A Virtual Instructor for Simulator Training

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Abstract**—There is a growing need for power system operators to use Operator Training Simulators (OTS). NERC requires that each power system operator practice 32 hours of Emergency Operations training using realistic simulations each year. The draft NERC PER 005 standard is supporting a Systematic Approach to Training (SAT) where training is directed at identifying and closing the gap between required knowledge and skills and the measured knowledge and skills of individual operators. Simulators are also valuable for this level of performance measurement.**

This paper addresses how a Virtual Instructor can be used to automate the steps that a human normally performs in setting up, briefing, monitoring and evaluating simulator scenarios. The Virtual Instructor has been implemented within the Emergency Operations with PowerSimulator (EOPS) product and the applications with this product are summarized. The Virtual Instructor has been built based on the principles of tacit to explicit knowledge transformation and the Recognition Primed Decision Model. The paper reviews these principles and how they are applied.

I. Introduction

Prior to the black out of 2003, only a small fraction of power system operators had ever trained with operator training simulators of any type.

For many years, EMS engineers had been forcefully making the argument that only full scale replica EMS simulators were worthwhile and kept telling the trainers and operators to wait until they could build them a perfect system. However, the development and maintenance costs of full scale replica simulators are high. Most require a full time instructor, a full time engineer and a dedicated training week for the operators. Costs for each hour of Replica EMS simulator training can exceed $500.

The overall situation changed completely with the blackout of August 14th 2003. Following the blackout, NERC Emergency Operations Recommendation No. 6 required that: “All reliability coordinators, control areas, and transmission operators shall provide at least five days per year of training and drills in emergencies, *using realistic simulations*, for each staff person with responsibility for the real-time operation or reliability monitoring of the bulk electric system. This system emergency training is in addition to other training requirements.”

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A. Generic Simulators

The NERC recommendation supported applications of Generic Simulators and they were widely adopted by RTOs, Transmission Operators of all sizes, as well as training vendors. The majority of operators have now had experience with a Generic operator training simulator at least by observing an instructor performing demonstrations and more and more are getting direct hands on experience.

Generic Simulators are provided with a built in Control Center interface and a built in sample power system model. The product will typically be supported by a training supplier with built in lessons, scenarios and exercises. Almost all the leading NERC certified training suppliers use some form of a Generic Simulator as a basis for class room training.

A Generic Simulator is the basis of the Emergency Operations with PowerSimulator (EOPS) Product. EOPS has been developed to address the needs of system operators that desire the convenience of a 24 by 7 online training environment. It includes nine courses that cover needs of Reliability Coordinators, Transmission Operators and Balancing Authority Operators for NERC Continuing Education Hour (CEH) and emergency operations training

B. Custom Simulators

In the Custom Simulators, a specific model of the customer’s power system is built including models of the substation breaker, switch and bus configurations, models of the transmission system lines and transformers and relays, models of the generators and prime movers and models of the loads. With Custom Simulators, the full customer’s model often with several thousand buses and several hundred station one line displays can be set up. The customer’s SCADA and AGC functions are emulated, rather than replicated with the Custom Simulator software. The Custom Simulator SCADA one-line displays can have the same symbols, conventions and layout as the real displays. Models can be built by importing using CIM XML or PSSE standard formats. The Custom Simulator configuration is now being widely used by Transmission

Operators and Reliability Coordinators for NERC mandated local and regional restoration drills.

C. Replica EMS Simulators

In the Replica EMS Simulator, a copy of the customer's existing Energy Management or SCADA System is connected to the simulator. There is one important difference in the configuration. The real-time analog and status points are produced by Power System Model instead of the Remote Terminal Units in the substations. The operator trains on a copy of the consoles and programs that he uses to control the real system. The operators play the roles that are supported by the actual EMS; typically Reliability Coordinator, Transmission Operator or Balancing Authority Operator. One or more instructors will act out the roles of power plant operators, substation operators and neighboring utility operators.

D. Personal and Team Drills

The Generic Simulator and Custom Simulator support both personal and team drills. In the personal drills, operators have the ability to implement the control actions of all the various power system operators, power plant operators and substation operators. The goal of personal drills is to train the operator in a broad range of operating issues. Operators develop a broad understanding of related electrical and mechanical principles and the roles of the all the players. And through imagining the role-play they gain insights into the coordination and communications problems that each type of operator encounters.

