Ontology based Modelling of Operator Training Simulator Scenarios from Human Error Reports

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Abstract: In industrial systems' simulated environments the assimilation of technical procedures by the operators under training is enhanced by reproducing similar to real situations experienced in the workplace. The experience and learning acquired in simulators is directly related to the quality and realism of the proposed training scenarios. On the other hand, the experience acquired is even more conducive to good working practices when it involves situations known to lead into errors. Often training scenarios are dependent on the tutor's experience and the knowledge of operator difficulties in the work environment. This paper proposes a systematic approach for building training scenarios to be simulated, based on the analysis and reproduction of situations described in the working environment error reports. This approach is based on the instantiation of ontologies built for both domains, covering the knowledge on both the error situations and operator training scenarios. This study is focused in the domain of electric power systems operation.

1 INTRODUCTION

The experience and learning acquired with simulators is directly related to the quality and realism of the proposed training scenarios. Different authors have demonstrated the potential of using ontologies to support the development of simulators and for modelling training scenarios for different domains (Parisi et. al., 2007; Long, 2010; Rocha et. al., 2013; Gorecky et. al., 2014). On the other hand, contrasting with the cited work, this paper proposes a systematic approach for building training scenarios for electrical power system operators in simulating environments from error scenarios.

Simulator based industrial training programs demand the description of a variety of training scenarios, adequate to different operator profiles and experience levels, and which cover from simple routine tasks to complex and rare situations. The diversity of scenarios expands when considering the skills and limitations of the operators involved, as well as the peculiarities of different installations such as it happens in electrical power systems working environment, the focus of this research. This application domain poses challenges due to the widespread variety of training requirements resulting from changes in the system, such as expansions and modernization of the plants (power grid node), and also due to a mandatory annual operator training program aiming the recycling of knowledge and skills.

In an electricity grid, one of the network system components is the substation, in which operators act in order to ensure the normal system behaviour by: (i) detecting changes in its configuration; (ii) correcting deviations by following operational procedures. All those actions must be performed within strict deadlines. During contingency situations, subsequent to locating the fault, operators must report to levels hierarchically above and act in a coordinated approach to problem solving. In this context, there is often information overload, and time pressures which combined with task complexity favour the human error. Strict regulations demand that system faults as well as human error should be reported to regulating boards in order to support the investigation of likely causes. To reduce the error incidence, periodical certifications and training is mandatory in this industry. Like in many other safety critical activities, the training proceedings are supported by simulators enabling the assimilation of operating procedures without interacting and thus interfering with the real system.

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Typically, a multidisciplinary team of professionals is required to elaborate a simulator training scenario. Another requirement is an infrastructure for sharing knowledge and information between the team members. This multidisciplinary approach often poses challenges.

In order to represent the working environment in a simulator it is necessary to model all the plant's equipment behaviour and to provide their initial statuses. Further to this it is also necessary to program the sequence of events, which must occur during simulation (e.g. triggering an alarm); and to prescribe the tasks that must be performed by the operator under training. Therefore, the effort in creating a training scenario is a function of the number of objects, events and tasks to be represented in the simulating environment.

In order to minimize the effort required for the development of simulated training scenarios, and considering that training scenarios must represent real situations, the authors consider that human error reports are important source of information which can help to mitigate the error. Creating training scenario from error reports imply in replicating the system configuration and resources employed to perform the tasks during the error event, bringing more realism into the training.

In addition, to facilitating scenario creation, scenario development based on ontology provides a common language among stakeholders favouring information sharing and reuse.

This paper proposes an approach to developing training scenarios based on reports of human error scenarios, during electric systems' operation. It aims to simplify the scenario building process as well as to bring more realism into training scenarios to prevent the occurrence of similar errors.

2 RELATED WORK

The ontological approach to industrial plants' modeling and process simulation is a reality in different contexts.

Many authors have demonstrated the application of ontologies for the Modeling and Simulation field - M and S, which allows the definition of a conceptual model of explicitly and unambiguously and can be processed by machines (Tolk et al, 2010), (Lee and Zeigler, 2010) and (Ören, 2012). Some of these systems using an ontological approach to the modeling of industrial plants and process simulation are briefly described below.

