# Combining Artificial Intelligence Techniques for the Training of Power System Control Centre Operators*

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**Abstract.** Control Centre operators are essential to assure a good performance of Power Systems. Operators actions are critical in dealing with incidents, especially severe faults, like blackouts. In this paper we present an Intelligent Tutoring approach for training Portuguese Control Centre operators in incident analysis and diagnosis, and service restoration of Power Systems, offering context awareness and an easy integration in the working environment.

## 1 Introduction

Power Systems have a very complex structure and require sophisticated and precise operation and control. The most important real-time decisions concerning Power System operation are taken in Control Centres (CC) by specially trained operators. Although Power System reliability has been increasing during the last decades, incidents still occur, resulting sometimes in blackout situations, with very high economic and social impact.

Blackouts have been a major concern in Power Systems specially since the occurrence of the 9th November 1965 Northeast Blackout in USA. In recent years, several blackouts assumed catasthrophic proportions. On 14th August 2003 a major blackout paralyzed most of the Northeast of USA and large areas of the Southeast of Canada. This incident affected directly more than 50 million people and took more than 4 days to recover from. More recently, on the 4th October 2006, the UCTE (Union for the Coordination of Transmission of Electricity) European Network experienced a quasi blackout situation affecting 9 European countries and North Africa and about 10 million consumers.

This last incident was due to a set of unforeseen circumstances and the difficulty felt by the CC operators in interacting quickly and in an effective manner. Moreover, the restoration process was hampered by the lack of coordination between the different entities involved. All this points to the creation of conditions allowing the restoration plans' training of the personnel belonging to the different utilities in a coordinated way [1].

Control Center operators performance is essential to minimize the incident consequences. The need of a good response of Control Centres to severe faults, is even more

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important nowadays, due to the widespread adoption of the Electricity Markets [2]. As Power Systems reliability increased, the number of incidents offering occasion for operator on-the-job training has decreased. The consequences of incorrect operator behaviour are all the more severe during a serious incident [3]. Operator training is vital for overcoming these problems, as well as the availability of adequate decision support tools.

Intelligent Tutoring Systems (ITS) have been chosen as the tool to address the operator's training requirements in diagnosis and restoration tasks. The reasons for that choice can be described as such:

1. They provide a way to represent domain knowledge in a structured and efficient way, allowing the inference of new knowledge.
2. They use a model of the trainee, showing a non-monotonous behavior and adapting better to the trainees characteristics and evolution.
3. With the right didactic knowledge they can select different pedagogical approaches in the various phases of the learning process.
4. They are able to monitor the trainees performance and evolution, gathering information to guide the system's adaptation.
5. They typically require very little intervention from the training staff, and can be used in the working environment without disturbing the normal routines.

In this paper we present an ITS used for the training of Control Centre operators. Several Artificial Intelligence techniques are used to make this system able to minimize experts'efforts in the training sessions preparation and to enable on the job and cooperative effective training. The ITS that has been developed for the Control Centre operators involves two main areas: one devoted to the training of fault diagnosis skills (DiagTutor) and another dedicated to the training of power system restoration techniques (CoopTutor). The Figure 1 shows this tutoring environment architecture.

## 2 Why Operators' Task Is So Demanding?

During the analysis of alarm messages lists, CC operators must look for the group of relevant messages that describe each type of fault. The same group of messages can show up in the reports of different types of faults. So CC operators have to analyze the arrival of additional information, whose presence or absence determines the final diagnosis. Additionally, operators have to deal with uncertain, incomplete and inconsistent information, due to data loss or errors occurred in the data gathering system.

In fact, if we consider all the messages that are generated during the period of an incident, including not only the messages originated in the plants involved in the incident but also in other plants of the Power System, operators can be forced to consider several hundreds of messages in just a few minutes. It is important to note that an incident usually causes the generation of not only the messages that are relevant to the analysis of this particular incident but also a lot of other messages that are not important in that context. However, on different contexts, these messages could be important, which stresses the need for a contextual interpretation of the information.

