Cooperation in Learning Power Systems Restoration Techniques

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Abstract: Adequate training programs for power systems restoration tasks must take into account that this is a cooperative activity involving several entities. The proposed architecture of the Intelligent Tutoring System presented in this paper is based on a multi-agent system offering a simulated training environment.

Index Terms: Intelligent Tutoring Systems, Multi-Agent systems, Constraint-Based Modelling, Power System Restoration.

I. INTRODUCTION

We can see the power restoration task in power systems having suffered a severe incident as a multi-objective optimisation problem, to be performed in several successive steps and being bound by multiple constraints.

If we look at each individual task to be performed during this process, none can be, in normal conditions, considered as specially transcendent, but when we consider the whole of the tasks to be handled, the various partial objectives to be attained and the multitude of constraints to be respected and conditions to be repeatedly verified, then the real difficulty of the whole process comes to fore. All this complexity must be addressed as much as possible in advance, by the careful analysis of the electric network, and the definition of suitable restoration strategies.

The power restoration strategies, on the other hand, seem to be very difficult to generalise, especially due to significant differences between network topologies and characteristics, economic constraints and requirements, or simply different approaches to the restoration problem used in different countries by different companies. This is to say that any effort to establish a training program for the operators responsible for the restoration process should be based on the identification of the basic building blocks of the restoration process upon which the specific procedures followed by their companies should be taught and drilled.

Some years ago, it was proposed the definition of what was called *generic restoration actions* (GRA) as a way of describing the generic tasks that should by force exist in any (or most) of the restoration strategies followed in the different power systems [1]. One example of these generic actions can be the pick up of a load in a way that its power requirements are met and no voltage or frequency limits are violated by the accompanying switching actions. Another obvious candidate is the synchronization of two subsystems for which certain known pre-conditions must be met.

Typically, the management of a power system involves several distinct entities, responsible for different parts of the network. The power system restoration asks for a close coordination between the generation, transmission and distribution personnel. Their actions should be based on planning analysis and guided by adequate strategies [2].

In the specific case of the Portuguese transmission network, four main entities can be identified:

- National Dispatch Center (N.D.C.), responsible for the energy management and for the thermal generation;
- Operational Centre (O.C.), controlling the transmission network;
- Hydraulic Control Centers (H.C.C.), responsible for the remote control of hydraulic power stations;

- Distribution Dispatches (DD), controlling the electric distribution networks.

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

It is therefore clear the need for the training programs to take this fact into account by providing an environment where these different roles can be performed and intensively trained. The way that traditionally this requirement has been addressed is based on the use of simulators. These systems are nowadays quite apt at describing accurately the behaviour of the power systems, representing the system's performance with realism, and integrating, in certain cases, the possibility of simulating the several control centers involved [3]. It is therefore possible to turn them into the core of a training environment with great realism.

Nevertheless, the fact that preparing these training sessions typically requires several days of work from specialised training staff, and the need to move away at least four control center operators from their workplace during several days for the simulation to be convincing, has as a consequence that no more than two training sessions per year are usually attended. Another facility usually absent from a simulator-based training session is the capability to perform an accurate evaluation of the trainees' knowledge level and learning evolution.

We see the use of Intelligent Tutoring Systems (ITS) as a complementary tool tailored specifically to address the shortcomings of the simulators when used in a training environment. The reasons for that can be summarized as follows:

- They embody knowledge about the trainee, which they use to lead the system adaptation to the trainee's characteristics and evolution;
- They can be fit with didactic knowledge allowing the system to choose different pedagogical strategies and methods in the different phases of the learning process and to use diversified approaches whenever the trainee's evolution reaches an impasse;
- They are able to constantly monitor the trainee's performance and evolution, gathering information not only to guide the system adaptation but also to be used by the training personnel;
- They typically require very little intervention from the training staff, and can be used in the working environment without disturbing the normal working routines.

Other aspect that we decided to consider was the role of a simulation facility for the training of Power Systems restoration procedures and techniques. To have a simulator at hand can be obviously convenient when building a power system restoration tutor, but do we really need a full-blown simulator in order to build a good power system restoration tutor? In fact, it doesn't seem mandatory to have one in order to give a tutor simulation capabilities good enough to give some realistic sense to it. Its purpose is not to accurately describe the network behaviour but only to lend some realism to the training environment. The purpose of the training tutor is, in this case, to allow for 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 execute and the procedures to follow in case of incident, be it serious or trivial, national or regional. In the case of the Portuguese grid, 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.