Long (2010) conducted a study on applying simulation for emergency situations such as disaster management and environment evacuation. He concludes that ontology is adequate for a formal representation of a disaster and that the correct description of the disaster area is at the basis of developing supporting tools and planning of training, allowing for exploratory analysis in emergency scenarios.

The Simantic platform, presented by Luukkainen and Karhela (2008), for example, allows a user to represent a plant or process from a 3D component library available in the tool. Parisi et. al. (2007) also proposes a methodology for automatic generation of 3D animations aimed at training and recycling of industrial systems operators. On the other hand, these works result in simulations which are not interactive, but restricted to animation and demonstration procedures. That is, the trainees do not interact with the simulated environment.

Both these works result in animation and demonstration procedures. There is no interaction between operators under training and the simulated system.

Rock et. al. (2013) propose a supporting architecture for modeling simulations for training firefighters. However, unlike the current work this architecture does not rely on the reuse of components and does not aim the design of training scenarios for simulators already developed. Whereas Gorecky et al. (2014) demonstrate the practical use of ontologies in the development of a simulator developed for training operators on the assembly processes in the automotive industry.

Although the cited works make use of ontological approaches to support simulation, none of them deal with training operators for the electrical sector. Moreover, these do not link error scenarios with training scenarios.

Industrial systems are considered critical, when subjected to material failure or human errors, may cause incidents and accidents which in turn can lead to: (i) total or partial system loss; or (ii) losses of lives; or (iii) financial losses (Knight 2002). On the other hand, the analysis of accidents and incidents is essential to the study and prevention of the human error. It allows identifying strategies to prevent the error such as: adapting the human interface; improving training programs or better adapting the task to the work environment. Contextual factors such as the work environment; personal traits such as the operator profile, status and behavior, These factors must integrate the knowledge acquired from the analysis of the potential causes for errors.

Li and Wieringa (2000) conducted a study to identify the elements that might affect operators' perception of supervisory systems complexity. From their study resulted that the perceived complexity was related to: (i) objective factors such as the complexity of the task; the process; the control system and its user interface; (ii) personal factors that include training; previous experience and knowledge; creativity and personality; and (iii) subjective complexity as perceived by the individual.

In the domain of nuclear plants, Xiang, Xuhong and Bingquan (2008) identified operator internal and external factors relevant to the occurrence of the human error. As internal factors the work identified: incomplete or inadequate knowledge; lack of attention; low level of commitment; anxiety; high workload; and excessive self-confidence. As external factors, these were identified: organizational management; human-machine interfaces; procedures and communication.

The study presented by Rothblum (et al 2002) in the domain of maritime accidents, identified as determinants for the human error: fatigue; inadequate communication; inadequate knowledge (technical, the task domain and information); faulty automation design; non-compliance with standards; policies and practices; inappropriate judgment of the situation, maintenance failures and natural causes.

In contrast, this work turns to another domain that of training electrical power systems operators and presents the research that sought to identify elements that are part of two domains: error scenario and training scenario. The purpose being the reuse of components when building a training scenario, thus reducing conception effort, and attaining the goal of training operators in situations which lead to the human error and prevent the error from recurring.

The reuse of concepts described in an ontology related to an error scenario reduces effort in the development of training scenarios and minimize the possibility of the occurrence of similar human errors.

3 METODOLOGY

Accident reports analysis is adopted by several authors in the error study such as ((Rasmussen et al 1981; Van Eekhout and Rouse 1981; Johnson and Rouse 1982) *apud* Scherer, 2010; Bove and Anderson 2000). These reports usually present in details the technical aspects of the system; adopted practices and operations; and also describe the state of the system before and after the error.

The analysis of a set of human error reports is at the basis of understanding the error occurrence, and can support the specification of training scenarios. These scenarios must be consistent with the situations described in the reports, adopting similar condition to those found when the error occurred. The analysis process consists on extracting a set of relevant information about the error in order to define training scenarios.

