Missouri University of Science and Technology
Scholars' Mine

Electrical and Computer Engineering Faculty Research & Creative Works

Electrical and Computer Engineering

01 Jan 1983

Considerations In Developing And Utilizing Operator Training Simulators

T. E. DyLiacco

M. K. Enns

J. D. Schoeffler

J. J. Quada

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/4962

Follow this and additional works at: https://scholarsmine.mst.edu/ele_comeng_facwork

Part of the Electrical and Computer Engineering Commons

Recommended Citation

T. E. DyLiacco et al., "Considerations In Developing And Utilizing Operator Training Simulators," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS thru 102, no. 11, pp. 3672 - 3679, Institute of Electrical and Electronics Engineers, Jan 1983.
The definitive version is available at https://doi.org/10.1109/TPAS.1983.317731

This Article - Journal is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in Electrical and Computer Engineering Faculty Research & Creative Works by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 11, November 1983

CONSIDERATIONS IN DEVELOPING AND UTILIZING OPERATOR TRAINING SIMULATORS

T. E. DyLiacco, Fellow IEEE
DyLiacco Corp.

M. K. Enns, Fellow IEEE
Electrocon International

J. D. Schoeffler, Fellow IEEE
Cleveland State University

J. J. Quada, Member IEEE
Electrocon International

D. L. Rosa, Member IEEE
C. W. Jurkoshek, Member IEEE
The Cleveland Electric Illuminating Co.

M. D. Anderson, Member IEEE
University of Missouri, Rolla

Abstract - Effective electric system operation depends on strengthening the relationship between the system operator and the electrical system with its associated control system. This relationship can be developed through a training medium which increases the operator's knowledge of the behavior of the power system under various operating conditions and contingencies, and its response to control actions. An Operator Training Simulator (OTS), which simulates the static and dynamic responses of the operator's power system and his control system, can accomplish these training objectives. The concepts developed in this paper are based on the work of the project team through funding by the Electric Power Research Institute.

INTRODUCTION

Today's operating problems are a result of events which occur both internally and externally to the utility's electrical network. The interconnected system, while bringing the advantages of increased system economy and reliability, also brings additional operational risks imposed by outside events. Not only must a bulk power operator be concerned with the security and reliability of his own system, he must also recognize the impact of his neighbor's system security on his operation. Implementation of supervisory control and data acquisition systems in computer based energy control centers has increased the dispatcher's awareness of his electrical system. However, the utilities are recognizing the need for additional training to improve the effectiveness of the operators. While the 1965 blackout gave impetuous to the creation of energy control centers, the 1977 blackout caused the utilities to re-evaluate the needs of the operator and to formalize programs for the improved training of operators. The training required to equip the power system operator with the necessary knowledge of system operation is a multi-faceted program that involves classroom style training, on-the-job training, and training for projected system conditions. The role of Operator Training Simulators has now emerged as a significant part of this training function.

SIMULATOR REQUIREMENTS

The basic problem in training programs is that the operator receives little or no operating experience in the preventive, emergency, and restorative states of operation. Because these operating states are infrequently encountered, the majority of operators are not experienced in dealing with the associated types of operational problems. Since it is infeasible to use the actual power system to create these operating problems, the simulator becomes the most effective means of providing the necessary training opportunities. The primary use of Operator Training Simulators is to accelerate and expand the experience of the operator in the operation of his own system.

This paper was published in the IEEE Conference Record of the 1983 Power Industry Computer Application Conference PICA - 1983.

While the range of requirements which can be specified for an operator training simulator are numerous and complex, the authors have chosen to specify two general requirements:

> The simulator must be realistic in representing the static and dynamic properties of the trainee's power system.
>
> The man-machine interface should be exact in that the same CRT displays, the same consoles, and the same controls are used as in the real system.

These requirements must be satisfied in order to provide the training necessary to adequately prepare the dispatcher for effective and efficient system operation. The simulator must be capable of presenting scenarios for the teaching of the basics of power system operation, to assist the trainee in learning how his system responds to each type of contingency, and why it responds the way it does. The simulator must provide the means of presenting new problems the operator has not seen before, even though it may not be possible to simulate every contingency and combination of contingencies that might occur on the power system. The simulator must be capable of realistic operation to the point of representing communications with people external to the center. This implies the need for an instructor's facility to enable him to work with the trainee, serving as the controller of the scenario and providing after-the-fact evaluation of the training session. Finally, the simulator must present the same power system. If a trainee learns emergency operating procedures on a different or generic system, there are no guarantees that he will even recognize the same problem when it is presented on his own system.

