Training Session Evaluation - A System Level Perspective Using a Dispatcher Training Simulator

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Abstract - Modern power systems are becoming increasingly complex to operate. The training departments need more tools to help them in the process of training the operators. In addition, they also need more help in evaluating the training session. This creates an iterative process, whereby the instructors can evaluate the feedback and modify the training program appropriately to cover any holes identified, or identify the weaknesses of each trainee and help them perform better.

The Dispatcher Training Simulator (DTS) has already been recognized throughout the industry as one of the best tools to perform operator training. The authors have recognized that the actual philosophy of operator training will vary from utility to utility and will always be subjective in nature. However one common factor in most training programs is the need to collect objective data which can be used to analyze trainee/training effectiveness and present this information in the form of a report.

In this paper, the authors are presenting a design and the results of a prototype implementation which will go a long way towards helping the instructor gather relevant data to evaluate the behavior of a power system during a training session. The training philosophy of a particular utility (Virginia Power) has been presented and the tool has been set up for it. The utilization of standard tools and methodologies in the design of this tool help in the ease of integration and usefulness of its outputs.

1. Introduction

Power system operator training has become more of a necessity than ever before with today's electric power utilities. There are many factors which have contributed to this situation.

- **New controls**: Today's power systems and their controls are increasing in complexity. The newer control centers include features (such as Volt/VAR dispatch) that were not available a few years ago. As a result, operators now are expected to do much more than their counterparts were doing a few years ago.
- **Economics**: There is a much greater emphasis on economics. The generation operators are being asked to monitor costs closely and consider various options between generating the power themselves or buying power in order to meet the load demand.
- **Energy brokering**: The closer watch on costs is even more important because of the difficulty utilities are having with getting rate increases. If the utility is to be a profit center, operators need to find more ways to decrease the operating costs by wheeling and dealing in power.
- **Security of the changing system**: Many utilities are finding that their generation and transmission facilities are not keeping pace with their increases in load. This creates new problems for the system operator, especially as more power is being wheeled. The power system is being strained in ways that were unforeseen a few years ago. Utilities are operating closer to their steady-state and dynamic security limits.
- **Safety concerns**: It is imperative that operators receive clear training in areas where their actions can affect the safety of field personnel, such as switching sequences and isolating equipment for maintenance.
- **Regulatory changes**: Regulatory agencies such as NERC, and local PUCs have set up power system operating guidelines which should be followed for proper system operations. It is imperative that the operator understand what is required for compliance with these rules.

These factors have complicated the operator's primary job of operating the system reliably and economically. An operator's performance is generally evaluated by how well he/she runs the power system. However, the following questions probe more fully into the specifics of an operator's performance, and should be considered when evaluating an operator:

- Are problems recognized and is proper corrective action taken in a timely manner?
- Are opportunities recognized and taken advantage of?
- Are the correct people contacted?
- Are available tools used correctly and efficiently?
- Are communications clear and direct with the various people contacted (field, division operations, and other support personnel?)

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- Are new tools needed to enable the operator to perform more effectively?

There are other considerations as well, but these tend to be more utility specific and vary among utilities.

1.1 Objectives of This Paper

The authors have the following objectives for writing this paper:

- Trainee evaluation is a touchy matter and could convert the whole process of operator training from a cooperative mode to an adversarial one. The concept of scenario evaluation is a broader yet equally valid one, moving the focus from the evaluation of the trainee to the evaluation of the power system's behavior during the training period.
- Present a generic process and set of guidelines to help in the evaluation of training scenarios. The host utility (Virginia Power Corporation) was chosen due to its varied nature of its training program.
- Present a platform where modern tools can be used to provide the right type of feedback using the proper evaluating guidelines. For instance the whole process of scenario evaluation is subjective in nature. Hence, a report of some type which will detail the set of activities and their consequences that occurred during the training session will be of more use than a pure grade.
- Present some results which were obtained by implementing a simple study using the Virginia Power DTS, and also provide some simple trainee evaluations based on those results.