This study was based on the analysis of accident reports caused by human errors during the operation of electrical power system. The study was performed with the support from Companhia Hidro Elétrica do São Francisco (CHESF), a state owed electric power company in Brazil, engaged in generation and transmission of electricity. The error study was performed in two points in time. The first, conducted by Guerrero et. al (2004; 2008) proposed a methodological procedure to build a model of human error based accident scenarios. The study also produced a typology of accidents caused by the human error. The typology was obtained from the knowledge extraction from a corpus of accident reports and incidents. This work builds upon the those results on human error study in electrical power systems (knowledge extraction, error prevention strategies and error taxonomy). It begun by expanding the error report analysis at CHESF, including a set of 42 accident reports caused by human error, which led to system shutdown) between 2008 and 2013. The analysis of this new corpus of study and the subsequent of knowledge extraction, allowed for the specification of a set of training scenarios.

The method employed during knowledge acquisition was the Incident Scenario Conceptual Model (MCCA) proposed by (Guerrero, 2004; 2008). This method consists of six major steps, namely: (i) *Definition of Corpus:* proposal of analysis criteria, sorting reports according to the proposed criteria and applying filters to define the corpus for analysis; (ii) *Analysis and Classification of Errors:* analysing cases of accidents in order to categorize the errors according to the classification found in the literature; (iii) *Knowledge Extraction*: extracting from each accident described in the corpus, the elements that are relevant to the representation of the accident scenario; (iv) *Analysis and knowledge abstraction*: building a domain ontology from the terminology employed in the scenario description and classification; (v) *Ontology Validation:* verifying, with the operator support, the correctness and appropriateness of the terms represented in the ontology; verifying completeness and sufficiency of the model elements to represent other accident scenarios; and, (vi) Building *the Scenarios typology*: identifying; describing and representing the main accident scenarios types that occur in the domain.

During this research, in order to support the analysis and classification of the human error reports, using MCCA, it was adopted the Rasmussen (1981) model. This model considers all phases of the cognitive process followed by the operator, since system's observation, to the action performed to change the system state, when the error becomes noticeable. The model also classifies the impact of the error, in terms of its consequences and time for recovery, and helps to identify the possible causes for the error. The causes can be assigned to external factors, such as lack of training or internal factors such as fatigue or inattention. Multiple causes can be assigned to the same error.

The knowledge was extracted from the corpus of study and represented as Ontology, and the process followed the steps proposed in the KOD method of knowledge extraction (Vogel, 1988). The knowledge extraction process was based on linguistic engineering, which is adequate for the extraction of knowledge from textual material represented in natural language. It was employed a bottom-up approach, allowing the MCCA model to be built gradually. In the MCCA model building, the designer is guided from the extraction of knowledge phase into the computational model building. In addition to formalizing knowledge, there is a graphical representation of the model using ontology building tools. The ontologies created are described in Section 4.

For the purposes of validation, a case study was performed during which a human error report from the industry was used as the basis for the instantiation of a training scenario, supported by the created ontology, as shown in Section 5.

4 ERROR AND TRAINING SCENARIO ONTOLOGIES

During this research, the ontologies developed were conceived for the domain of electric power plant automated system operation, aiming to support scenario building for training simulators.

The resulting ontological model can be used to support scenario modelling and building for a variety of applications within this domain, such as programming simulators, conceiving training programs, developing management tools; supporting operator performance evaluation during training; amongst others. The ontological model facilitates the interoperability and compatibility between applications, independently of specific implementations.

A set of eight ontologies was built to represent this domain: *Training, Resources, Scenario, Training Scenario, Error_Scenario, 3D_Model, Plant* and *HMI*. Each of these ontologies is a subset of the domain in which they were integrated, as illustrated in Figure 1.

The concepts in the ontologies: *3D_Model*; *Plant* and *HMI*, were incorporated into the ontology *Scenario_Training*. Furthermore, some concepts of the ontology *Scenario_Training* were incorporated into the ontology *Training* (Torres and Vieira, 2014).

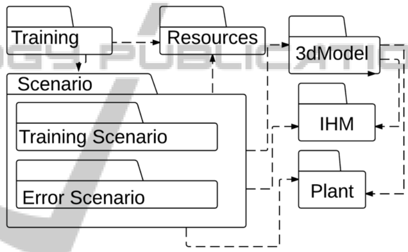

Figure 1: Ontological representation for the semantic description of the operator training domain.