On the other hand, several incidents can take place almost at the same time, and one incident can have consequences in much more than two plants, resulting on a much

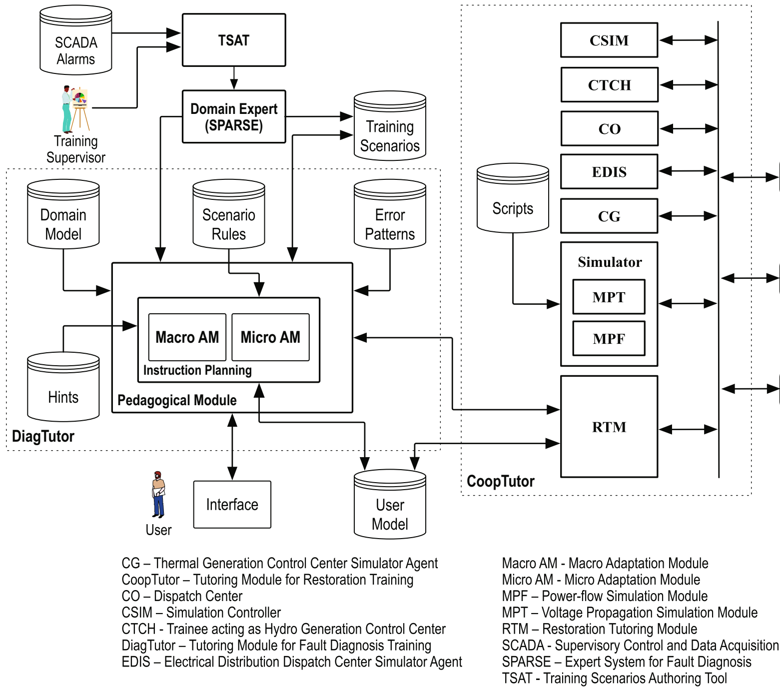


**Fig. 1.** Tutor Architecture

more complex interpretation of the situation. If we also take into account the need to consider missing information, we can have an idea of the difficulties CC operators face.

The occurrence of an incident demands a quick response from CC operators in order to minimize the consequences of that incident, avoiding the propagation of the incident to other power plants. It requires the start and completion of the service restoration as fast as possible, minimizing the period of service unavailability. Such goals require immediate CC operator reaction in two phases: first, he must make the correct incident diagnosis, and second, he must select and execute the correct maneuvers in order to restore power. This second step requires a close coordination between the teams responsible for power generation, transmission and distribution. Their actions should be based on a careful planning and guided by adequate strategies but those plans are often derailed by unforeseen circumstances. The correct execution of the restoration plan is very important because an incorrect maneuver can often leave the power system in a unstable state or even expand the area affected by the original blackout.

All these facts stress the need for preparing the CC operators to face the difficulties presented by the Power System operation. This paper presents a tutoring environment that addresses the two main areas of training: fault diagnosis skills (section 3) and power system restoration techniques in a cooperative environment (section 4).

# 3 Tutoring Module for Fault Diagnosis Training

This tutoring module, named DiagTutor, is focused on Fault Diagnosis Training. In order to illustrate how a training session is conducted and the interaction between the operator and the tutor, this section presents a very simplified diagnosis problem containing a DmR (monophase tripping with reclosure) incident, occurred in panel 204 of SED substation. The relevant SCADA[1] messages related to this incident are included in Table 1. These SCADA messages correspond to the following events: breaker tripping, breaker moving and breaker closing [3]. In a real training scenario the operator is faced with a huge amount of messages, typically several hundreds.

**Table 1.** Incident in panel 204 of SED substation

| | | | | | |
|---|---|---|---|---|---|
| 14-12-2003 04:24:45.200 | SED | 204 | CCL,2 | TRIPPING | 0 1 |
| 14-12-2003 04:24:45.240 | SED | 204 | CCL,2 | -BK BREAKER | 0 1 |
| 14-12-2003 04:24:45.860 | SED | 204 | CCL,2 | -BK BREAKER | 0 1 |

## 3.1 Reasoning about Operator Answers

The interaction between the trainee and the tutor is performed by means of prediction tables (Figure 2) where the operator selects a set of premises and the corresponding conclusion. The premises represent events (SCADA messages), temporal constraints between events or previous conclusions [4].