This paper will define a set of criteria which can be used to comparatively judge an operator's performance under controlled conditions. The paper will also provide the basis for tools that can be used to track this performance over the course of a study period (simulation period, class, and others)

2. Operator Training - A System Level Perspective

Before going into any great details of operator training, it is important for every utility (or its training center) to answer some preliminary questions:

- What is the operator's job in the control center?
- How well does he/she perform the job, and what specific things tell us about his/her performance?
- How can we show these things in an objective manner and help the trainee to overcome any deficiencies?
- How is the job responsibility changing in the short and long term?

The evaluation of the system operator is best done with the use of the DTS for everything from the very basic task such as using the man-machine interface (MMI), to the complex task of performing system restoration.

2.1. Training Philosophy at Virginia Power

Virginia Power is a large utility whose training department covers a wide range of operating conditions in their training program. Operators are trained in all activities ranging from normal operating procedures (operating economics, network security, switching operations and others), to emergency procedures (restoration, analysis of disturbance data in the EMS, and others).

Several key policies are essential to the System Operator Training Program at Virginia Power [1-5]. These policies are:

Training Responsibility: Each System Operator is responsible for successfully completing the training modules and on-the-job training (OJT)/qualification requirements. Each System Operator must work closely with the Shift Supervisor and the training staff to establish a training program schedule. The System Operator is then responsible for completing that program through available classroom instruction, self-study, Dispatcher Training Simulator (DTS) time, OJT, and other assigned training activities. The System Operator's training progress is measured by passing a training module test, qualifications check-off, and by evaluations done during the time spent on the Dispatcher Training Simulator. This responsibility requires each System Operator to be motivated to complete the training requirements.

Each Shift Supervisor is responsible for the training of all members of that shift. The Shift Supervisor works with the training staff to establish the training support needed for that shift as a whole and for the individuals on that shift.

Performance-based Training: The Training Program focuses on training which is specific to the System Operator's job performance requirements. As part of the training design an analysis of the System Operator job tasks and training needs was conducted. The training modules in the program have been carefully designed to address the skills and knowledge the System Operator needs. An on-going review and modification of each module is done to keep the training program current. Any training that is irrelevant to the job should be avoided.

Multi-media approach: The training program uses a multi-media training approach to improve interest and increase learning retention. This includes self-study, classroom, field visits, videotapes, OJT, and simulator sessions.

2.2. Training Program at Virginia Power

The training program at Virginia Power is divided into five major phases:

- **Orientation Phase**:
    - Orientation to system operation center
    - Introduction to power system operation
    - Overview of the basic principles of operating a power system
    - Overview of all generation stations and the transmission system

- **Basic Training Phase**:
  - Overview of the system operation center: This includes the hardware, software, communications, and the user interface
- **Power System Control Principles Phase**:
  - AC power applications
  - Electrical workers safety practices
  - Power system facilities
  - Power system control principles: Generation
    - generation control
    - Energy interchange
    - Hydro and pumped storage operation
    - Non-utility generation
    - Energy resource planning
  - Power system control principles: Transmission
    - MW flow controls and limits
    - Voltage controls and limits
    - Switching and clearance procedures
- **Normal Operations Phase**:
  - Normal operations: generation
  - Normal operations: transmission
    - Security analysis and outage planning
    - Switching operations
    - Transmission system monitoring and control
- **Off-normal and Emergency Operations Phase**:
  - Transmission contingencies
  - Generation contingencies
  - Extreme minimum and peak loads
  - System dynamics
  - Load curtailment and system restoration

2.3. Future Directions of Training Both at Virginia Power and Nationwide.

With the ever increasing complexity of the Power System, the System Operators need more advanced training in the areas of Power Flow, Voltage and VAR Control, Contingency Analysis and Network Analysis. In the past, these were not part of real-time control systems. As systems are updated and these advanced applications are included in new Energy Management Systems, training became much more important. This is where a DTS stands out over other forms of training.