Our aim is therefore to develop a training environment able to deal adequately with the training of those procedures, plans and strategies of the power system restoration, using what may be called lightweight, limited scope simulation techniques. This environment is meant to make available to the trainees in an expedite and flexible way all the knowledge accumulated during years of network management and control translated into detailed power system restoration plans and strategies. The embedded knowledge about procedures, plans and strategies should be easily revisable, anytime that new field tests, post-incident analysis or simulation data supplies new data.

II. DIDACTIC ISSUES

The previous work laid out by our research team in the area of power systems operators training has been based, from the pedagogical point of view, on a more traditional ground, by which the burden of the initiative lays always on the tutor's shoulders, leaving for the trainee a more passive role [4]. Hence, it looked as an interesting challenge the investigation of possible alternatives to this way of considering the tutorial process.

One such approach has been offered by the constructivist theories that suggest that the learners should be given the opportunity to construct their own understanding by means of the interaction with a suitable environment. They put the emphasis in the process of learning rather than on the actual acquisition of the domain knowledge as a pre-determined set of concepts or techniques [5]. They support therefore the development of a more active attitude from the learners, by paying special attention to the *context*, or situation where the learning takes place, and the enabling of *activities* by which the learners interact in a active form with the environment, building their own knowledge out of their own experiences.

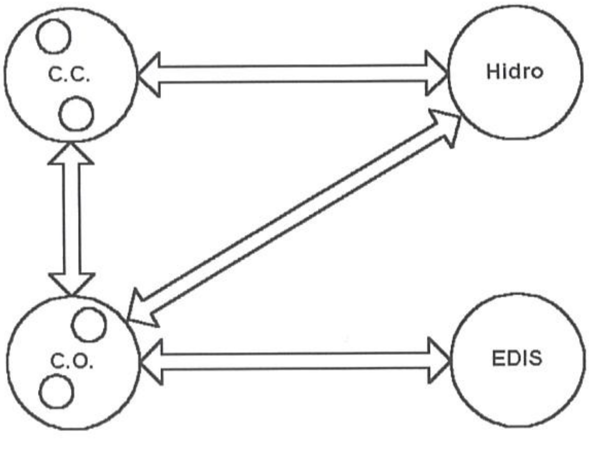

Figure 1 - Multi-agent community

It seemed problematic from the beginning to try to use this kind of novel approach to the acquisition of the special aptitudes needed to conduct a complex process such as the power systems restoration process with its multiple objectives, multiple stages and multiple constraints. But looking further into the problem it seemed like a promising path to try and use these views in order to build a suitable environment for the learning of the basic concepts and techniques without which there is no point in going further learning the whole picture. So, as the trainee gets better knowledge of those basic elements and builds confidence, he can be slowly guided to a more hands-on approach to the whole process of the restoration, with intensive practice using real-life cases. In fact, we don't see how the restoration process as a set of parallel sequences of procedures performed from the beginning to the end could be learned by means of the mere interacting of the learner with the right context. Nevertheless, we think that a mixed approach could be a wise way of tackling the pedagogical problems posed by this particular domain.

III. SYSTEM ARCHITECTURE

Our system's architecture is based on the interaction of several agents personifying one of four entities that are present in the power system restoration process: O.C. (Operational centre), N.D.C. (National Dispatch), Hydroelectric Generation (H.G.C.) and Distribution Dispatch (D.D.C) (Fig. 1).

We have chosen this multi-agent architecture because it seemed the most natural way of translating the real-life roles and the split of domain knowledge and performed functions. It is known that the use of agents' technology is well suited to domains where the data is split by distinct entities physically or logically and which must interact with one another to pursue a common goal [6]. It seems just to be the case with the problem at hand, where we have several entities responsible for separate parts of the whole task that must interact in a cooperative way towards the fulfilment of same global purpose.

It is not the first time that a multi-agent approach has been used in the area of power system restoration. One such previous work has been the one developed around the ARCHON project [7]. Within this framework, each agent is basically centered on a tool or a skill. In fact, the members of the agent community share the knowledge, resources and authority to execute their tasks in a coordinated way, aiming at attaining the common goal of restoring power to the grid. The system manages the interaction and cooperation between those problem solving agents, called Intelligent Systems (IS), in order to have the work done.