The representation of the domain by these ontologies is detailed in (Torres Filho and Vieira, 2014). This representation supports the process of developing training scenarios for electric power system substation operators, to be run in simulators. This scenario building process is based on the generation of software artefacts from a knowledge base as illustrated in Figure 2.

The ontologies *Training_Scenario* and *Error_Scenario* extend the *Scenario* ontology to accommodate, respectively, concepts common to a training situation and to a human error situation in electric power plant operations.

During this research, the knowledge representation model building phase led into identifying common elements between an error scenario and a training scenario, thus allowing the reuse of error scenario elements in the composition of one or more training scenarios. This strategy has proved advantageous since the training objective is to prevent the reoccurrence of previously reported human errors and thus reducing the effort when modelling the training scenario.

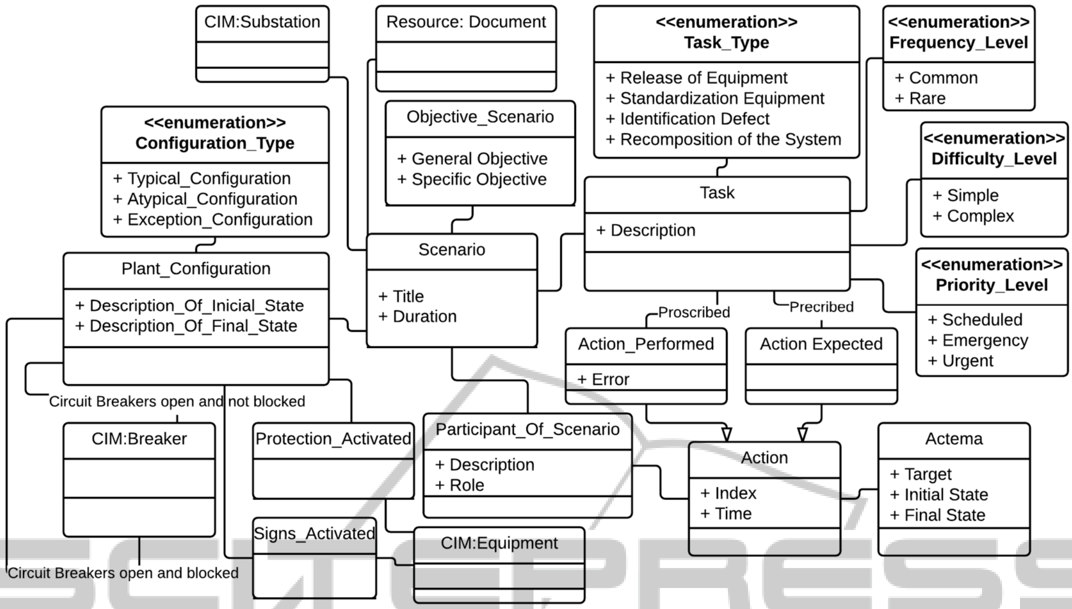

Figure 2: Scenario Ontology.

The ontologies were developed in the OWL-DL language, with the support of the Protégé editor.

4.1 Scenario Ontology

The scenario ontology consists of concepts that describe more general aspects of a training scenario which are also required when representing a human error scenario during system operation. More specific concepts of the training scenario are defined in the ontology Training Scenario, whereas specific concepts of error scenario are defined in the ontology Error scenario. Both ontologies: Error Scenario and Training Scenario are subclasses of the ontology Scenario. Figure 3 illustrates part of the Scenario ontology.

A scenario has the description attributes shown in Table 1. According to this descriptor structure, a scenario is composed of: a general description and the plant configuration status. The general description encompasses data such as: scenario identification (title, reference installation and scenario description); objectives; tasks description; supporting documents, scenario duration and participants' roles.

The scenario description consists of a title, the reference substation and the description of the initial and final statuses of the electricity plant. The objectives can be general and specific.

The prescribed scenario specifies the set of actions and the sequence, which must be followed by the operator in order to achieve the intended level of performance. This information is based on the company's formal operational procedures.