System Operators can receive training which can then be applied to the Simulated Power System. The effects of what they have learned become much more apparent with this type of hands on activity. This also allows them the means to try new approaches to problem areas of the Power System and find the best way to deal with them. The DTS is the best tool for giving the System Operator confidence and experience in the use of new tools to better manage the Power System.

3. Operator Training Using a DTS

3.1. Dispatcher Training Simulator

The DTS [6] simulates the electrical network, the behavior of the power system, and the user interface of the control center. It provides a realistic environment for operators to practice operating tasks under normal, emergency and restorative conditions. See Figure 3.1 for an overview of the DTS.

Although the DTS is used primarily for operator training, it may also be used for operator evaluations, engineering studies, power system model evaluation, and off-line testing of energy management system functions and operating procedures [7,8]. All of these uses could be enhanced by having criteria for evaluating the behavior of the power system, and tracking mechanisms for reporting on this behavior.

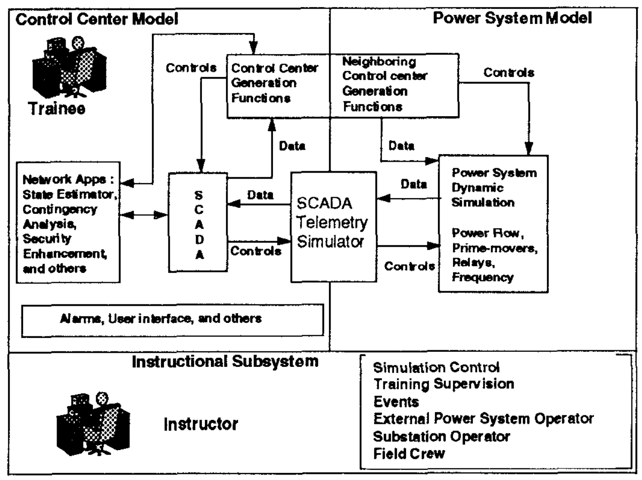

Figure 3.1: DTS a Brief Overview

3.2. Scenario Evaluation Criteria

The behavior of the power system can be broken down into the areas of economics, security, and regulatory compliance. These criteria can be expanded as follows:

Economics

Generation dispatch:	Generators dispatched economically Generators committed economically
Energy transactions:	Buying/selling of capacity/energy

Security

Reserves:	Maintain proper generation reserves
Frequency:	Maintain proper frequency
Voltage Control:	Maintain voltages within limits Capacitor/reactor bank switching
Transmission Line:	loading, outages, (scheduled/ unscheduled)

- Transformers: Loading, outages, (scheduled/ unscheduled)

Regulatory compliance:

- ACE: Area Control Error
- NERC: Violations

3.3. Criteria Measurement

The DTS, which includes a replica of the control center, allows the capture of all relevant data to measure the compliance of the above criteria. The criteria elements can be divided into two distinct types: continuous data and discrete events. The continuous data will be captured by sampling at pre-defined rates. The discrete events will be captured as they happen.

Continuous data:

Generation dispatch:

Monitor control and advisory economic dispatch.

Monitor a units MW (for comparison to the advisory economic dispatch.)

Energy Transactions:

Monitor scheduled and actual interchange.

Reserves:

Monitor calculated reserve margins.

Frequency:

Monitor a specific frequency measurement.

Transmission line loading:

Monitor a specific line's loading.

Transformer loading:

Monitor a specific transformer's loading.

ACE:

Monitor ACE.

The continuous data can be displayed graphically versus simulations time for easy comparisons. Relevant discrete events could be shown on these graphs for a more complete view of the topic in question.

Discrete Events

Generation dispatch:

Log the times the units are on/off dispatch.
Log the times the units are on/off control.