SIMULATOR USAGE

There are several general concepts involved in the training of transmission and power dispatchers which are addressed through a training simulator.

- It allows for the teaching and re-enforcement of training of electrical and mechanical concepts without requiring an understanding of the associated mathematics.
- It enables the teaching of complex system procedures without endangering costly equipment or operating personnel.

Training done on a simulator not only obviates the need for a mathematical background, but ensures that the operator learns to operate his electrical system through his control system. The need for realistic system models allows for experimentation with the electrical network while gradually increasing

0018-9510/83/1100-3672$01.00 © 1983 IEEE

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.

the number and degree of system variations from rudimentary generation control to complicated preventative switching schemes. The simulator will graphically present its results through the normal man-machine interface, thus enhancing the training experience and lending a significant degree of credibility to the training session.

Through effective training and feedback of results, a significant increase in the expertise of dispatchers for economic operation can be realized. This increased ability can result in financial savings in the day-to-day operation of the power system. Next to economic operation, the most frequently used operating techniques are encountered in the preventive state, where during normal operation control actions are taken to enhance system security. The building of expertise and proficiency in this area results in a more reliable, secure mode of system operation and can reduce the probability of encountering severely degraded system states. Though each control center will have a different hardware and software system, the majority of the control centers will have available to the operator most of the following application programs: power flow; state estimation; supervisory breaker control; security analysis techniques; automatic generation control; load shedding and restoration; and circuit restoration procedures. It is these available capabilities with which the operator must become proficient in order to obtain effective preventive control.

Though the need for emergency control is not frequent, it and restorative control are the areas of operation in which training is most needed. During system emergencies, the most difficult decisions, intricate operating techniques, most information, and the fastest changes in system state occur. Simulation of the emergency state and practice with its control is not only imperative, but the only means available for preparation for actual operation. Simulation can increase the dispatcher's confidence in handling emergencies, lessen stress, and assure better control of the power system. The restorative system state exists when some loss of load has occurred, usually after an emergency operating condition. The control objective is now to restore service to all load in a mimimum of time. The emergency and restorative procedures are the most difficult of the operating controls, and yet it is here that the operator is usually least assisted, both in established procedure and computer assistance. Training for restoration has been minimal in the past. Procedures usually consist of some verbal discussions and a small amount of written suggestions while practice of these restoration procedures has been infeasible due to the lack of training tools. Through the use of system simulation not only can effective restoration techniques be taught and practiced, but restoration procedures can now be developed with a higher degree of confidence.

During all control operations, there is a chance for system degradation, even though the attempt is to return to the normal state. The trainee must be provided with the opportunity to explore various control operations in order to better prepare for actual operating conditions. What better place to experiment with operational decisions than on an operator training simulator.

FUNCTIONAL REQUIREMENTS

To develop the functional modeling requirements for an effective Operator Training Simulator, the two main characteristics of realistic representation of the trainee's power system and the exact representation of the trainee's control system must be satisfied. Because of these characteristics, the simulator can be divided into the two functionally distinct parts of the power system and the control system. A

SIMULATOR	
CCM CONTROL CENTER MODEL	PSM POWER SYSTEM MODEL
SAME CONTROL CENTER COMPUTER HARDWARE AND SOFTWARE	REPRESENTATION OF ACTUAL POWER SYSTEM
OPERATING SYSTEM DATA ACQUISITION SUPERVISORY CONTROL MAN-MACHINE INTERFACE APPLICATION PROGRAMS	INTERNAL & EXTERNAL SYSTEM STATIC & DYNAMIC PROPERTIES PROCESS CONTROL COMMANDS SCENARIO BUILDER PERSONNEL INTERACTION
EXACT	REALISTIC

FUNCTIONAL DIVISION OF SIMULATOR

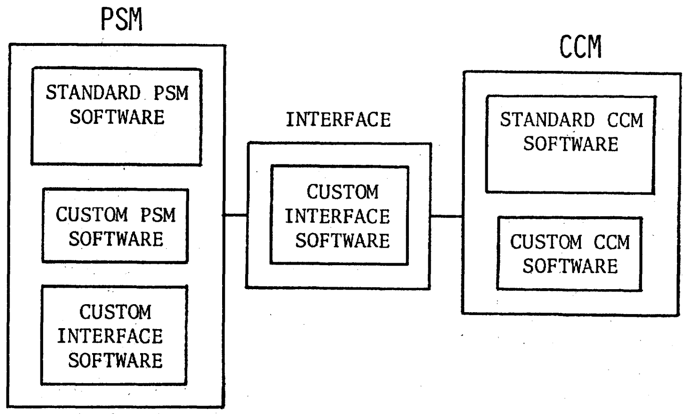
FIGURE 1

realistic representation of the power system will reside in a Power System Model (PSM), while the exact control center representation will reside in the Control Center Model (CCM). (See Figure 1.)