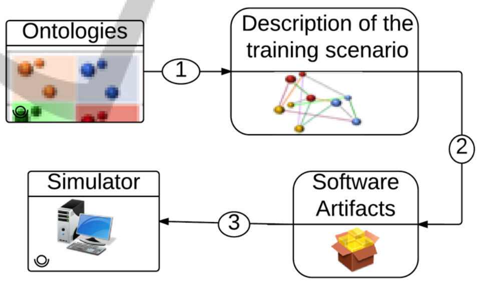

Figure 3: Ontological approach to building scenarios for training simulators.

The postscript corresponds to the list of actions actually performed by the operator during training or reported as an error. In the case of training, a *logfile* with a historical content is usually recorded by the simulator software, and can be used to evaluate the operator's performance during the training.

An action is represented by the tuple <action index, actor, actem, time_stamp>; where an actem is represented by the following set of attributes <Equipment, initial state, final state>. The concept of an actem was adopted from the method KOD (Vogel, 1988), which was adopted for knowledge extraction in previous work in order to describe error scenarios. The actems employed in the scenario action description were extracted by Guerrero et. al. (2008), from a set of error reports registered by the electricity company.

The electricity plant configuration is described as: a list of triggered protection devices; signalling issued; circuit breakers and their respective statuses (open, closed, blocked or unblocked); and the plant identification which has an associated ontology with complementary information. In the case of representing scenarios for a 3D simulator, each of these components references a 3D model in the 3D simulator. This consists on an ontology-driven process to support scenario representation in a 3D operator training simulator, as described in (Torres Filho and Vieira, 2014).

Table 1: Scenario Descriptor.

<table>
<tr><td rowspan="22">Scenario</td><td colspan="2">Scenario title</td></tr>
<tr><td colspan="2">Reference installation</td></tr>
<tr><td rowspan="2">Scenario description</td><td>Plant’s initial state</td></tr>
<tr><td>Plant’s final state</td></tr>
<tr><td rowspan="2">Objective</td><td>General objective</td></tr>
<tr><td>Specific objectives</td></tr>
<tr><td rowspan="7">Task</td><td>Task description</td></tr>
<tr><td>Task type</td></tr>
<tr><td>Level of difficulty</td></tr>
<tr><td>Urgency of action</td></tr>
<tr><td>Problem frequency</td></tr>
<tr><td>Prescribed</td></tr>
<tr><td>Proscribed</td></tr>
<tr><td colspan="2">Supporting Documents</td></tr>
<tr><td colspan="2">Scenario duration</td></tr>
<tr><td colspan="2">Participants’ roles (operator, engineer, ...)</td></tr>
<tr><td rowspan="6">Plant Configuration</td><td>Relative configuration</td></tr>
<tr><td>Configuration type</td></tr>
<tr><td>Circuit Breakers open and not blocked.</td></tr>
<tr><td>Circuit Breakers open and blocked.</td></tr>
<tr><td>Activated protections</td></tr>
<tr><td>Activated signs</td></tr>
</table>

4.2 Error Scenario Ontology

The Error Scenario ontology was conceived to describe accident scenarios caused by human error during the operation of automated electric power systems. The terms and relationships present in this ontology were extracted from the corpus of study, previously mentioned.

In the class diagram, illustrated in Figure 4, it is shown part of this ontology’s concepts and relationships.

As previously mentioned, the model proposed by Rasmussen for human error categorization was adopted as the basis for this ontology, represented in Figure 4. It follows a brief explanation of the error categories and subcategories proposed in this model.

- *Observation of the system state*: excessive; falsely interpreted; incorrect; incomplete; inappropriate; absent; unnecessary; correct...
- *Choice of hypothesis*: inconsistent with the observation; consistent but unlike; consistent but too costly; functionally not pertinent, absent; consistent but insufficient, unnecessary; correct;.
- *Evaluation of a hypothesis*: incomplete; acceptance of an incorrect hypothesis; rejection of a correct hypothesis; absent; unnecessary; correct;
- *Definition of objectives*: incomplete, incorrect, superfluous, absent, not necessary, correct;
- *Choice of procedure (task)*: incomplete; incorrect; superfluous; absent; unnecessary; correct;
- *Execution*: omitted action (omission); repeated action (repeat); adding an operation (addition); operating out of sequence (sequence); intervention in inappropriate time; incorrect operation; incomplete task; unrelated or inappropriate action; correct action on the wrong object; incorrect action on the correct object; unintentional execution;
- *Recovery*: very late; late; immediate;
- *Consequences:* no load interruption; load interruption; equipment overload; equipment loss or damage; personal injury;
- *Causes:* inattention (overconfidence; negligence; simplicity of task); stress (time; urgency; workload); personal problems; inexperience; incompetence; distracters (phone; people, etc.); lack of concentration; haste; confusion; pressure; anxiety; improvisation; overconfidence; lack of skills; fatigue.