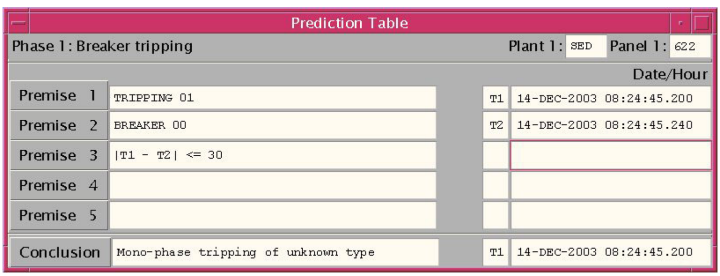


**Fig. 2.** Prediction Table

DiagTutor does not require the operators reasoning to follow a predefined set of steps, as in other implementations of the model tracing technique [5]. In order to evaluate this reasoning, the tutor will compare the prediction tables content with the specific situation model. This model has been obtained by matching the domain model with the inference produced by the SPARSE expert system [3]. With this process, the system is able to identify the errors that reveal the operators misconceptions, to provide assistance on each problem solving action, to monitor the trainee's knowledge evolution and to offer different learning opportunities.

[1] Supervisory Control and Data Acquisition system.

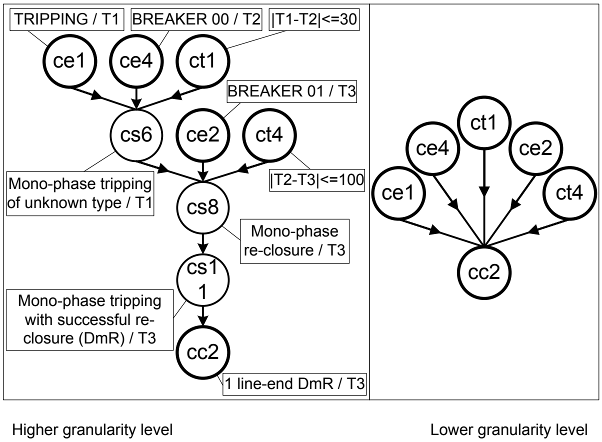


**Fig. 3.** Higher and lower granularity levels of the situation specific model

The identified errors are used as opportunities to correct the faults in the operators reasoning. The operators entries in prediction tables cause immediate responses from the tutor. In case of error, the operator can ask for help which is supplied as hints. Hinting is a tactic that encourages active thinking structured within guidelines dictated by the tutor [6]. The first hints are generic, becoming more detailed if the help requests are repeated.

The situation specific model generated by the tutoring system for the problem presented is shown in the left frame of Figure 3. It displays high granularity since it includes all the elementary steps used to get the problem solution. The tutor uses this model to detect errors in the operator reasoning by comparing the situation specific model with the set of steps used by the operator. This models granularity level is adequate to a novice trainee but not to an expert operator. The right frame of Figure 3 represents a model used by an expert operator, including only concepts representing events, temporal constraints between events and the final conclusion. Any reasoning model between the higher and lower granularity level models is admissible since it does not include any violation to the domain model. These two levels are used as boundaries of a continuous cognitive space.

The DiagTutor behavior during a training session includes two activities: the inference of the trainee reasoning during problem solving, in order to detect misconceptions; and the reaction to trainee errors and assistance through presentation of hints. These functions of DiagTutor are implemented by the Micro Adaptation Module (in Figure 1).

### 3.2 Adapting the Curriculum to the Operator

The Macro Adaptation Module, included in the Pedagogical Module (Figure 1), is responsible to adapt the Curriculum Plan to the current trainee needs. In particular, this module is able to select, from the Training Scenarios library, a problem fitting the trainee needs.

The preparation of the tutoring sessions learning material is typically a time-consuming task. In industrial environments, there is not usually a staff exclusively dedicated to training tasks. Specifically, in the electrical sector, the preparation of training sessions is done by the most experienced operators which are often already overloaded with power system operation tasks [7]. In order to overcome this difficulty, we developed two separate tools. The first one generates and classifies training scenarios from previously stored real cases. As these may not cover all the situations that CC operators must be prepared to face, another tool is used to create new training scenarios or to adapt already existing ones [7].