The PSM is composed of several related areas of simulation. The first and most obvious area concerns the mathematical models of the physical electrical network, including its static and dynamic characteristics. This physical network includes the directly controlled power system as well as the indirectly affected external systems. The PSM must have the capability to act as well as react with the trainee. It is this reaction capability that fundamentally alters the characteristics of the mathematical models from their normal methods of use. The modeling techniques must now be expanded to process in an interactive mode through the CRT with the trainee. In the second area of simulation, the PSM must provide for simulation of the operatonal personnel who interact with the operator. These people include not only the field personnel who assist in the operation of the electrical system, but also the personnel involved with operating the external world system. This representation is part of the instructor position portion of the PSM. The third area included in the PSM is the simulation of the data as gathered from the electrical network and then presented to the trainee through his control center system. This area includes the reception and processing of control commands as initiated through the control center system.

The CCM is composed of several related areas of simulation. In order to satisfy the exactness criterion of the OTS, it is necessary that a substantial portion of the CCM be composed of the same components as found in the Control Center Computer (CCC) system, defined as the entire set of hardware and software systems which together form the trainee's actual control center system. The set of hardware includes the computer system, supervisory control and data acquisition (SCADA) system, the man-machine interface (MMI) system, and all other related control center hardware. The software set is composed of the computer operating system, the SCADA software, the MMI software, and all of the related application programs as found in the trainee's actual control system. It must be noted

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.



- STANDARD PSM SOFTWARE IS INDEPENDENT OF USER OR CCM COMPUTER
- CUSTOM PSM SOFTWARE DEPENDS ON ACTUAL POWER SYSTEM BUT NOT CCM COMPUTER
- CUSTOM PSM INTERFACE SOFTWARE DEPENDS ON HARDWARE INTERFACE AND CCM COMPUTER
- CUSTOM INTERFACE SOFTWARE DEPENDS ON CCM COMPUTER
- STANDARD CCM SOFTWARE DEPENDS ON CCC COMPUTER
- CUSTOM CCM SOFTWARE DEPENDS ON CCC SOFTWARE AND INTERFACE

SIMULATOR HARDWARE AND SOFTWARE CONFIGURATION

FIGURE 2

that the term "modeling" in the CCM title is derived not from the replication of the CCC function, but rather from the need to modify hardware and software into a system which meets the overall simulator requirements.

By developing the PSM and the CCM functional division, the OTS design will be developed in much the same way as the actual power system and control system are developed, i.e. the independent development of the two systems is reflected in the simulator design. The power system is already in existence when the control center system is designed. The utility normally chooses from a set of available control center designs and then applies that design to its own system. By separating the development of the PSM and CCM systems and then defining the interface between the two, the simulator becomes a more workable design. This independence factor will be applied to the actual OTS configuration. (See Figure 2.)

SYSTEM CONFIGURATION

The computer configuration design for the Operator Training Simulator will support the control center and power system models with the appropriate level of response as measured at the trainee's normal operating position. Though many computer configurations are available to satisfactorily execute the power system model, the need to accurately duplicate the control center's system significantly constrains the overall configuration.

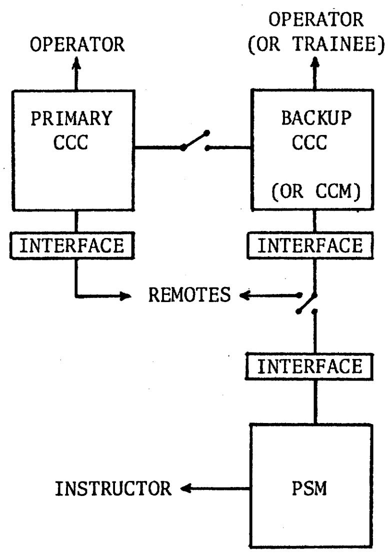
A review of single computer configurations reveals that the integration of the power system model into a computer system which contains the control center software results in an unacceptable training environment. The power system model requires a significant set of computer resources to develop the modeled data and then provides the results in a manner which imitates that of an external data acquisition system in quality, quantity, and speed. This processing burden will constrict the control center software execution and not allow the same response characteristics as found on the on-line system. As a minimum, the power system model and the control center model must be resident in separate computer systems. The power system model, since it is not specific in the sense that it does not yet exist on a particular computer system, can be implemented on any computer system with the proper resources. This system must then be able to support and interface to the computer system executing the control system software.