For team drills the Generic and Custom Simulators, are very flexible in the assignment of roles. Any operator at any console can play the role of any entity for any area of the system. The roles can include transmission operator, balancing authority area operator, reliability coordinator, generator operator, distribution operator and substation operator.

The Generic and Custom Simulators scale well to support drills that involve operators from multiple organizations and multiple NERC entities. They can support large classroom environments with as many as 200 attendees and up to forty logged on users. Phones, radios or runners can be used to support conversations between operators at different locations.

E. WEB and BRICK Versions

The Generic and Custom simulators can be implemented on WEB server or on a portable Linux server known as a BRICK. The WEB server is accessed over the public internet with a web browser. Operators in different locations can work on a common scenario. The WEB server runs 24 by 7 from a secure location.

The BRICK is an acronym for Bulk Reliability in a Compact Kit. The BRICK is accessed by a wireless network and supports training in a single classroom The BRICK provides an extra level of response and performance especially when there are many logged on users. The BRICK is ideal for use in hotels and conference centers where the internet access may be slow and unpredictable.

II. Tacit and Explicit Knowledge

The distinction between tacit and explicit knowledge [1] is very helpful to build a Virtual Instructor. Explicit knowledge is formal and systematic. It can be easily communicated and shared, for example as operating procedures, disturbance reports, databases or a computer program. Tacit knowledge is highly personal. It is hard to formalize and difficult to communicate to others. Tacit knowledge is deeply rooted in one's own lived action, life experience, and an operator's commitment to participate in his/her profession and craft.

"We know more than we can tell" applies to tacit knowledge. Imagine that you have five days to write down all that you know about your favorite craft or sport. The document that you produced would be explicit knowledge. Assume your friend, who is not experienced in your favorite craft or sport, has five days to practice using only your document. Would they become very good at your favorite craft or sport? The document you produced would only capture a very small part of your tacit knowledge.

Tacit to tacit knowledge transfer is the basis for on the job training. An operator in training works side by side with an experienced operator and learns his tacit skills through a long process of observation, imitation and practice. On its own, socialization or tribal learning is a rather limited form of knowledge creation. The apprentice learns the master's skills. But neither the apprentice nor the master gain any systematic insight into their craft knowledge. Because their knowledge never becomes explicit, it cannot easily be leveraged by the organization as a whole.

Explicit to explicit knowledge transfer occurs when an individual combines discrete pieces of explicit knowledge into a new whole. For example all the key papers on a subject may be compiled into a book. It also occurs when a manual is used to develop a procedure; e.g. an operator applies well documented switching principles to develop a specific switching order.

The development of explicit knowledge from tacit knowledge is often one of the more difficult transformations and it has a very high payoff. With a simulator the process becomes very systematic.

The simulator provides a catalyst and context for expert operators to express their tacit knowledge. Frequently when an experienced operator is using the simulator they will check if it can simulate some past condition that they have experienced. These experiences may have been accumulated over an entire career. Scenarios have been collected from interviewing and observing system operators, reading operating reports of past disturbances and incidents and experimentation using the simulator.

When an expert operator is presented with a challenging operating condition on the simulator; he uses his tacit knowledge and experience to develop a specific set of operating actions. Actions of the master operator and how he responds to solve various problems can be recorded. The operating principles that the master operator applied can be documented and explained.

Explicit to tacit knowledge transfer occurs as operators perform the simulator exercises and develop their skills in power system operation. Explicit knowledge is assimilated by the operators and they begin to internalize it.

They use it to broaden, extend and reframe their own tacit knowledge. This is done only after a new "truth map" has been created. Most adults will test the new knowledge against formerly held knowledge and assimilate it into tacit knowledge only after gaining trust in the new experience. This places a high premium on the fidelity of the simulator experience. They adapt the procedures and principles that they have learned and observed under one set of operating conditions on the simulator and apply them to other operating conditions in their own system. These operators eventually come to take it for granted as part of the background of tools and skills needed to do their jobs.