The process used by the Macro Adaptation Module to define the problems features involves two phases. First, the tutor must define the difficulty level of the problem, using heuristic rules. These rules relate parameters like the trainees performance in previous problems and his overall level of knowledge. In the second phase, the tutor uses the user models contents to select the most suitable type of incidents to be included in the problem, taking into account the domain concepts involved in each type of incident and the corresponding trainees expertise.

### 3.3 Difficulty Level Selection

To evaluate the problems difficulty level, we need to identify the cases characteristics that increase their complexity. The parameters involved here are the number of incidents contained in the case, the variety of incident types, the number of affected plants and the existence of chronological inversion in SCADA messages.

The choice of the difficulty level depends on two factors contained in the trainees model: the trainees global knowledge and a global acquisition factor. The first parameter is a measure of the trainee knowledge level in the whole range of domain concepts and is calculated using the mean of his knowledge level in each domain concept. The Macro Adaptation Module needs appropriate thresholds for deciding on the next problem difficulty level. The opinion of the trainees, regarding their personal evolution as the problems difficulty level is changed, can be used to adjust these thresholds.

The acquisition factors record how well trainees learn new concepts. When a new concept is introduced, the tutor monitors the trainee performance on the first few problems, namely how well and how quickly he solves them. This analysis determines the trainees acquisition factor. The procedure used to determine the trainees acquisition in each domain concept is based on the number of times the trainees knowledge level about the concept has increased, considering the three first applications of the concept.

The mechanism used to define the difficulty level of the problems is based on the following rule:

*If the global knowledge level and the global acquisition factor change in opposite directions*

*Then the problem difficulty level does not change*

*Else the problem difficulty level changes in the same direction of the global knowledge level.*

### 3.4 Problem Type Adequacy to the Trainee Cognitive Status

The mechanism used to classify each kind of incident in terms of adequacy to the trainee is based on a neural network (Figure 4).

The nodes belonging to the input layer correspond to the concepts (included in the domains knowledge base) to be assimilated by the trainees. Each node represents the application of a concept in a specific context. For instance, the nodes ce1/T1 and ce1/T5 represent two instances of the same concept and characterize the application of the concept of breaker tripping in the situations of first tripping and tripping after an automatic reclosure. The input vector contains an estimate of the trainees expertise level for each concept or its application and is obtained from the user model. Therefore, this vector represents an estimate of the trainees domain knowledge.

The output layer units represent the adequacy of an incident type to the current learners knowledge status. The number of units corresponds to the number of incident types (DS, DtR, DmR, DtD, DmD). Each output layers node, representing a type of