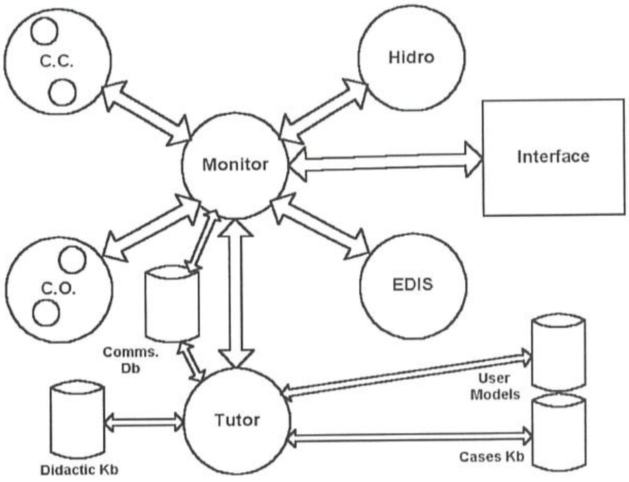

Figure 2 - System Architecture

Basically this system appears like a distributed expert system, dividing the power restoration task amongst its IS. Examples of those problem-solving entities in one of ARCHON's incarnations (CIDIM) are a telemetry agent that gathers telemetry data from different data acquisition systems and feed it to the concerned agents, high and low voltage diagnosis agents to find the location, time and type of fault, or a switch planning agent. Differently, the system we devised, although being multi-agent based, organises itself around agents personifying entities present in the real life power system control activity.

In our system, the trainee can choose to play any of the available roles, namely the C.O. and the C.C. ones, leaving to the tutor the responsibility of simulating the other fictitious participants.

The agents that play those roles possess the model of the ideal operator, as well as deviations to that model, be it at operational and technical level, or at the psychological level. Those agents can be seen as virtual entities that possess knowledge about the domain as well as characteristics that can be described as psychological traits, in order to approximate the simulation to what happens in real life, with real operators and their way to react to stressful and complex situations. As real operators they have tasks assigned to them, goals to be achieved and beliefs about the network status and others agents' activity.

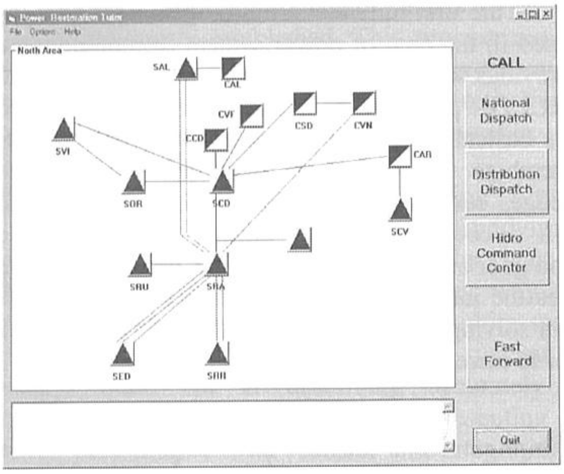

Figure 3 - Tutor Interface

Those agents perform their duties asynchronously, performing their duties simultaneously and synchronising their activities only when this need arises. Therefore, the system needs an arbiter (another agent) that supervises the process, ensuring that the simulation is coherent and convincing, apart from the important function of controlling the temporal aspects of the simulation (synchronisation and acceleration). This and other agents are not explicit, as opposed as the ones performing public roles.

The ITS architecture was planned in order that future upgrades of the entities involved or the adjunction of new agents should be painless. The idea is also to allow for the inclusion of tools like diagnostic modules to be available to the community of agents.

Implementation-wise, the multi-agent system used is based on the LPA-Prolog Agent Toolkit. Our choice was motivated by the ease of integration it allows with the A.I. part of the application, itself built on Prolog. No standard Agents Communication Language, as KQML, has been used; instead, a simple and less verbose dialect was developed, covering the basic communication needs.

IV. TRAINEE'S MODEL

In order to give the tutor the ability to adapt to the trainees' characteristics, it is fundamental that it possesses detailed knowledge about trainee's characteristics, grasp of the domain concepts and techniques and proficiency levels. The key adaptation factor is the type and degree of help that the tutor is able to give to the trainee in order to support his/her evolution in the learning process. This knowledge about the system's user is embodied in the Trainee's model module.

