TRANF1 MASTER RELAY
OPERATED  NORMAL
```

Comparing this list with the original input, it can be seen that the processor reduced 21 events to 11 without losing information, or to 2 (displaying only the summarized messages), losing some events of minor importance that the dispatcher could review in order to estimate the credibility of the summarized messages.

Actually, the expert system constantly reads a text file for rules. A RAM storage of the rules in the future can further improve the event processing capacity of the system.

Efficiency

In [3] [6] [7] [8] the efficiency of the processor is not determined numerically but estimated comparing the number of events entering versus those exiting, which could be only the summarized messages or all the events minus those effectively eliminated by the processor. In the example, 21 would compare with 2 or 21 with 11. This paper suggests

to define the efficiency as the ratio between the events that have actually been eliminated by the processor and the disposable events. The determination of disposable events must be made by an expert dispatcher. In the example, the processor effectively eliminates 10 events since the summarized messages represent 2 events that replace 12. The disposable events are the following entry events: 2, from 5 to 10, 12, 13, 15, 16, 17 and 20, adding up to 13. Efficiency, then reaches 76.9 % for this example.

The dispatcher's agree with the ratio and more importantly they are satisfyed with the alarm processor.

5. CONCLUSIONS

Although it has been developed specifically for the Alfalfal hydroelectrical station, the rule's structure of the Intelligent Processor can be applied to other stations. An improvement of the system's response through RAM storage of the rules would be enough to manage the rest of the power stations of Chilgener. Modifications must be made in the messages defined in the SCADA for the electric elements at the plants and should consider the direct connections of protections. As each rule is linked to a single electrical element, the change in the rules is easier. Also, to structure a knowledge base appropiate for the alarm processor, it is required to consider the characteristics of the SCADA system to which it is applied and the criteria used by the dispatchers.

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