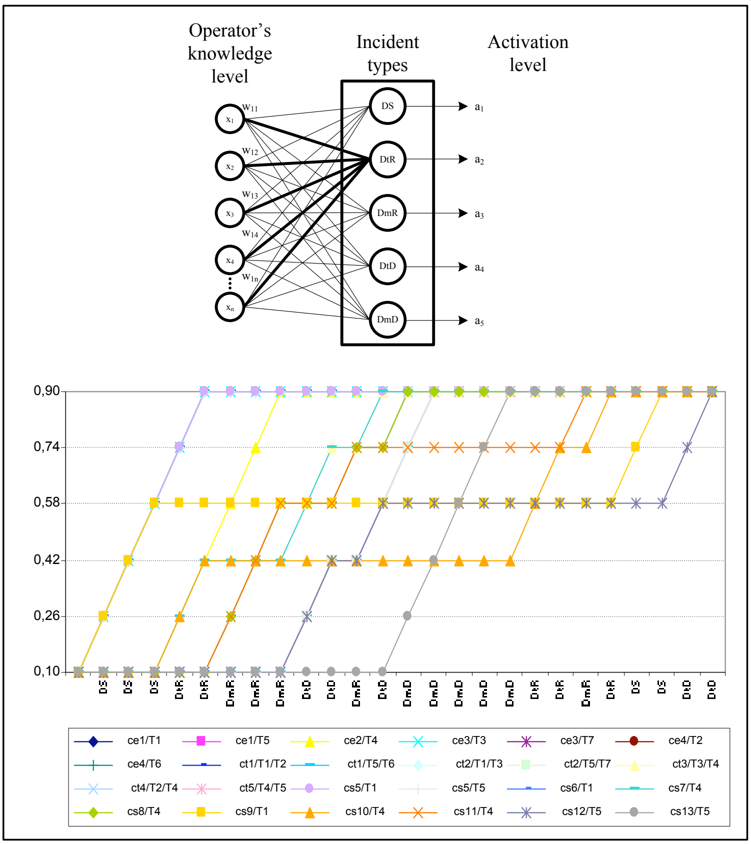


**Fig. 4.** Classification Mechanism

incident, is connected only to the input nodes corresponding to concepts involved with that incident type. These connections are done with links of weight $w_{ij}$.

The values used as weights are $w_{ij} = \{1, 0, N\}$ where N is used to indicate that there is no connection between node *i* of the output layer and the input node *j*. This means that concept *j* is not involved in an incident type *i*.

Each output neuron activation level is computed using the input vector and its weight vector. The activation is defined by the Euclidean distance, given by (1).

$$a_i = \sqrt{\sum_{j=1}^{n} (w_{ij} - x_j)^2} \tag{1}$$

We can see that a neuron with a weight vector (*w*) similar to the activation level vector of the input nodes (*x*) will have a low activation level and vice versa. The output layers node with the lowest activation will be the winner.

In Figure 4 we illustrate a situation where all the model variables are set to their minimum value (0.1) and achieve a maximum value of 0.9. It is also assumed that the ideal operator applies correctly all the domain concepts involved in the problem and that the updating rate is constant.

It can be observed that, after the third iteration, the concepts used in the DS incident type overcome the medium level (0.5), leading to a new type of incident (DtR) in the next iteration. After the fourth iteration, some concepts that are not used in DS but are involved in DtR incident overtake the minimum level for the first time.

We observed that an early introduction of new concepts can contribute to increase the instructional process efficiency. The problem selection mechanism ensures that the sequence of problems is not monotonous, tending to stimulate the operators performance with new kinds of incidents.

## 4 Tutoring Module for Restoration Training

### 4.1 Restoration Training Issues

The management of a power system involves several distinct entities, responsible for different parts of the network. The power system restoration process requires a close coordination between generation, transmission and distribution personnel, whose actions must be based on a careful planning and guided by adequate strategies [8].

In the specific case of the Portuguese transmission network, four main entities can be identified: the National Dispatch Centre (CG); the Operational Centre (CO); the Hydroelectric Control Centres (CTCH); and the Distribution Dispatch (EDIS).

The power restoration process is conducted by these entities in such a way that the parts of the grid they are responsible for will be led to their normal state, by performing the actions specified in detailed operating procedures and fulfilling the requirements defined in previously established protocols. This process requires frequent negotiation between entities, agreement on common goals, and synchronization.

The purpose of the training tutor is to allow the training of the established restoration procedures and the drilling of some basic techniques. Power system utilities have built detailed plans containing the actions to be executed and the procedures to be followed in case of incident. In the case of the Portuguese network, there are specific plans for the system restoration following several cases of sectorial blackouts as well as national blackouts, with or without loss of interconnection with the Spanish network.

One typical restoration plan, to be applied after a regional blackout induced by a fault on the 150kV bus of the SRA substation, can be described as follows:

1. Notify Distribution Dispatch Center about the incident and expected restoration time. Wait for the fault on the SRA 150 kV bus to be repaired.
2. Feed the 150kV to SRA bus using the 400/150 kV autotransformers.
3. Switch SVI substation to manual.
4. Energize the lines fed by the 150 kV bus of SRA with priority to lines connected to substations SOR and SRU and to power plants CCD and CVN.
5. Contact the Hydroelectric Power Plants CC, asking for the restoration of their lines with priority for the ones between CCD and CAR and between CCD and SVI/CVF.
6. Wait for the automatic operators of SCV and SGR substations to restore the 150/60 kV transformers, if no voltage is available in 60 kV buses.
7. Wait for SOR substation automatic operator to restore the service, including the line to SVI.
8. Finish the restoration of 150 kV line between substations SRA and SED.
9. Check if the automatic operators work is concluded and finish the restoration if it has not been done automatically.
10. Notify Distribution Dispatch Center about the end of the restoration process.

