

Discussion

R. Ramanathan and H. Ramchandani (Boeing Computer Services, Energy Control Systems, Tukwila, WA): The authors are to be commended for developing a large-scale dispatcher training simulator. It would be much appreciated to have the following points further clarified by the authors.

1. According to the paper external area is simulated by an equivalent generator and an equivalent load, by this how do the authors justify proper training can be given to the trainee in learning the effect of external area in the function of internal area.
2. What parallel processing algorithm is used for power flow and what modifications where carried out?
3. If this simulator power flow is run every 3 seconds and load is computed only once in a minute. During a minute is the load assumed constant?
4. From Fig. 6 how 0.25 seconds can be achieved if there is a large imbalance in power.
5. What type, and what model have you implemented for nuclear plants?
6. Do you have any backtracking capabilities? That is to restart the DCM and PSM from the playback snapshot/save case snapshot? If yes, please explain.

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R. P. Schulte and W. L. McReynolds (Bonneville Power Administration, Portland, OR): The authors have accomplished the implementation of a dispatcher training simulator and training program that many utilities can only dream about. Our congratulations.

Could the authors explain the faithfulness of the power system model to simulate actual system responses. For instance, have you recreated actual disturbances? Have you performed before and after checks of actual line or generator outages to a simulation of the same conditions?

The Substation Controller Model appears to perform some functions that may be directed by a dispatcher to a substation operator or SCADA operator. It also is explained that some switching is prearranged in the training session. This reduces instructor workload. Are these two functions the same model?

During a training session, a trainee may take an unexpected course of action. Does the training scenario literally follow unexpected scenario shifts? Do subsequent preprogrammed events get cancelled if they no longer follow the trainee's course of action? Analysis of past wide spread disturbances shows that poor judgment during restoration actually worsened the power system state. Does this simulator and the training session account for these possibilities?

Figure 6 shows a disconnected low speed model. Would the authors explain its relationship to simulation?

BPA has completed an extensive blackout restoration program. Two keys to it's success were stability studies and actual practice in generator black start, paralleling, line charging voltage control, and finally load pickup. The amount of generator voltage bucking and load pickup increments took considerable study and practice. A training simulator would have helped. Is the generator model capable of simulating a similar black start scenario described above?

Could you summarize the staff time required to develop this system? How many people maintain the hardware? The software? What is the size and background of the training staff?

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Anjan Bose (Arizona State University, Tempe, AZ): The authors are to be congratulated on developing a stand-alone dispatcher training simulator of high fidelity. The power system, the control system, and the control center environment has not been duplicated in this detail in any one previous training simulator. The instructional capability of scenario building, scenario control, and training session monitoring and review are also significantly enhanced. The following questions pertain to the power system model which has features specifically developed for their suitability to real time training simulation, and are raised for clarification.

- **Generator Model** — The excitation system appears to be the usual generator bus model for a power flow with the var limits linearly dependent on the generator power. The dynamics of the excitation system are in the transient range and are normally neglected in the slow dynamic simulation is a training simulator. However, it is known that this fast action of the AVR can affect slow oscillations in the power system but it is not clear how this can be modeled. Was any consideration given to the modeling of excitation system dynamics?

- **Load Model** — The main difficulty with modeling loads at the high voltage buses is the absence of available empirical data. Load models are often designed for flexibility in case load characteristics become available. Were the load models chosen here influenced by TEPCO load data or were they chosen for convenience? For example, why was a constant current load (linear dependence on voltage) not included? Why was 85% rated voltage chosen as the cut over to all constant impedance load? For frequency characteristics of load, was anything other than system load damping used in the model?

- **Interconnected Power Network Model** — The Tohoku system is represented very simply as one generator and one load. Does this provide sufficient accuracy in the power flows when a Tokyo system high voltage line is suddenly opened near the Tohoku system?

- **Substation Controller Model** — Are the VQ controls modeled as usual in the power flow or are their dynamics taken into account?

- **Load Flow Calculation** — The DC power flow is the same as the first half iteration of the Fast Decoupled power flow. Did the authors try continuing the Fast Decoupled method instead of reverting back to a full Jacobian in rectangular coordinate voltages? In taking advantage of the pipeline structure of the array processor, were the modifications done only to the computer program or also to the solution algorithm itself?

- **Frequency Deviation Calculation** — The step size used is 0.25 second which is different from the one second size used in many long term dynamic simulation. Was the smaller step size necessary for sufficient accuracy?

- **Transient Stability Calculation** — The use of a transient stability program to determine the breaker openings after a system fault is meaningful only if the protective relay characteristics are modeled in the program. In addition, the man-machine interface to the program should be such that the scenario building information could be easily selected (automatically or easily by the instructor) from the voluminous output. What features does this transient stability program have that are different from the usual program used for off-line studies? If a sequence of events is built from the usual program used for off-line studies? If a sequence of events is built from this transient stability calculation into the middle of a long training scenario, it is possible that certain trainee actions in the early portion of the scenario can make the sequence invalid. Are there any facilities for the instructor to watch out for such conditions and take alternative action?