Energy transaction:

Log transactions as they are made by the operator.

Voltage Control:

Log voltage limit violations

Log capacitor/reactor bank switching.

NERC violations

Log NERC violations.

Additionally, all alarms and operator actions are logged. These can be separated into like topics for easier review, such as all alarms for a specific substation, or all operator switching actions.

4. A Preliminary Design and Implementation of a Scenario Evaluation Tool

Background: When a training session is in progress, a variety of activities are happening in parallel.

- The instructor is controlling the simulator.
- The instructor is controlling the power system simulation. This is done by events (prepared before or during simulation) and by various other tools that the instructor has under his/her control.
- The instructor is coordinating with the trainee(s) as a field crew member, neighboring control center operator, or any one of the several other roles that he/she must play during a training session. If more than one trainee is being trained then this becomes an even more difficult task.

The point of the above list is to emphasize the fact that when the training session is in progress the instructor is a very busy person. Typically the instructor is forced to keep notes (using pencil and a paper) of any quick observations that he/she can make during training. Once the training session is completed the instructor and trainee go over those notes, the event scenario and the various logs maintained by the DTS and try to analyze the trainee's actions. This can be difficult in large and complex power systems.

Objectives: The main objective of this design is to provide a semi-automatic means for the instructor to monitor and evaluate the behavior of the power system during the training session. The instructor can set up the system to collect the appropriate data/events in a separate buffer ahead of time. This will allow the instructor to easily review the system events and the operator responses to those events. Other concerns were that the implementation have a flexible user interface, is easy to use, adds negligible load on the machine running the simulation, and is inexpensive.

Design: The authors chose the following design:

- A client-server architecture with the simulator running on the server and the monitoring system running as a client on an IBM-compatible PC.
- DECnet (an OSI protocol) as the connecting agency between the client and the server.
- Dynamic Data Exchange (DDE): Take advantage of the capabilities of DDE to provide links into an assortment of PC tools such as spreadsheets (Microsoft Excel, Lotus 1-2-3 and others), databases (Microsoft Access, Paradox and

others). Basically any DDE compliant client can be set up.

One other important facet of this design is to get the data out of the DTS and into popular third-party packages which accommodate the data gathering/storing and reporting needs. Using these third-party packages allow the users to select their own package which will facilitate the process of reviewing the data and allow customized reports to be created easily and at a low cost.

Implementation: Figure 4.1 provides the architectural overview of the implemented system. The application set used on the PC were Microsoft Access, Microsoft Excel, and Microsoft Word.

The data captured from the DTS has the following variety:

- Continuously changing data which can be sampled at different rates.
- Discrete data that is sampled upon change.
- Simulator time.

Prior to the start of the training session, the instructor defines the values to be sampled as well as the sample rate, and also any discrete events to be captured. This provides the instructor the flexibility to vary the data captured across different training sessions, an important feature since the goals of each training session may be different.

Any value available in any of the DTS databases may be chosen for tracking during the training session. Some examples are provided below:

- A specific generator's MW and MVAR output.
- Line loading for a specific line
- Breaker status for a specific circuit breaker
- MW output for all generators.
- NERC violations

As a part of the implementation and testing process, the authors have set up a default set of data to be captured. The identified data that has been marked for capture has been set up in such a way that the instructor does not have to redefine everything for each training session. The pre-identified data includes:

- System load
- System generation
- Area control error for the EMS operating area.
- Actual and scheduled interchange
- Regulating, spinning, and operating reserve margins
- Control and advisory lambdas

The above-defined values are being collected at a 2 minute scan rate and stored in an Excel spreadsheet. In addition, all alarms issued by the system due to various operator actions during the training session are recorded. All operator actions are logged for each console in the DTS and they can be brought over after the training session is completed.