Our Restoration training subsystem, the CoopTutor, is based on a Multi-Agent system [9]. These agents can be seen as virtual entities that possess knowledge about the domain. As the real operators, they have assigned tasks, goals to achieve and beliefs about the simulated reality and others agents activity. They work asynchronously, performing their different duties simultaneously and synchronizing their activities only when the need arises. Therefore, the system needs a facilitator entity (Simulator in Figure 1) that supervises the process, ensuring that the simulation stays coherent and convincing. In our system, the trainee can select which of the available roles he wants to play, leaving to the tutor the responsibility of supplying the virtual agents that will simulate the other would be participants.

### 4.2 Trainees Model

The representation method used to model the trainees knowledge about the domain knowledge is a variation of the Constraint-Based Modelling (CBM) technique [10].

This student model representation technique is based on the assumption that diagnostic information is not extracted from the sequence of students actions but rather from the situation, also described as problem state, that the student arrived at. Hence, the student model should not represent the students actions but the effects of these actions. Because the space of false knowledge is much greater than the one for the correct one, it was suggested the use of an abstraction mechanism based on constraints. In this representation, a state constraint is an ordered pair (Cr,Cs) where Cr stands for relevance condition, and Cs for satisfaction condition. Cr identifies the class of problem states in which this condition is relevant and Cs identifies the class of relevant states that satisfy Cs.

Under these assumptions, domain knowledge can be represented as a set of state constraints. Any correct solution for a problem cannot violate any of the constraints. A violation indicates incomplete or incorrect knowledge and constitutes the basic piece of information that allows the Student Model to be built on. This CBM technique does not require an expert module and is computationally undemanding because it reduces student modelling processing to basic pattern matching. One example of a state constraint, as used in our system, can be found below:

*If there is a request to CTCH to restore the lines under its responsibility*
*Then the lines that supply the hydroelectric power plants must have already been restored*
*Otherwise an error has occurred*

Each violation to a state constraint like the one above allows the tutor to intervene both immediately or at a later stage, depending on the seriousness of the error or the pedagogical approach that was chosen. This technique gives the tutor the flexibility needed to address trainees with a wide range of experience and knowledge, tailoring, in a much finer way, the degree and type of support given, and, at the same time, spared us the exhaustive monitoring and interpretation of students errors during an extended period, which would be required by alternative methods.

Nevertheless, it was found the need for a metaknowledge layer in order to adapt the CBM method to an essentially procedural, time-dependent domain like the power system restoration field. This layer is composed of rules that control the constraints application, depending on several parameters: the phase of the restoration process in which the trainee is; the previously satisfied constraints; and the set of constraints that can be simultaneously triggered.

These rules establish a dependency network between constraints that can be represented by a graph (Figure 5). The relationships between constraints expressed by this graph can be of precedence, mutual exclusion or priority [11].

The constraint evaluation is the responsibility of the Tutoring Module (RTM in Figure 1). Its mechanism is triggered by the arrival of messages relating certain actions performed by the trainee on the simulated reality or other external events that should force the verification of past trainee's actions.

The range of events that are so monitored include the change of status of circuit breakers, the change of status of a substation (from automatic to manual mode or vice-versa), the sending of some special messages and, finally, events automatically triggered after certain time intervals. The output of the Constraint Evaluation module will be one or more pedagogical actions.

The Constraint Evaluation mechanism on Figure 6 is responsible for for checking which constraints (if any) are triggered by the event. This behavior is modulated by the