Traditionally user models used in Intelligent Tutors tend to be tightly controlled by the system, no user control being allowed over the model's contents. This may lead to the user developing a certain mistrust about the system reasoning and decisions regarding his own knowledge and performance.

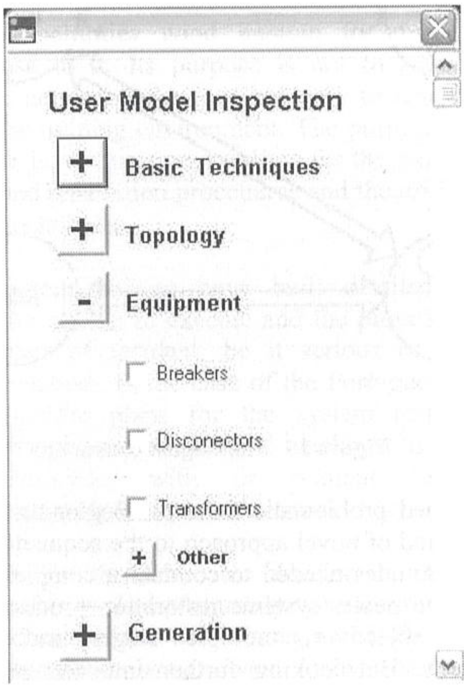

Figure 4 - User Model Inspection Module

Pursuing the aim of offering full inspectability, the model's knowledge should be explicit. We decided to create an environment where not only the user would be able to consult his own model, but he would also be called to participate in the evaluation process, inciting him to perform an *auto-evaluation* of his work so far. We decided not only to allow the user to inspect his model, but to give him the power to change it, obviously under a guided supervision, making the process of user model revision a cooperative one.

If the trainee feels that the evaluation made by the system is optimistic, he can change that system's assumption. There is no point in going further if the trainee himself says that he is not confident of his own proficiency in that area. This change is mandatory and must therefore be accepted by the system and trigger the appropriate tutoring methods.

In the opposite case, if the user decides to consider as known a knowledge area or item that the system considers as not known, the overriding of the system's assumption cannot be accepted without further investigation. Consequently, it will require that the trainee submits to a specific test or that he solves a specific problem, before his request for change can be accepted.

In both cases, this open disagreement between the system and the user has implications in the confidence level of these systems' assumptions and must be registered for future system's maintenance.

A prototype tool for trainee's model data acquisition and maintenance has been built with the purpose of testing these concepts. Check boxes are attached to the tips of each terminal branch, representing every specific item of knowledge to be acquired. If all the check boxes are checked, that means that the tutoring process for that particular knowledge branch was a success. A colour scheme has been specified to graphically exhibit the completion level of the tutoring process in each branch. As stated above, if the user disagrees with the evaluation being performed by the system, he has the possibility of directly changing the status of those check boxes. The acceptance of this change is governed by the criteria defined above.

We figured that the system would not need to make any a priori assumptions concerning trainee's prior knowledge and characteristics, due to the long period of interaction between user and system to be expected. In tutoring systems it is common to privilege the accuracy of the model over its immediate availability. The system will therefore assume that any new user will be a novice and treat him like that until further notice. We thought nevertheless that it would be wise to devise some kind of mechanism to enable semi-proficient operators to bypass part of the tutoring process, when they start to use the system. He will be able, in this case, to require that a quick examination be made in certain areas that he feels confident on. We also plan to authorise the user in certain cases to totally disable the first stages of the tutoring process in order to directly concentrate himself on more challenging problems. We are foreseeing the use of this mode as an aid for experienced operators, allowing for the recalling of past incidents that they may want to review and be confronted with.

In what concerns specifically the representation method used to model the trainee's knowledge about the domain knowledge, it was used a variation of the Constraint-Based Modelling (CBM) technique [8]. This student model representation technique is based on the assumption that diagnostic information is not extracted from the sequence of student's actions but rather from the situation, also described as problem state, that the student arrived at Hence, the student model should not represent the student's actions but the effects of these actions [9]. Because the space of false knowledge is much greater than the one for the correct knowledge, 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 those constraints. A violation indicates incomplete or plain incorrect knowledge and, as such, constitutes the basic piece of information that allows the Student Model to be built on.