An error can be classified in multiple categories, due to cascading effects. For example, an inadequate observation of the system state can lead the operator into choosing a hypothesis consistent with the observation, but insufficient to solve the problem.

All those classes are related in the model. Another consideration is that more than one classification may be assigned to the same category. For example, an error may be the result of anxiety associated with fatigue and poor training.

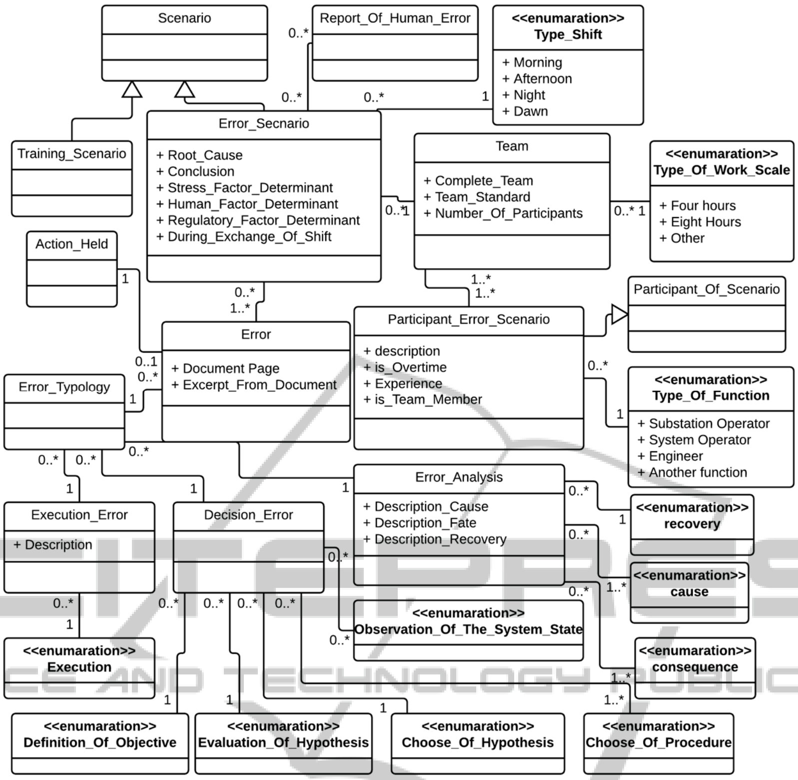

Figure 4: Error Scenario Ontology.

4.3 Training Scenario Ontology

The attributes and relationships of the training scenario class are inherited from the Scenario class (Table 1), except for prerequisites and scheduled events. The prerequisites specify the necessary conditions to run the training scenario. And the scheduled events are occurrences in the electrical power system, specified to occur during simulation. For instance: opening or closing of a circuit breaker; blocking device; and load changes.

Different simulators run specific sets of scheduled events. In general, these events have attributes such as defined in Table 2.

The trigger type determines whether the scheduled event is temporal or conditional, as follows:

- *Timed Trigger* - events must occur on the specified time:
  - *Trigger with absolute time* - the time set for the event trigger is relative to the simulator clock.
  - *Trigger with relative time* - the time set for the event trigger is relative to the time of the simulation start. For instance, an event can be triggered to occur within five minutes from the start of the simulation or at a specific time such as 16h45min.

Table 2: Elements of a scheduled event.