An effective Operator Training Simulator then, is based on the design that the power system model resides in a separate dedicated computer system configured to meet the needs of the power system model. The control center model would be configured on the same kind of hardware as used in the control center or an essentially identical computer system. If this control center model operates on a separate computer configuration not otherwise used in the control center, then this design will be referred to as the stand-alone Operator Training Simulator. (See Figure 3.) If the control center model operates on the backup or redundant portion of the on-line control center computer, this design will be referred to as the integrated Operator Training Simulator. (See Figure 4.)

The power system realism, as defined in the modeling requirements, will provide the training capability for the various system states and trainee skill levels. The power system model design is modular in order to allow each utility to tailor the simulator to its own unique configuration. For example, most utilities will utilize only a subset of the various models for boilers, turbines, etc. since their system is normally composed of only three or four types of generating units. The OTS can be developed with a minimum set of simulation capabilities, while other functions can be added at a later time as required by the implementing utility. This building block approach provides the individual utility with the ability to specify the level and detail of simulation and system capability as required to satisfy their present or future needs.

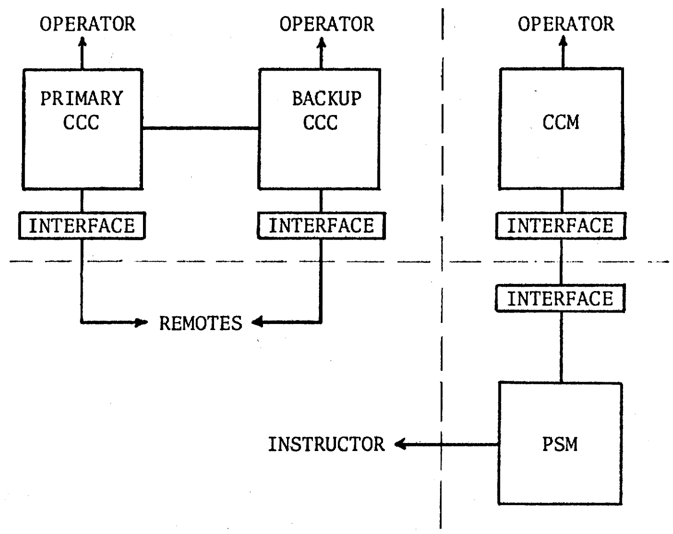
An accurate operator work environment is obtained through the use of identical software for the control center system representation. This software will control a training console which is identical to the normal workstation. In fact, one of the normal operating consoles could typically be utilized for training. The OTS design will support any training configuration ranging from the minimum single operating console through to a full replication of the entire control

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.



DUAL COMPUTER CONFIGURATION
WITH SIMULATOR ON BACKUP

FIGURE 3



DUAL COMPUTER CONFIGURATION
WITH SIMULATOR AS STAND ALONE

FIGURE 4

room. Since the OTS configuration contains the control center computer system or its duplicate, all normally supported devices could be included in the OTS configuration. If the utility so desired, a mock-up control room containing a fully duplicated control system could be implemented.

The OTS design is structured to satisfy the general system design requirements of realistic representation of the power system and the exact replication of the control center system. These two requirements have dictated that the OTS contain two distinct models - one for the power system and one for the control center system. When analyzed in terms of potential computer configurations required to support the models, it becomes apparent that the division of the models into separate computer systems is the most effective method of implementation. To satisfy the needs of the utility industry, the OTS system design must be implementable on the wide diversity of control center configurations in service today and projected for future systems. This design concept has been verified as feasible by reviewing the various categories of control center computer configurations and determining the effective point of interface for the OTS design. The concept will also insure the development of an OTS which is generic in design, yet utility specific in implementation.

In addition to allowing the simulator design concept to be applied to this diversity of configurations, the independence of the power system model and the control center configuration will extend the life of the simulator since it is not an integral part of the control center configuration. A change in the control center configuration, whether it be a minor or total system replacement, will not negate the usefulness of the OTS system. The power system model and its associated computer configuration will still be operable. The interface logic and hardware may need modification to support the new control center configuration, but essentially this is the only portion of the OTS that need be changed.