This CBM technique doesn't require a runnable expert module, although the pedagogical process can clearly benefit from its existence. Another advantage is its computational simplicity because it reduces student modelling processing to basic pattern matching.

Two examples of state constraints, as used in our system, can be found below:

```
If
   There is a request to HGC to restore the lines under
   its responsibility
Then
   The lines that connect to the Hydroelectric power
   stations must already have been restored
Otherwise
   An error has occurred

If
   Breakers are closed in substations in automatic
   mode
Then
   The breakers must have been closed by the
   Automatic Operator
Otherwise
   An error has occurred
```

Each violation to a state constraint like the ones above enables 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 illustrates the reason why the CBM technique is said to be "pedagogically agnostic".

This technique has allowed us to give the tutor the flexibility needed to address trainees with a wide palette 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 student's errors during an extended period, that alternative methods would require.

V. KNOWLEDGE ACQUISITION

One of the issues we had to address was the need to facilitate the tasks related to the creation and maintenance of the power system network specification, including grid topology, power stations parameters and switchyard diagram descriptions.

This is a tedious and time-consuming task due to the sheer volume of information involved. One way of tackling the problem has been the one followed by [3], and it was based on the use of a “grid description language” to describe the power system network topology, constituents and status in an almost free-form text description.

We decided to evaluate the possibility of developing graphic tools to assist in the input of network description data, specifically the switchboard diagram data in a quick and reliable manner. The Diagram File Composer (Fig.5) gathers the data and automatically converts it into Prolog facts to be used by the interface and the simulated agents.

The interface agent, making the maintenance process totally transparent, automatically builds the switchyard diagrams.

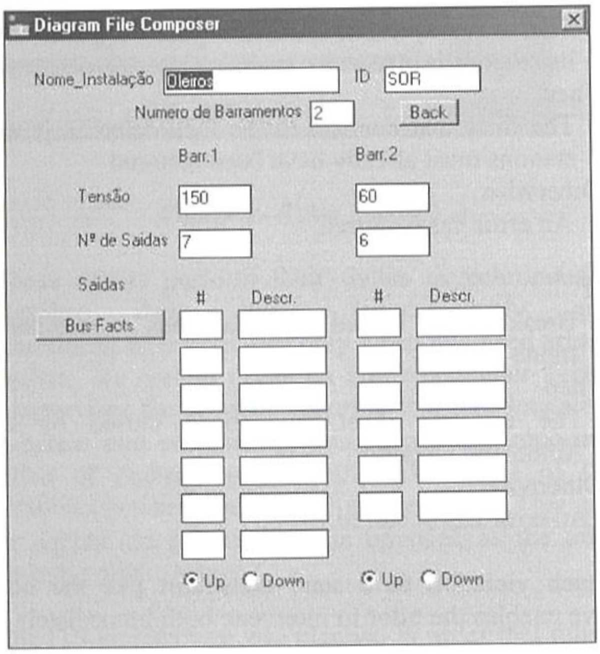

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Figure 5 - Diagram File Composer

We plan to use this approach also for the acquisition of the procedural knowledge needed to guide the simulated power system restoration process. This knowledge is to be used by the tutor module and the concerned agents alike. The expert will basically use the system’s interface to perform the right actions and sequences for the case at hand, and the system will translate his actions into a script. Later, this script can be edited, adjustments can be made and variations introduced, in order to increase the richness of the simulation process.

VI. CONCLUSIONS

In a typical power system, several different entities are usually present, each one taking care of a part of the network. Close cooperation and coordination between the generation, transmission and distribution related entities must be assured, especially when dealing with power system restoration related tasks.

Power system’s operators training programs should take these needs into account, providing an adequate training environment, where the required skills are developed in a realistic manner.

Intelligent Tutoring Systems (ITS) can be a viable and more flexible alternative to electrical network simulator-based training. A multi-agent architecture seems to be a natural way of organising the training tutor.

In the absence of a full-blown simulator, and in order to provide a realistic set-up, light-weight simulation capabilities should be present at the ITS, targeted specifically at the acquisition of power system restoration procedures and techniques.

The system is in its final stages of implementation. As such, it has not yet been evaluated in a real world environment. It is scheduled for a first evaluation phase with a extended group of Electrical Engineering students, prior to the final evaluation with power system network operators.

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