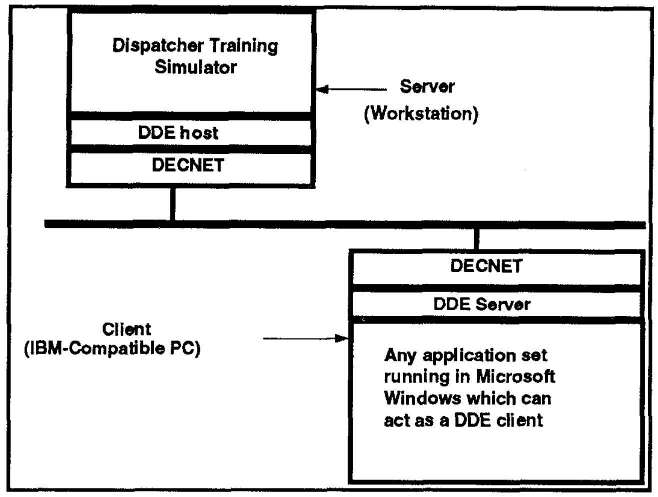

Figure 4.1: Architectural Overview of the Implemented System

There is a potential to gather and store a huge amount of data over the course of a training session. This could make it somewhat difficult to get a clear picture of what is important or even relevant to the training session. However, if the instructor is using a familiar PC tool, he/she can take advantage of the various reporting capabilities provided and display the data in a more visual manner rather than just numerically. The instructor can also view the data in a variety of ways to get many different views of the system and operator performance; improving the analysis of the training session and allowing for better feedback to the trainee.

5. Test Results

5.1. Test System

The test was performed on the Virginia Power system model, which consisted of the following:

- 3500 buses
- 542 generating units
- 5000 analogs, and 9000 status points
- 4800 transmission lines

The DTS was installed on a VAX 4000-90. The client was installed on an IBM compatible PC.

5.2. Test Scenario

The test scenario set up is a weekday morning. The scenario starts at 8:00 in the morning and goes for about 4 hours. An unexpected load surge occurs shortly after 9:00 am. This occurs in parallel with the normal weekday morning load pattern. At the beginning of the scenario the total generation is 7109 MW, the total load is 6948 MW, and the total scheduled interchange is 182 MW. This is a generic scenario for the operator to learn about recognition of a generation-load imbalance and check on his/her capability to buy/sell power appropriately.

5.3. Test Results

The data is transferred from the on-line DTS to a spreadsheet (Microsoft Excel). Excel tools were used to create the following data views, which are intended to illustrate a set of data views which can be acquired and formatted (very easily) for inclusion into reports.

In Figure 5.1 note the sudden rise in load shortly after 9:00. This is the main test of the operator during this scenario. Generation rises to follow the shift in load, but there is not enough readily available to keep up.

Figure 5.2 shows how ACE dips significantly with the shift in load, otherwise it holds a fairly even pattern of crossing zero.