POWER SYSTEM MODEL

The objective of the power system model (PSM) is to simulate as realistically as possible the electromechanical characteristics of the power system and to produce as its principle output the set of analog values and status changes which are monitored by the data acquisition function of the control center. The action of the PSM will be based on a scenario prepared by the instructor through the scenario builder. In addition, the PSM will respond to control commands from the control center model.

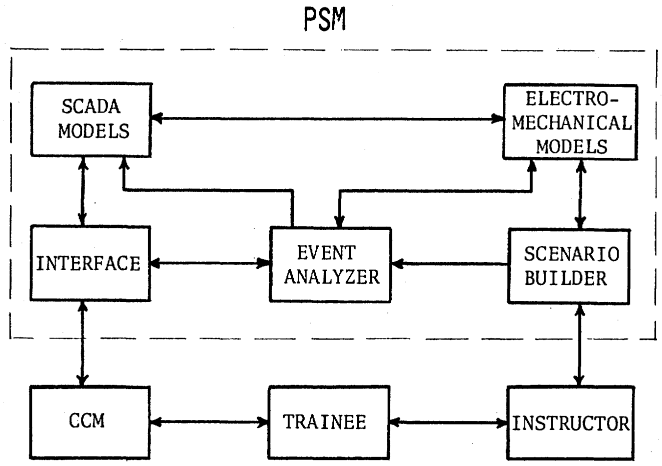
Though the PSM design must be applicable to various types and sizes of utilities, the design criterion is based on a power system network model of 1,000 buses. This model size will accommodate the requirements of any of the control centers presently in existence and those expected in the near future. Hence, with the necessary response times being met for the 1,000 bus model, practically all of the potential users of training simulators could design their PSM models to perform as well as, if not better than, the prototype simulator developed from this project's guidelines.

System Model

The power system network model is divided into two subsystems which will be designated as the Internal System and the External System. The internal system refers to the power system which is to be supervised and operated by the trainee, while the external system refers to the electrical system beyond the internal system.

The external system is divisible into a maximum of ten areas, comprising a maximum of 100 buses total and representing, in general, separate operating entities. This external system model must fit within the 1,000 bus, complete system model. The system representation can be a combination of actual and equivalent generators and loads. For a highly interconnected system, at least one area should be reserved to represent, by a single generator, all of the remaining generation beyond the boundaries of the area adjacent to or electrically close to the internal system.

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.



FUNCTIONAL OVERVIEW OF PSM

FIGURE 5

The PSM consists of various models representing the equipment and the dynamics of the complete power system. (See Figure 5.) The transmission network models include the conventional steady-state representation of transmission lines, transformers, and other electrical elements. All monitored circuit breakers and motorized switches are represented. Automatic controls and switching equipment, tap changers, shunt capacitors and reactor switching are also modeled. The turbogenerator models include representations of generators, thermal turbines, hydro turbines, governors, generator excitation systems, and automatic voltage regulators. The automatic generation control (AGC) function resides in the control center model, and provisions should be made in the PSM for accepting the AGC signals and interfacing them with the turbine governor models. The PSM should also include AGC models for the external areas with the flexibility of representing either a tie-line bias control or a free-flowing tie operation.

The system dynamic models are simplified in order to achieve practical implementation without sacrificing realism. Ideally, the entire power system would be represented in a dynamic simulation with the full capabilities provided in a transient/midterm/long-term stability program such as EPRI's RP1208, "Extended Dynamic Stability Analysis Using Advanced Techniques." However, dynamic simulation of power systems, particularly in the transient stability region, is a very demanding computational process. The need for simplified models has been generally recognized and the use of those models in fast simulation applications has been accepted in the industry. In fact, "exactness" or sophistication in modeling may not be practical if it requires data which are not readily available or do not enhance the simulation results. The approach adopted for this training simulator is to divide the overall system dynamic requirements between the PSM, which is on-line, and the scenario builder, which is off-line. The scenario builder will have a full dynamic stability analysis program, while the PSM will only have a long-term dynamic stability program.

In the dynamic model of the PSM, the system frequency (or the frequencies of several islands) is the frequency of the "center of inertia" of the system or each island. The global modeling of an entire interconnected system, plus the ability to break up this global model into smaller and smaller subnetworks, permits the realistic simulation of the effects on system frequency, power flows, and bus voltages by generator-load imbalances during normal, emergency, and restorative states.

Response to Trainee

As to events triggered by control actions taken by the trainee, the PSM would be able to simulate the resulting long-term dynamic and steady-state effects. In general, the trainee can do what he pleases, justified or not, and the PSM would be able to respond correctly. However, certain control actions taken by the trainee may alter or invalidate later events which had been originally planned in the scenario.