Scheduled Event	**Node:** Identification of the substation where the event should occur;
	Device or equipment targeted for action: Identification of device or equipment associated to the event;
	Trigger Type: Trigger type identification associated with the scheduled event;
	Value: Attribute which carries the value magnitude

- *Conditional Trigger* - An event is triggered when the condition becomes true. The event may occur just once, or whenever the condition becomes true. The conditional trigger can be set by: measurements in the plant; values; results of logical operations (AND, OR, NOT, XOR, NAND, NOR) or comparisons (greater than; less than; equal to; different) or mathematical operations (addition, subtraction, multiplication, division)

5 REAL TRAINING SCENARIO

A case study was developed to build a training scenario from an error scenario, for a substation belonging to the company CHESF (2015). This scenario was developed to be used in a real training activity. The objective of this case study was to validate both the Error Scenario Ontology and Training Scenario Ontology, from the points of view: correctness and appropriateness of the terms adopted and the completeness of the model elements.

The human error scenario description found in the report follows.

The event consisted of a partial shutdown of the substation as a result of the emergency over_current protection action applied to the transmission line LT 04F5; resulting in over_current voltage-restrain on the 69 kV side of transformers: 04T1, 04T2, 04T3, 04T4 and switch 86 for 04T3 transformer. Before the partial shutdown, the substation was on its typical configuration, with all 230 kV circuit breakers closed (except 14D1) and all 69 kV circuit breakers closed (except 12D1).

On the other hand, after the event occurred, the configuration of the substation was described in the report as being the following: circuit breaks 14T3 e 12T3 were open and blocked ; circuit breaks 14T3 and 12T3 were also opened and blocked; circuit breakers 12H4, 12J3, 12T1, 12T2, 12T4 and 12T5 were open but not blocked; and all circuit breakers of 230 kV were opened and not blocked except for 14T3 and 14F5. The report concluded that the line protection LT 02J4 FTZ / DMG failed after the fall of a cable.

The plant operator was expected to perform the following task sequence:

- Report the incident to the operation centre;
- Perform an inspection in the substation plant;
- Prepare the substation for re-energizing;
- Reenergize the substation;
- Inform the operation centre.

The substation re-energizing task, after a partial shutdown, is classed as complex; performed in emergency and rare. In addition, the power companies provide operating standards for cases of total shutdown of the substation, setting the exact sequence of actions that must be performed by the operator. On the other hand, in a partial shutdown, the operator uses the same operating standard as a reference, but should only perform a subset of actions required in this particular case.

From diagnosis contained in the error report, the operator did not correctly identify the substation configuration after the event, misinterpreting the correct sequence of actions to apply. In preparation for re-energizing the substation, the operator performed an improper action opening of the 14F4 breaker. Thus, the transmission line LT 04F4 and the bus 04B1 were de-energized. The action of the operator would be valid only in a situation of general shutdown of the substation which was not the case..
According to the error model, this error was characterized as follows:

- Runtime error: adding an extra action;
- Error during the decision process: acceptance of a wrong hypothesis and choice of wrong proceeding;
- Causes: Confusion, Inability, Lack of information and Non-compliance with operational standards;
- Recovery time: late
- Consequences: load interruption.

The error scenario described was instantiated in the knowledge base using Protégé (2015). Based on the scenario instance, a training scenario was built. The entire error scenario descriptor (Table 1) was reused as the training scenario description. In addition, the prerequisites and scheduled events were also reused. Figure 5 illustrates the developing process of the artefacts to represent training scenario for the simulator used by CHESF - Simulop.

Simulop is a 2D operator training simulator, built from the integration of the electric power system supervisory and control software - SAGE with a real time Operator Training System (OTS) developed and distributed by EPRI (2014). Simulop is the simulator widely used by electricity and utility companies in Brazil, for operator training and certifying purposes (Silva et. al., 1998).

As a result of the case study two artefacts were generated from the knowledge base: a script file for the training scenario in a format which can be interpreted by the simulator and a document file with the scenario descriptor.

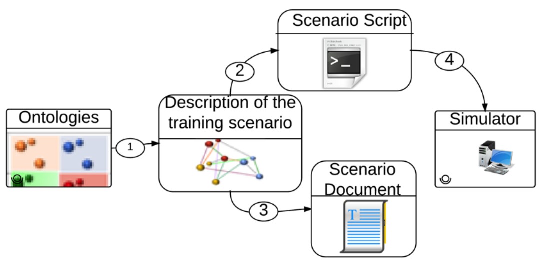

Figure 5: Process flow for building training scenarios for Simulop.