In summary, simulators can be used to build a Spiral of knowledge. Step 1 involves articulation by the expert - converting tacit knowledge to explicit knowledge. Step 2 involves internalization by the apprentice - using that explicit knowledge to extend the apprentice's own tacit knowledge base. Both require the active commitment of the individual. The master has to stretch and grow to communicate more of what he knows. The apprentice has to stretch and grow to apply the explicit knowledge and extend his own operating skills.

III. Recognition Primed Decision Model

The Recognition Primed Decision (RPD) Model [2] has been successfully applied to training mission critical teams in a number of industries including crews of air-line pilots and teams of nuclear plant operators. Following the August 14th 2003 blackout the RPD was introduced to the power industry in a series of seminars by Doug Harrington. The RPD has been very valuable for planning, development and implementation of the Virtual Instructor.

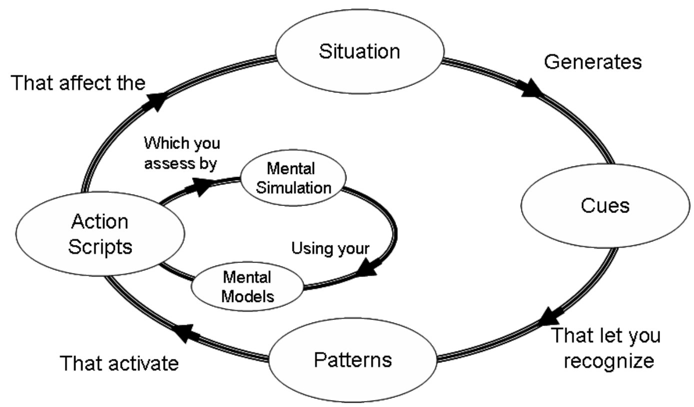

Figure 1: Recognition Primed Decision Model

A. Situation

The situation or state of the system will vary based upon a number of factors including, time of day, current and forecasted system load and weather conditions for local and interconnected areas, current and forecasted generation and transmission maintenance outages for local and interconnected areas, current and forecasted interchange levels and flow patterns. The situation or state of the system is presented to the system operator from a variety of sources including: measurements from the SCADA system and data links, communications with plant operators, substation operators, line crews, distribution operators, neighboring control area operators, reports on results of on-line analysis programs, results from operation planning studies and operation planning engineers.

B. Cues

The Cues describe the operator's level of awareness regarding the current situation. The Cues are analogous to a sphere of understanding. A more experienced operator will have a larger sphere of understanding. He or she will be more sensitive to and will have a greater appreciation for various explicit and sometimes subtle inputs. Cues for the system operator are generated from system summary displays, alarm logs, abnormal summaries, charts, map boards, system overview displays. Even in a medium sized Transmission Operator there are thousands of variables to potentially look at. The saying "Too much data and not enough information" is often used to describe the current situation. The more experienced operators can extract and focus on the key variables that summarize the overall situation. Examples include; MVAr reserves in an area, transfers and voltage stability affecting the P-V margin, generation levels & response rates affecting sustained ramping capacity, spinning reserves and ACE.

C. Patterns

Using the cues to recognize key patterns is a critical step in the decision making process. Only by recognizing the correct patterns can the operator determine the appropriate actions.

Some examples of the patterns that can be recognized from the various cues include the following, the system is vulnerable to a single line contingency, line or transformer overloads are about to cause cascading thermal outages, the voltages in an area are very weak, a neighboring system is experiencing voltage problems and is drawing excessive MVARs from our system, the system is on the verge of voltage collapse, a unit in our own control area has tripped and the generation reserves are insufficient to comply with the NERC CPS2 criteria.

The more experienced operators will be able to recognize a wider range of patterns and will more quickly detect when a new pattern has emerged.

D. Action Scripts

Action scripts are stored in our memory based upon past experience and proven responses. The more experienced operators will have a wider range of action scripts.

Based upon the different patterns that we recognize our mind selects one or more actions scripts for us to put into action.

Corrective actions can consist of, generator rescheduling, adjusting control area interchanges, adjusting phase shifters, line switching, changing transformer taps, switching shunt capacitors or reactors

The NERC policy states that these corrective actions should be implemented as quickly as possible without regard to the economic cost.

If there are lines or transformers that are exceeding their Short Term Emergency Ratings or buses that are exceeding their voltage limits, the System Operator has the authority, responsibility and obligation to implement the necessary remedial actions, including shedding load, to alleviate these overloads and violations.