To handle trainee-initiated events which affect the scenario, a form of heuristics is proposed. During the building of the scenario, the engineer/instructor would determine which system conditions in the scenario would most likely require operator action. An off-line transient/mid-term/long-term dynamic analysis should be made to determine the effect on the scenario if the trainee does take various actions. Most operator action will have minimal transient effect on the system. The results of those operator actions which have significant effect on the system can be saved as part of the scenario and incorporated into the working scenario at the appropriate time.

Simulation Process

A typical training scenario starts with an initial set of base conditions determined by the chosen time of day, day of week, and network conditions as determined by a load flow. The simulation of power system conditions is then normally performed over a training time period in real time, though it is possible to compress or expand the training time period. Once started, the PSM goes into a tracking mode and continues until interrupted by a planned or trainee-initiated event. After processing the event, the PSM resumes the tracking mode until the next event. The simulation continues until a preset completion time or intervention of the instructor.

The tracking mode is used when the power system is operating under quiescent conditions, i.e. the system loads are changing normally and the system generation is adjusting to meet the load. No disturbances are occurring to change the network configuration or to significantly change the generation/load balance. Such disturbances, referred to as events, may occur in the internal or external system and may be scenario or trainee-initiated. It is a design goal to perform in less than 5 seconds the entire process of solving for each new system load the various models (frequency, turbine generator, etc.), plus the full load flow solution. Of the total processing time, the largest component would be utilized for the load flow solution. Whenever an event occurs, the tracking mode will be temporarily suspended in order to immediately process the event. Events are introduced into the training session in three ways: by scheduling the event via the scenario builder; by operation of relays modeled in the PSM; and by control action of the trainee. Trainee initiated events need to have been processed first by the events analyzer according to the previous description of heuristics.

For a typical event such as a breaker operation (either tripping or closing) that alters the network configuration, the first step is to very rapidly calculate the change in flows and voltages in the window of interest. This window of interest is defined as the subnetwork composed of the bus where the breaker

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.

operation occurs and all surrounding network elements up to the next adjoining buses. The solution of this window of interest can be accomplished by the load flow models using network compensation methods with partial forward and backward substitution. The resulting analog values and status changes would be passed to the data acquisition models in the control center model for a very rapid update of the area surrounding the operated device. The window of interest technique is an approach for minimizing the response time by, in effect, applying the load flow function through a small subset of the 1,000 bus system. This desirable technique is based on the fact that the operator expects to see a rapid, correct response on his CRT to his operation.

Immediately after the solution of the window of interest, the load flow routine is run with the new topology, but with the generator phase angles held at the values of the last load flow run. This requires processing all generators as swing buses. If the breaker operation involves sudden changes in generation and/or load, these changes have to be incorporated in the load flow. The result of this particular load flow would be a new set of electrical powers which will then be sent to the frequency models. From this point on, the processing will be the same as in the tracking mode.

Instructor Position Requirements

A training session on the OTS will typically involve the trainee performing the dispatching functions at an actual or duplicated operating console, while the trainer or instructor interacts with the session through an independent console. Though the OTS function can be activated by the trainee alone, the normal training session will have a designated instructor participating in the session. Through his independent console, the instructor will be able to initialize the session, control the scenario as it progresses in time, and summarize the results of the training process. This console, referred to as the instructor position (IP), will provide the instructor with the same information being received by the trainee and additional data available from the power system model (PSM). This console will allow the instructor to monitor the session activity, initiate additional control action, and activate any desired session control.

In order to initiate a training session on the OTS, the instructor or person acting in place of the instructor will begin by selecting a scenario from a library of predefined scenarios. Each scenario defines the initial system conditions, such as generation unit schedule, interconnection power transactions, line outage conditions, loading constraints, time of day, system load profile, etc. If the desired initial conditions are not present in an available scenario, the instructor may select the scenario which is the closest match, modify it to the desired starting conditions, and then retain the scenario either for the duration of the session or permanently in the library.

The instructor can next establish a set of predefined scenario events which will occur at various times within the execution interval of the scenario. These events are defined to occur at specified clock times or at time intervals relative to the start time of the scenario. Events may also be defined to occur when a prespecified system state occurs. Such events may or may not be activated, depending upon whether the scenario reaches a certain state such as a designated load level, voltage level, frequency, etc. The instructor can determine another set of events which may occur based on a probablistic event function. This function will control whether a system event will occur based on a randomized value. These events can also be scheduled to occur if a predefined training action occurs.