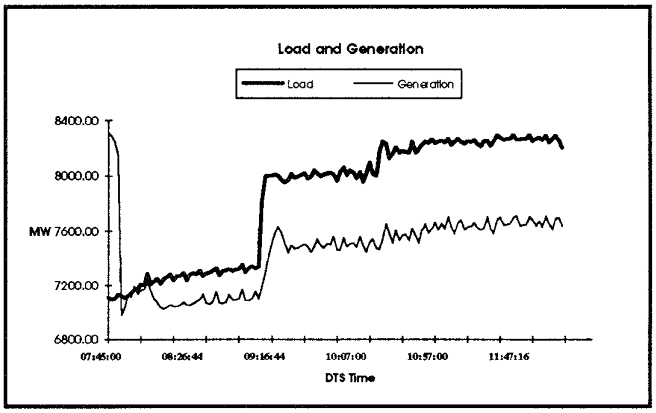

Figure 5.1: Load and Generation

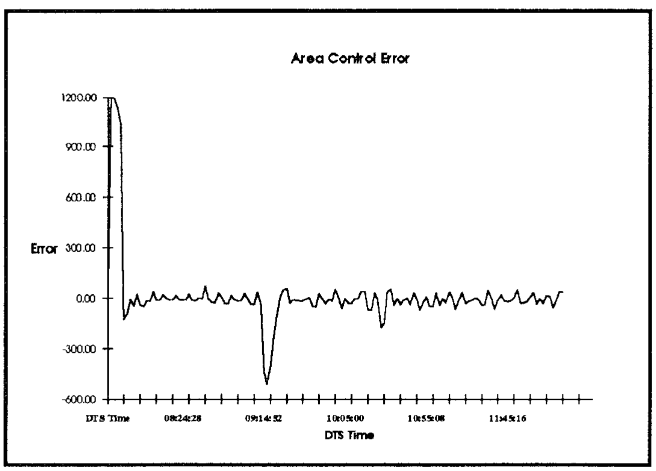

Figure 5.2: Area Control Error

Figure 5.3 shows a large mismatch between actual and scheduled interchange occurs with the shift in load. Note that the operator schedules a transaction to compensate for the load. Further details regarding transaction scheduling are captured in the messages shown in the transaction scheduling log which is shown in the appendix A.

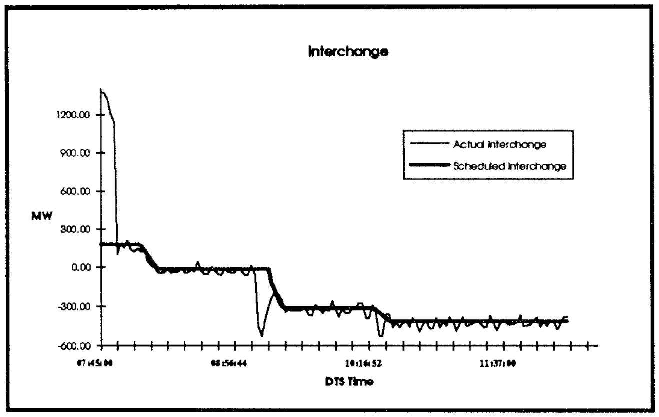

Figure 5.3: Actual and Scheduled Interchange

Figures 5.4 and 5.5 show the system reserve margins.