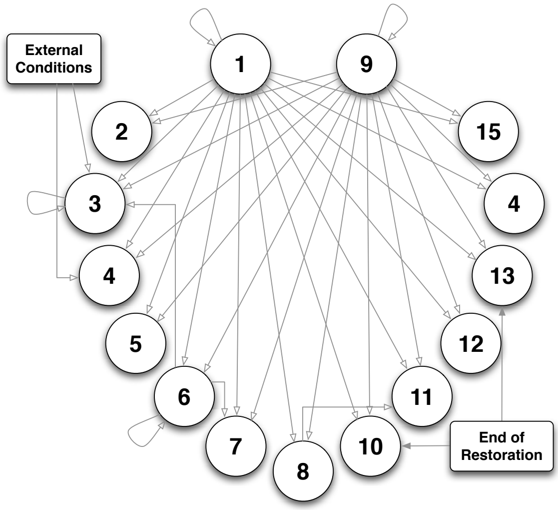


**Fig. 5.** Constraint Dependency Graph

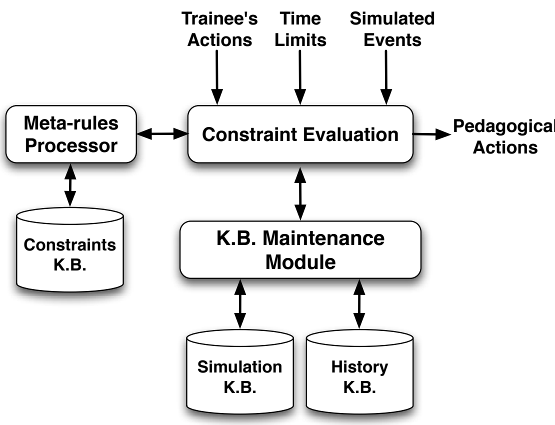


**Fig. 6.** Constraint Evaluation Mechanism

Meta-rules Processor that states which constraints are available for evaluation in each situation, as explained before in this section.

### 4.3 The Cooperative Learning Environment

The CoopTutor is prepared to offer two different modes of training: it can train individual operators as if they belonged to a team, interacting with virtual operators, but is also capable of dealing with the interaction between several trainees engaged in a cooperative process, providing specialized agents capable of fulfilling the roles of the missing operators.

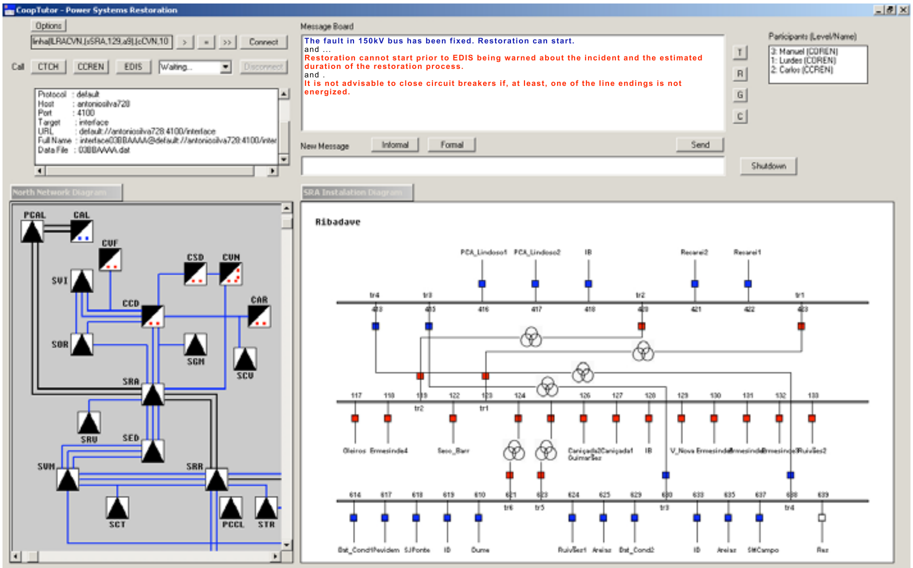


**Fig. 7.** CoopTutor Interface

At the same time, when several trainees are are working in cooperative mode, it monitors their interaction, stepping in when a serious imbalance is detected. The tutor can therefore be used as a distance learning tool, with several operators being trained at different locations. This simplifies considerably the logistics of the training sessions preparation.

In order to support the monitoring activities of the cooperative discussion and decision processes, the core data contained in the student model has been complemented with information concerning the quantity and characteristics of the interactions detected between trainees. The tutor gathers this data by loosely monitoring the interaction patterns and performing a surface level analysis of the messages' contents.