Once the training scenario is selected, verified, and initiated by the instructor, the emphasis in activity now shifts to the trainee and his interaction with the training session. The instructor maintains an active role through:

- o initiation of various session controls
- o monitoring of the trainee's response to operating events
- o monitoring of the power system model response to the trainee's action
- o participation in the role of outside personnel contacts with the trainee

The OTS, in addition to its role as a power system operations trainer, also functions as a training system for the operation of the control center system and its associated functions. The instructor will have the capability of defining system events which affect the informational quality of the control center, and ultimately the operation of certain control center functions. The use of such informational control can introduce training scenarios which reflect devices such as generators or circuit breakers not responding to supervisory controls, lack of data from critical locations at critical times, and nonresponse of critical control center functions. These scenarios are a necessary part of the dispatcher's training for the various operational situations which arise.

The hardware configuration of the IP console is designed to satisfy the functional needs of the instructor. The requirements for scenario planning, scenario operation and session review will be reflected in the console interface with the PSM computer configuration. The session evaluation needs will be addressed by a set of interfaces with the CCM computer system and with the trainee, to allow the instructor to monitor the trainee's action. Options include placing the IP physically close to a training console, utilizing closed-circuit television systems, interfacing slave CRT monitors, or interception and subsequent display of the requested formats.

The IP configuration will also serve as the interface to the model building support and the scenario building support systems. These systems require significant inputs from engineering and operating support personnel in order to accurately portray the power system model and the operating scenario. Using the interactive capabilities of the IP console, the modifications and update procedures can be effectively and efficiently performed. Thus the functions of the IP console are extended beyond the bounds of the scenario activities to include the support functions required as part of the overall simulator maintenance. The workstation now becomes the tool for the instructor, the system support personnel, and the programming staff. By not constraining the uses of the console, it becomes a strategic resource in the overall operation of the simulator.

CONCLUSIONS

This paper has reviewed the set of guidelines developed for a generic operator training simulator system which can be applied to all levels of digital computer based energy control systems. The objective of these guidelines is to outline the OTS requirements and then establish a design which when implemented can be utilized by many utilities, regardless of their control center configuration. The generic qualities of this OTS design stem from the placement of the power system model on a separate computer system which is then interfaced to the control system computer

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.

configuration. This design provides for realism in modeling while preserving the exactness of the operating environment. Given the constraints of requiring training on a system which is as close as possible to the on-line control center configuration, this design meets both objectives effectively. Being modular in nature, the logical construction of the system allows for expandability, model upgrades, computer resource enhancements, and control system modifications. The next phase of this design is to implement these concepts on a demonstration system to verify the design feasibility.

ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of the EPRI staff and the project industry advisors for their assistance on this project. The final report on this project will be published under EPRI Project RP 1915-1, "Considerations in Developing and Utilizing System Operator Training Simulators."

REFERENCES

1. R. T. Byerly and E. W. Kimbark, Eds. Stability of Large Electric Power Systems. New York: IEEE Press, 1974.

2. B. Stott, "Review of Load-Flow Calculation Methods." Proceedings of the IEEE, Vol. 62, No. 7, pp. 916-929, July 1974.

Discussion

K. Hemmaplardh, H. Biglari, and **S. A. Sackett** (Boeing Computer Services Company, Tukwila, WA): The authors are to be commended for their excellent work and very well written report. The presentation is also being made in a useful and timely manner. It would be much appreciated to have the following points further clarified by the authors:

1. The approach to system dynamic models adapted for the training simulator is "to divide the overall system dynamic requirements between the PSM, which is on-line, and the scenario builder, which is off-line. The scenario builder will have a full dynamic stability analysis program, while the PSM will have only a long-term dynamic stability program." It appears then, that a long-term dynamic stability simulation methodology is to be used. The discussers are in agreement with such an approach. As the authors also hinted, some model data may not yet be readily available. In which area does the scarcity of data lie? To which extent may it affect the overall applicability of the models?
2. When a line is taken out of service, the configuration of the network changes hence the JACOBIAN is changed, which in turn gives rise to longer period for the Power Flow convergence. Does your "compensation method" imply introduction of pseudo injections to the corresponding buses? If this method of compensation is used on the "window of interest," how often should the JACOBIAN be updated?
3. Would you comment on the Area Interchange Scheduling between two external areas, in what section should it reside, working scenario or PSM?
4. Would the authors please comment on the possible guidelines that should be established for the OTS when used to train operations personnel in restoration from severe outages or even black starts?
5. In Fig. 1, the authors properly emphasize the importance of maintaining the exact control center software for use in the CCM. In the discussion of the Instructor Position Requirements, the authors allude to a possible extended role for the OTS programming development and testing support; have the authors considered what specific criteria, if any, should be established concerning the use of OTS for nontraining functions such as system testing of new functions or program development support?