The descriptor follows the CHESF company template where the planned scenario is detailed. It covers the following information, which is organized in sections:

- Objectives
  - General objective
  - Specific Objectives
- Installation Configuration
- Event description
- Event duration
- Circuit Breakers (Open and Blocked)
- Circuit Breakers (Open and Unlocked)
- Signalling
- Main protection triggered
- Preparation Script
- Execution script

The scenario descriptor is generated in the .docx format, using the iText API (2015), and the scenario description stored in the knowledge base is accessed using the Jena API (2015).

The scenario script is a text file in ASCII format used to configure the system before a scenario simulation. This file caries the definitions of: event groups; events and instances of the plant variables' values.

A group with two events was implemented to simulate the scenario described above, consisting of a conditional event and a temporal event.

The timed event was planned to be triggered three seconds after the start of the simulation, causing the opening and blocking of the circuit breakers mentioned in the human error report; therefore simulating the reported fault which caused the error.

The conditional event was programmed to be triggered only if the circuit breaker 12J4 is closed during simulation and if there is a voltage level on the bus 02BP above zero. This triggering condition is illustrated in Figure 6. Therefore, the conditional event is only triggered when the condition shown in Figure 6 is satisfied.

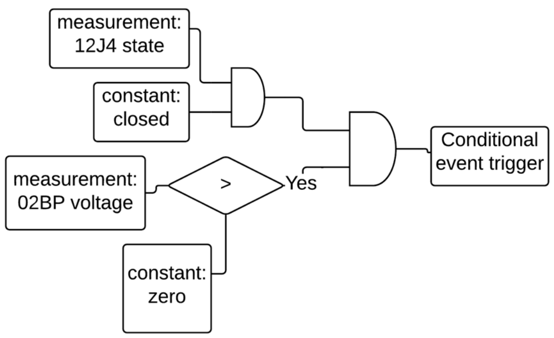

Figure 6: Trigger for a conditional event.

This training scenario was incorporated into a database containing training scenarios and made available to the tutors in charge of elaborating scenarios for the company simulator.

From the case study it was possible to verify the correspondence between the concepts represented in the human errors scenarios and the training scenarios in the ontologies. Moreover, the effort to prepare the training scenario was comparatively much lower than without the ontology support and the knowledge base on human errors made available. Therefore it can be said that the adopted approach was successful from its application in the preparation of a real training scenario for the industry.

6 CONCLUSIONS AND FUTURE WORK

During the process of knowledge extraction it was identified common elements between training scenarios and accident scenarios caused by human error. Thus, when describing an error scenario based on the proposed strategy, the knowledge information becomes reusable and available for the composition of training scenarios, thereby reducing the efforts during scenario construction - one of the main objectives of this work. Moreover, training operators in error situations occurring reduces the possibility of its recurrence.

From the instructional point of view, this is an advantageous strategy because the objective is to prevent the recurrence of errors and decreases the effort of tutors in conceiving the training scenario. During the design phase, the teams in charge of training programs resort to their personal experience as well as in their personal knowledge of the incident and accident history in the company, as a source of inspiration. Training operators in human error situations aims to prevent error recurring. As it was discussed in this paper, the proposed approach for creating scenarios is supported on the fact that key knowledge elements are part of the two domains: error scenario and training scenario. Thus, elements used to describe error scenarios can be reused to compose a training scenario, reducing building efforts.

This ontology based approach to knowledge representation simplified the integration of knowledge from different sources, such as error reports, task scripts and simulator scenarios. It also enabled the reuse of scenario components and the automatic generation of scenarios for simulators. From the human-error reports analysis and using a typology of errors associated to the electric power system operation, the error scenarios were grouped according to: causes; consequences; frequency; task (difficulty; priority); devices and other relevant attributes. This classification allowed selecting the error scenarios more relevant to be used as a basis for training.

As future work it is proposed to develop tools to support the editing of training scenarios extracted from the error scenarios. And as further step, to develop tools to support the automatic generation of training scenarios from the analysis of error reports.

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