E. Mental Models

As the operator decides which corrective actions to implement they should test them out using various mental models to anticipate their impact on the system.

The experienced operator can usually estimate the directional trends that will occur for various control actions. For example; adding capacitance will increase local bus voltages, a line will be unloaded by decreasing generation at the sending end and increasing generation at the receiving end. However, estimating the quantitative effects of control actions when the system is an unusual operating condition can be very difficult.

In a modern Energy Management System, State Estimator, Contingency Analysis, and Dispatcher Power Flow programs can be run quickly to get results especially during system emergencies.

If these programs are not available, less experienced operators know the art of how to control the system a little at a time, monitor the changes and then decide on a more definitive action. More experienced operators may be able to anticipate results and take more or less aggressive action based on the system conditions and previously proven and accepted operating techniques.

IV. EOPS

Emergency Operations with PowerSimulator (EOPS) is a nine course on-line curriculum that addresses the Continuing Education, Emergency Operation and Simulation training needs of Reliability Coordinators, Transmission Operators and Balancing Authority Operators.

Transmission I includes three courses:
SCP – Simulator and Communication Protocols (4)
RSO – Reliable Switching Operations (5)
MMF – Managing MW Flows (11)

Transmission II includes three courses:
PVC – Preventing Voltage Collapse (9)
SS – System Shutdown (4)
SR – System Response (5)

Balancing, Interchange and Generation includes three courses:
EGM – Electric Generation Management (5)
EBAL – Energy Balancing (4)
EINT – Energy Interchange (3)

The number of modules in each course is shown in parentheses. Each module was originally designed to last one hour. Following the benchmarking with actual operators, the CEH time for the courses was somewhat increased. Each module includes an Online Tutorial and a Test that covers principles of power system operation. It also has a series of PowerSimulator exercises where the operator practices his/her operating skills on the 29 station Power and Light Company (PALCO) System. The system is large enough to demonstrate a wide range of power system operating phenomena and small enough to build familiarity within the first course. In the early modules of a course the operator is implementing basic operating procedures which we refer to as “driving with directions”. In the later modules the operator is given more challenging tasks; e.g. take corrective actions following multiple contingencies, develop a black start plan and restore the system. We refer to these scenarios as ‘flying on a mission”. Operators have to score better than 75% on the Module Test, the Module Exercises and an End of Course Test to pass. Once they pass, they are awarded their NERC CEH certificate.

The entire training process from the initial operator orientation to award of the CEH certificates is largely automated. The utility operations manager can review the operator's scores on-line and ensure that they have completed their courses.

In the EOPS program the operator works alone on-line in a personal training mode. In the simulator scenarios the operator plays the role of transmission operator, balancing authority area operator, substation operator, generator operator and reliability coordinator.

For team training and development of communication and leadership skills, operators can attend a complementary Strategic Team Awareness and Response (STAR) class. In this class the operators play designated roles and operate the same Generic PowerSimulator with the PALCO system.

V. Instructor Roles

The Systematic Approach to Training (SAT) has been used by the military for many years and it may soon be mandated by NERC Standard PER 005 for Training Power System Operators [3]. The SAT requires the following steps:

1. Analysis
2. Design
3. Development
4. Implementation
5. Evaluation

Implementation and Evaluation are steps most suited for application of a Virtual Instructor. These are the steps that are repeated over and over for each operator. Automation of the instructor's duties in these tasks and can lead to the greatest savings in instructor's time and, even more importantly, acceleration of operator learning.

The instructional style that is most appropriate for a given training session will vary depending on the objective the instructor is trying to meet [4]. Accordingly, the instructor may take on any of the following roles.

A. Virtual Demonstrator

The Virtual Demonstrator uses the OTS to demonstrate how the power system works or how to perform a particular task [4]. A Virtual Demonstrator has been built into the On-Line Tutorial segment of EOPS. Screen shots were taken during a series of simulations that were run in the Development phase. During the Implementation these screen shots are played to the operator along with a narration of what is happening. The Virtual Demonstrator is an effective method for capturing lessons from past operating disturbances and operating incidents. The "Line Re-energization with Breaker and Half Bay" module re-lives and dramatizes an incident in which a safety clearance was violated when a rookie operator mistakenly closed the middle breaker of a breaker and half scheme feeding two parallel lines. The "Unit Motoring with Stuck Breaker" module re-lives and dramatizes an incident in which a unit was motoring and the plant operator directed the substation operator to open a disconnect switch under load. In the "WECC July 2nd Disturbance" module the operator watches the WECC system break up into five islands as the events are replayed in real-time.