The tutor will intervene in the cooperative discussion process only if it detects a clear imbalance between participants. It may be called to step in though by the trainees themselves, if they are not able to agree on a course of action or if they find themselves in an impasse. In the first case, the tutor will use the knowledge contained in the CBM module to evaluate the different proposals. In the second case, it will combine the constraint satisfaction data previously gathered with procedural knowledge representing the sequence of the specific restoration plan, in order to issue recommendations about the next step to perform. The general aspect of the CoopTutor interface is shown in Figure 7.

## 5 Conclusions

This paper describes how an Intelligent Tutoring System can be used for the training of Power Systems Control Centre operators in two main tasks: Incident Analysis and Diagnosis; and Service Restoration. Several Artificial Intelligence techniques were combined to obtain an effective Intelligent Tutoring environment, namely: Multi-Agent Systems, Neural Networks, Constraint-based Modelling, Intelligent Planning, Knowledge Representation, Expert Systems, User Modelling, and Intelligent User Interfaces.

The developed system is used in the training Electrical Engineering BSc students, since the selection of new operators is frequently done from this kind of students.

The most interesting features of this training environment can be summarized as follows:

1. The connection with SPARSE, a legacy Expert System used for Intelligent Alarm Processing [3].
2. The use of prediction tables and different granularity levels for fault diagnosis training.
3. The use of the model tracing technique to capture the operators reasoning.
4. The development of tools to help the adaptation of the curriculum to the operator - one that generates training scenarios from real cases and another that assists in creating new scenarios.
5. The automatic assignment of the difficulty level to the problems.
6. The identification of the operators knowledge acquisition factors.
7. The use of Neural Networks to automatically select the next problem to be presented.
8. The use of the Multi-Agent Systems paradigm to model the interaction of several operators during system restoration.
9. The use of the Constraint-based Modelling technique in restoration training.

## References

1. UCTE: Union for the co-ordination of transmission of electricity - system disturbance on 4 november 2006 - final report (2007), `http://www.ucte.org`
2. Praça, I., Ramos, C., Vale, Z., Cordeiro, M.: Mascem: A multiagent system that simulates competitive electricity markets. IEEE Intelligent Systems- Special Issue on Agents and Markets 18, 54–60 (2003)
3. Vale, Z., Moura, A., Fernandes, M., Marques, A., Rosado, A., Ramos, C.: Sparse: An intelligent alarm processor and operator assistant. IEEE Expert - Special Track on AI Applications in the Electric Power Industry 12, 86–93 (1997)
4. Faria, L., Vale, Z., Ramos, C.: Diagnostic tasks training based on a model tracing approach. International Journal of Engineering Intelligent Systems for Electrical Engineering & Communications (CRL) 13, 223–230 (2005)
5. Anderson, J., Corbett, A., Koedinger, K., Pelletier, R.: Cognitive tutors: Lessons learned. The Journal of the Learning Sciences 4, 167–207 (1995)
6. Razzaq, L., Heffernan, N.: Scaffolding vs. hints in the assistment system. In: Ikeda, M., Ashley, K.D., Chan, T.-W. (eds.) ITS 2006. LNCS, vol. 4053, pp. 635–644. Springer, Heidelberg (2006)
7. Faria, L., Vale, Z., Ramos, C., Silva, A., Marques, A.: Training scenarios generation tools for an ITS to control center operators. In: Gauthier, G., VanLehn, K., Frasson, C. (eds.) ITS 2000. LNCS, vol. 1839, p. 652. Springer, Heidelberg (2000)
8. Sforna, M., Bertanza, V.: Restoration testing and training in italian iso. IEEE Transactions on Power Systems 17 (2002)

9. Jennings, N., Wooldridge, M.: Applying agent technology. Applied Artificial Intelligence: An International Journal 9, 351–361 (1995)
10. Ohlsson, S.: Constraint-based student modeling. In: Greer, McCalla (eds.) Student Modeling: the Key to Individualized Knowledge-based Instruction, pp. 167–189. Springer, Heidelberg (1993)
11. Silva, A., Vale, Z., Ramos, C.: Cooperative training of power systems restoration techniques. In: 13th International Conference on Intelligent Systems Applications to Power Systems, Washington (2005)