Manuscript received June 10, 1983.

T. E. DyLiacco, M. K. Enns, J. D. Schoeffler, J. J. Quada, D. L. Rosa, C. W. Jurkoshek, and **M. D. Anderson:** The authors thank the discussers for their comments, questions, and kind remarks. Our thoughts on the points raised by the discussers are:

1. The primary objective of the project (EPRI RP1915-1, "Considerations in Developing and Utilizing System Operator Training Sumulators)" was to formulate guidelines for the development of an effective Operator Training Simulator (OTS), rather than to investigate the details of its implementation. Hence the authors did not pursue the very important problem of the availability of data for the power system dynamic models. Experience indicates that it is not always possible to obtain good values for parameters in generating unit models from either manufacturer's data or from routine operation and test data. The same will hold for the OTS generating unit models. Even if a utility has good data for generating unit models in a stability progrm, the OTS models might require parameters that cannot be derived from these data. There may be similar data problems for dynamic models of other power system components, such as LTC transformers, but they should be less severe because these devices are less complex than fossil, nuclear, or hydro generating units. The variation of real and reactive load with frequency also presents model data problems, but this is of relatively minor importance in the OTS. All of these data availability problems are compounded when the utility attempts to obtain compatible data from neighboring utilities. In summary, the most significant data availability problem concerns generating unit model data, and the severity of this problem depends on the models used in the OTS and the utility's data resources.

The OTS guidelines are based on the assumption that the primary application of the OTS will be operator training, and that the OTS will be designed for this application. This led to the requirement that the simulator provide a realistic dynamic representation of the utility's power system. Hence the extent to which data problems may affect the applicability of the models is to be judged by this criterion. This judgment is not possible at the present stage of OTS development. Realistic dynamic simulation for operator training is not as stringent a requirement for applicability as are criteria for other potential OTS applications such as postevent analysis, which requires very accurate simulation of actual system disturbances. Thus rough approximations to unavailable data that rule out some secondary OTS applications might not affect the primary application of operator training. On the other hand, the need to simulate system behavior under extreme condisions of frequency and voltage may require data not ordinarily used in stability programs.

2. Temporary network changes are handled by the compensation method (also known as the matrix inversion lemma), which avoids matrix refactorization and which does not slow convergence. It adds a small auxiliary computation to each iteration, which may be viewed as finding a pseudo injection. It is used with the "window of interest," which amounts to a "fast" forward and backward solution for only those buses of immediate interest to the operator: those at and around the points of breaker operation.

It seems that with some of the recent developments in sparse compensation methods the Jacobian or other system matrix should not be updated until many (50 - 100) network changes have been made. However, if the system matrix is truly a Jacobian instead of some constant approximation, it may have to be changed each iteration in any case.

3. The normal OTS training mode includes an instructor at the Instructor Position. During the creation of the training scenarios the instructor will enter, through the Scenario Builder model (see Fig. 5) of the Power System Model (PSM), the area interchange schedules between all pairs of companies modeled in the PSM. During scenario operation, these schedules will be retrieved and enforced by the power flow computations. As the scenario progresses, the instructor can im-

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.

pose further schedule changes between any pair of areas or agree to and make a change with the trainee's area. The trainee operating the OTS alone will be able to change only his own schedule, as he does not have access to any others; in effect, he cannot change the interchange schedule at all when in this mode.

4. An OTS built according to the guidelines in this paper will have the capability of simulating many types of severe conditions. Black start simulation capability could be specified by a utility for an OTS. Training guidelines were not considered by the authors in this project, since they will vary widely from utility to utility. Each company has different operating procedures, operating problems, and training needs. Training guidelines useful for one utility may be completely inapplicable for another. Each utility will have to develop its own training guidelines.

5. The authors have not considered criteria that a utility should establish for nontraining uses of the OTS. These criteria must be developed by the utility, because such uses will depend on a number of factors that vary widely among utilities. These factors include the availability of other computer systems to perform the nontraining functions, the time the OTS is available for nontraining functions during normal working hours, and whether the OTS uses the control center back-up computer system or a separate computer system.

Manuscript received August 19, 1983.

Authorized licensed use limited to: Missouri University of Science and Technology. Downloaded on July 14,2023 at 19:28:40 UTC from IEEE Xplore. Restrictions apply.