B. Virtual Director

The Virtual Director guides the operator in how to perform a task or respond to an event [4]. The operator operates the OTS under the direction of the Virtual Director.

A Virtual Director has been implemented with the On-Line Exercise segment of EOPS. The operator is given directions to operate the PALCO system. The operator is required to implement an operating order and record certain variables. We call these the "driving with directions" exercises.

In the first Simulator and Communication Protocols course, the Virtual Director directs the operator on how to monitor the electrical state of the system using the simulator System Map, Station one-line displays, event logs, AGC summaries and tabular displays. These can be then be used within all the successive courses by the operator to monitor cues such as line and transformer overloads, voltage violations, load patterns, generation and load imbalances.

A very basic exercise at this level is to "Read MVA loading on the Grange to Homer line". A slightly more advanced exercise is to "Calculate the MVAR losses on the Grange to Homer line". A more advanced exercise would be to "Apply the Make before Break rule to transfer the Homer to Grange line from Bus 1 to Bus 2". The operator has to figure out which breakers to open and the correct sequence.

In the terms of the Bloom taxonomy of learning [5] the EOPS driving with directions exercises address the skills of identify, recognize, distinguish, explain, discriminate, comprehend, analyze, apply and extrapolate.

C. Virtual Coach

As Virtual Coach, the instructor allows the operator to determine the course of events but intervenes to provide additional explanation or guidance as needed [4].

Both the roles of Virtual Demonstrator and Virtual Director involve one-way communication from instructor to operator with the instructor taking the lead. The role of Virtual Coach, however, requires the instructor to take cues from the operator and provide advice as needed to support the operator's actions and decisions. Thus, there is two-way interaction between the instructor and the operator, but the instructor retains the dominant role.

A Virtual Coach has been implemented at a very basic level. The operator is requested to monitor and enter certain measurements. If the recorded measurements are beyond a range, the operator is given feedback. This often indicates that the operator has misinterpreted an operating instruction.

The development of a more advanced Virtual Coach is a promising area for research and development. For example, it could run contingency analysis to determine System Operating Limit (SOL) and Interconnected Reliability Operating Limit (IROL) violations and use speech synthesis to give verbal feedback to the operator on how he/she was performing. “Have you considered the impact of Line XY tripping”? Do you have sufficient MVAR reserves in the southwest area?

Human trainers are still way ahead of the computer in terms of their effectiveness in the area of coaching.

D. Virtual Facilitator

The Virtual Facilitator sets up an OTS exercise or scenario and operates the OTS but allows the operator to complete the exercise or respond to the event with minimal intervention. The Virtual Facilitator designs a context for learning and provides feedback after the fact, but the primary learning takes place through direct interaction between the simulator and the operator [4].

In EOPS a Virtual Facilitator has been used to conduct the most advanced level of exercises. We call these “Flying on a Mission” exercises. In the pre-briefing, the Virtual Facilitator presents the external factors such as weather conditions, location of line crews, planned outages using a combination of narration and text.

As an example, the operator is charged with the mission of “Operate the PALCO system within secure limits and avoid cascading outages and a blackout as an approaching storm passes through the northeast area”. Over a period of twenty minutes, multiple lines will trip in the northeast section of the PALCO system. The inverse time over current relays are activated to simulate lines sagging and tripping under thermal overload. The operator must take a combination of preventative actions before each contingency and remedial actions following each contingency to prevent a system blackout.

The operator is evaluated based on the number of contingencies that he can handle without suffering a blackout. In the terms of the Bloom taxonomy the EOPS Flying on Mission exercises address the most advanced skills of, synthesize, strategize, predict and prevent.

E. Virtual Challenger

The Virtual Challenger interacts with the operator primarily to stimulate more thought-provoking interaction with the simulator. The challenge may be provided either in the way the exercise or scenario is formulated or in the way in which it is implemented [4].