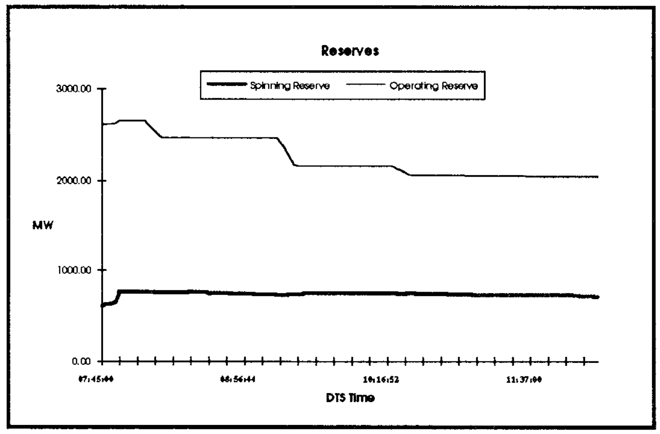

Figure 5.4: Spinning and Operating Reserve

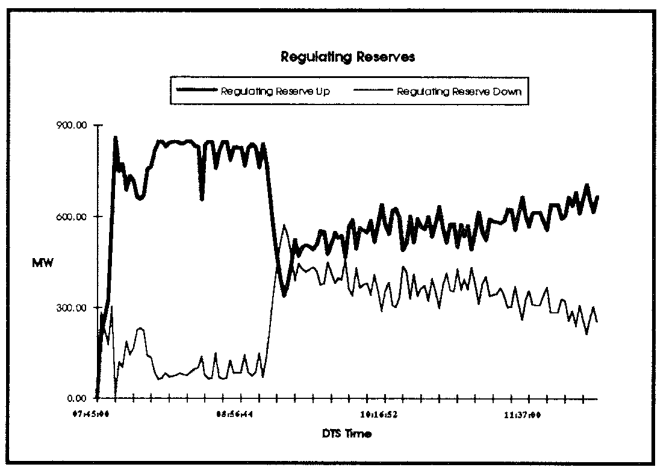

Figure 5.5: Regulating Reserve Margins

Appendix A also shows a section of the alarm log. Note the alarm caused by the sudden drop in the regulating reserve up margin with the shift in load, and the subsequent recovery, as the newly scheduled transaction takes effect.

Figure 5.6 shows the comparison between the advisory and the control lambdas. An economic goal mentioned during training is that the control and advisory economic dispatch lambdas should be kept as close together as possible. From this graph it can be seen that possibly some generation could have been scheduled more effectively towards this end. This conclusion could be supported by comparing several of these graphs from separate runs of this scenario.

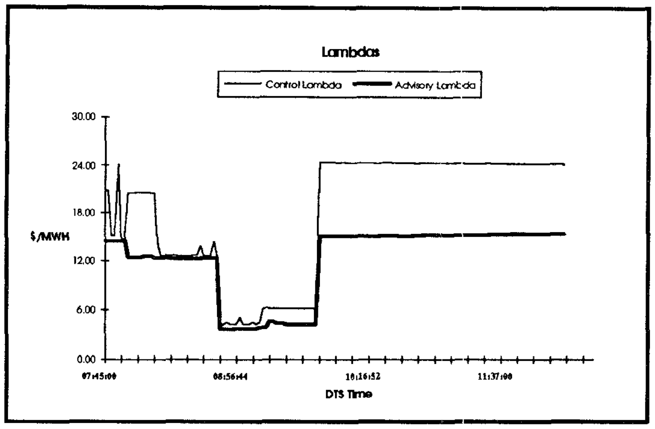

Figure 5.6: Advisory and Control Lambdas

Additionally, each student's actions on the system (and the time they were performed) can be captured and reviewed, possibly showing other areas where the operator needs improvement, is doing well, or even aspects of the system which may be difficult to use.

6. Conclusions and Recommendations for Future Work

6.1 .What did we achieve?

In this paper the authors have achieved the following:

- Presented their understanding of the operator training from a system level perspective and some of the needs.
- Presented a list of criteria for the evaluation of system operators using the DTS as one of the steps in the basic training programs.
- Presented details of the design and implementation methodologies for a particular scenario evaluation tool.
- Presented test results using the developed tool on a real power system model.

This paper presents a framework for using a set of metrics to evaluate both a training session and an operator's performance during the training session.

6.2 Where do we want to be?

The authors are looking into the use of various intelligent methodologies to further enhance the concepts of scenario evaluation. They are:

- When different types of raw data have been collected such as generation data, production costing data, component violations, alarms, scheduling data, and others - it is difficult to connect the cause and effect relationships between the various pieces of data. The strengths of expert systems in the arena of synthesis can be used to aid the evaluation process.
- Since operators typically work in shifts, training departments try to train them in shifts. This serves to foster the team spirit. In this case it is important to be able to diagnose the individual contributions of each member of the team so that their strengths and weaknesses can be identified for improvement. Both fuzzy logic and expert system could be used here.
- When two transmission operators (for example) are being trained in parallel sessions, it might be important to find how they fared relative to each other. This is a little more difficult because the behavior of the power system also depends upon the other members of each team. Fuzzy logic could be used here.

It is important to realize that as we move into the future, the complexity of power system training will definitely increase. Hence more tools which provide the instructor with better evaluation capabilities will definitely be a welcome addition to the instructor's repertoire.