At the basic level the activation of the relays during scenarios that involve multiple events does make the scenario a lot more challenging. But more research and development is definitely needed to improve the computer’s ability to act as a Challenger.

A virtual challenger could monitor progress of the operator and then inject additional disturbances and malfunctions as the scenario progresses. A Contingency Analysis program could determine which contingencies could have low, medium or high impact on the system and activate the appropriate ones depending on the dialed in level of difficulty.

An Optimal Power Flow program would determine a solution that satisfied SOL and IROL constraints. The virtual challenger would challenge the operator from time to time to develop a solution that also satisfied SOLs and IROLs and performed as well as the Optimal Power Flow.

From the trainer’s viewpoint, the simulation environment is a lot more defined, controlled and constrained compared to the real time environment. It should be possible to develop a virtual challenger which can respond in real-time with the same degree of effectiveness as a human challenger.

VI. CONCLUSIONS

This paper has introduced the concept and defined the functions of Virtual Instructor for simulator training. A Virtual Instructor has been implemented and tested as an embedded part of the EOPS product. The product has been used to date to train over five hundred operators with more than fifty companies.

The Virtual Instructor has been built by observing experienced power system instructors in how they set up scenarios, pre-brief operators, monitor operator performance and de-brief operators after the scenario.

The principles of tacit to explicit knowledge transfer, the Recognition Primed Decision Model and the EPRI OTS Instructor Roles are proving to be very useful in the planning, design, implementation and evolution of the Virtual Instructor.

Of all the instructor roles, the Virtual Coach and Virtual Challenger are the ones that require more research and development. This research work could also lead to improved tools such as audible warning systems and heads up displays for improved monitoring and control of real-time systems.

VII. REFERENCES

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VIII. BIOGRAPHIES

Robin Podmore (M'73, F'96) was born in Palmerston North, New Zealand on July 20, 1947. He received the Bachelors and Ph.D. degrees in Electrical Engineering from University of Canterbury, N.Z in 1968 and 1973. In 1973 he worked as a Post-doctoral fellow at University of Saskatchewan, Saskatoon Canada. From 1974 to 1978 he managed the Power Systems Research group at Systems Control, Palo Alto, CA. From 1979 to July 1990 he was director and Vice President of Business Development with ESCA Corporation (now Areva), Bellevue WA. In July 1990 he founded and is President of Incremental Systems Corporation. He has been an industry leader and champion for open energy management systems, the Common Information Model and affordable and usable Operator Training Simulators. He is a licensed Professional Engineer in the state of California.

Marck Robinson was born in Richland, Washington on September 27, 1963. He received a Bachelors of Science degree in Computer Science from Washington State University, May 1986. He was a senior software engineer at ESCA Corporation (now Areva) in Bellevue, WA from 1987 to 1990. In 1990 he founded Applied Software Technologies. In 1995 he founded and is President of PowerData Corporation. He is the developer of the PowerData real-time relational database and the inventor of Abstract Object Modeling, an innovative method for integrating real-time applications and software architect for PowerSimulator including the WEB server and BRICK versions.

Mathew Sadinsky was born in New York, NY on November 14th, 1957. He received the Bachelors of Science degree in Industrial and Labor Relations at Cornell University in 1979. He completed Masters work in clinical psychology at the University of Texas. From 1979 to 2001 he worked as Chief Human Resource Officer for major divisions of Continental Can, PERGO Flooring, Magellan Laboratories Alcatel and Vivendi-Universal. From 2001 to 2002 he was Chief Human Resource Officer for GridSouth. In 2002 he founded and is CEO of SOS International.

Rocky Sease was born in North Carolina on May 29, 1956. He received the Bachelors of Science degree in Agricultural Engineering from Clemson University in 1978. From 1996 to 2001 he served as Manager of System Control for South Carolina Electric and Gas Company. From 2001 to 2002, he was Director of System Operations for GridSouth. In 2002, he founded and is President and Chief Operating Officer of SOS International. He has served on the Southeastern Electric Reliability Council (SERC) Systems Operators Subcommittee as Chairman, the SERC Board of Directors, the Virginia-Carolinas Electric Reliability Council (VACAR) Executive Committee, and the VACAR Operating Task Force. He is a licensed Professional Engineer in the state of South Carolina.