One of the side issues that arose from this work was as follows: Since the set of tools that have been demonstrated in this paper are actually obtaining their information from the control center subsystem of the DTS - ***it is also possible to implement this subsystem in the EMS itself.*** This can be a very powerful tool for the shift supervisor and can become an excellent shift report which can be used for the purposes of automating the documenting process for the activities of each shift.

Acknowledgments: The authors would like to thank Jay Giri and Tom Athay (both of ESCA) for their technical help during the development period of these tools. In addition, thanks are due to Jeff Osborn for helping with the implementation. Lastly, the authors would like to thank Keri Mischke and Lynn Paulson for their help in the editing process. The input of all these people are deeply appreciated.

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Biography

Subramanian V. Vadari received his BSEE in Electrical Engineering from Osmania University, India. He received his MSEE and Ph.D in 1986 and 1991 respectively from the University of Washington at Seattle. Since 1987 he has been with ESCA Corporation, Bellevue, Washington where he is currently leading the development of Dispatcher Training Simulator and source database applications. He is a member of Tau Beta Pi, Eta Kappa Nu, and IEEE. His research interests include power systems control and stability, Dispatcher Training Simulator, expert systems, and artificial neural networks. He can be contacted through E-Mail at VADARI@ESCA.COM.

Darrin J. Lubash received his BSEE and MSEE in Electrical Engineering in 1987 and 1989, respectively, from Iowa State University in Ames, Iowa. Since 1989 he has been with ESCA Corporation of Bellevue, Washington, where he is currently working on Dispatcher Training Simulator applications. His research interests include operator training and economic operation and control of power systems.. He can be contacted through E-Mail at DARRIN@ESCA.COM.

Leroy W. Morris joined Virginia Power in 1969. He has more than 24 years of field and operations experience in the electric utility industry. In the last fourteen years Mr. Morris has worked in the power supply department of Virginia Power, where he has worked as a system operator, operations liason to the EMS project team, and (in the last two years) as a system oeprator training specialist. In his present position, Mr. Morris has direct responsibility for the training and evaluating system operators using the Virginia Power DTS.

Foroud Arsanjani joined Virginia Power after earning his BSEE from the University of Maryland in 1981. His work experience includes data communications, SCADA/EMS, and power system operations. Mr. Arsanjani is presently supervisor of the operating services supervising the coordination of emergency plans, system operator training programs, as well as other engineering and statistical support activities. He is a member of the IDEC's technical and executive subcommittees. He is also a senior member of IEEE power engineering society, as well as several affiliated subcommittees and working groups.

Appendix A

DTS Time	Transaction Log Text
9:16:36	GW292 I:PURCHASE SCHEDULE INSERTED FOR OPA: VPCO, TRA: PJM START/STOP TIME RAMP MW/CAPMW TYPE URATE/BILL/ORATE LEDGER CYCLE 5/2/1994 09:15 10.0 300 STD 4.00 1693 NO 5/2/1994 13:00 10.0 0 4.00 4.00
10:19:16	GW292 I:PURCHASE SCHEDULE INSERTED FOR OPA: VPCO, TRA: APCO START/STOP TIME RAMP MW/CAPMW TYPE URATE/BILL/ORATE LEDGER CYCLE 5/2/1994 10:19 10 300 STD 8.00 1694 NO 5/2/1994 14:00 10.0 0 0.00 0.00

Figure A.1. Section of Transaction Log

DTS Time	Alarm Text
8:45:08	RGTRSK 05/02/94 08:45:08 VPCO ONE OR MORE TRANSACTION SCHEDULES ARE NOT COST EFFECTIVE
9:14:04	RGCED 05/02/94 09:14:04 VPCO - CONTROL ED: RESERVE INSUFFICIENT
9:23:08	RGRETN 05/02/94 09:23:08 VPCO - RESERVE SUFFICIENT
9:45:08	RGRETN 05/02/94 09:45:08 VPCO ALL TRANSACTION SCHEDULES ARE CURRENTLY COST EFFECTIVE

Figure A.2. Section of Alarm Logs