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James G. Waight (ControlData Corp., Minneapolis, MN): The authors are to be congratulated on developing a sophisticated large scale dispatcher training simulator. It is evident from the results that this simulator is the outcome of a major development effort which was planned and executed well. The following questions elicit additional information about the capabilities of the TEPCO simulator, and request classification of why certain design choices were made.

- **System Configuration**

The authors have designed a configuration of three identical computers (ISS, PSM, DCM) plus peripherals and an array processor. Consoles are attached to the ISS and CCM computer. Separation of the DCM as a separate computer allows replication of the Dispatch Center with high fidelity. Would the authors please comment on why the ISS and PSM models were assigned to two identical computers instead of to a single larger computer.

- **Dispatch Center Model**

To what extent were the functions of the Central Load Dispatching Center replicated in the DCM. Figure 5 lists the AFC and ELD functions where other application functions such as supervisory control and emergency load shedding are included.

The organization of TEPCO's operations is hierarchical with central, area and local dispatching centers. The simulator is used for training dispatchers from all three centers. To what extent does the Man-Machine Interface and control functions of the simulator match the central, area and local dispatching centers.

- **Transient Stability**

The authors have included a transient stability program in the TEPCO simulator. What types of features, Man-Machine Interface and functional interfaces where built into this program to reduce instructor workloads.

- **Playback/Evaluation**

The TEPCO simulator includes a substantially improved playback/evaluation function. Any further information the authors could provide about this feature would be welcome.

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I. Susumago, M. Suzuki, K. Miyama, T. Tsuji, K. Dan and A. Yamanishi: We are very pleased at the response of so many discussers to our paper and acknowledge their contributions to the subject.

In reply to Prof. Anjan Bose's question

- **Generator Model** — As the low-frequency oscillation by the fast action of the AVR is negligible in the TEPCO's power system and the main objective of the training simulator is to teach operation skills of system restoration after system faults, the simulation related to the dynamics of the excitation system is considered to be unnecessary.

- **Load Model** — The load model is determined by combining the constant impedance load and the constant power load, based on actual results in the TEPCO's power system. The constant current load can be simulated by this method. Changing the load characteristics entirely to the constant impedance ones below 85 percent rated voltage is a means of ensuring that the load flow can be calculated even in the severe conditions of the power system, and the training can be continued. The load flow calculation is unlikely to converge below 85 percent rated voltage. For load frequency characteristics, both active power and reactive power are considered.

- **Interconnected Power Network Model** — The system capacity ratio between the TEPCO and the Tohoku is 5:1, and the TEPCO's system employs flat frequency control and the Tohoku system tie-line bias control. A fault near the Tohoku system is not included in the training items, because it is certain that such a fault does not seriously affect the TEPCO's power system.

- **Substation Controller Model** — VQC controls substation secondary bus voltages and transformer primary reactive powers within their specified ranges. It integrates the deviations from standard voltage and reactive power values every three seconds, and automatically controls the transformer tap settings, capacitors, or shunt reactors, when the deviations exceed the permitted values.

- **Load Flow Calculation** — In the training simulator, clearing a severe fault may produce separated systems, the large energy imbalance, and/or unstable power flow conditions. The load flow calculation method using a full Jacobian was adopted to get more reliable solutions under these circumstances. The load flow program was first developed and checked in FORTRAN. Then the program was re-written in array processor assembler language to make best use of the pipeline architecture (add, multiply, data fetch, and data store).

- **Frequency Deviation Calculation** — TEPCO's UFR is a digital type using microprocessor, with a f/t function. As the minimum t is specified as 0.5 second, the step size of 0.25 second was adopted for the integration width of the frequency deviation calculation.

- **Transient Stability Calculation** — The transient stability calculation program includes out-of-step relay models, and is applied only to evaluate a fault at training start. When an instructor inputs a fault case, the program simulates the power system behavior for about two seconds, and determines operated out-of-step relays, tripped CB's, and their trip times. These data are automatically inserted into the training scenario. At the instructor's request, these transient stability data can be displayed on the CRT, and the power system behavior CB/LS conditions, power flows, bus voltages, and frequency can also be displayed on the mimic board at each integration step of the stability calculation.

Regarding the comments and questions from Mr. James G. Waight

- **System Configuration** — To effectively utilize the operating software and hardware, the same kinds of computers as the DCM computer were adopted for the ISS and the PSM.

- **Dispatch Center Model** — In the central dispatching center model, the automated computer system functions (power system monitoring, AFC, and ELD) were replicated except demand-supply planning functions. In the area and local dispatching center models, the automated computer functions were replicated exactly. As the man-machine interface, trainee's consoles and telephone consoles can be changed corresponding to each dispatching center model.

- **Transient Stability** — This point was described in Prof. Anjan Bose's question.

- **Playback/Evaluation** — All man-machine inputs by instructors and trainees during the training session are stored in the disk, and instructors can make snapshots by designating any points during the training. The playback is performed by executing the same simulation as during the training session from the selected snapshot. The playback, it is possible to shift back into the training session mode by using the "switch-over" feature. Evaluation data collected and stored during the training session can be printed out on the line printer at the instructor's request. There are evaluation data such as interrupted load MW and MWH, number of telephone calls to each station, the start time of system restoration, and the time required for restoration.

In answer to the remarks and questions from Drs. R. P. Shulte and W. L. McReynolds

- Since all system data (P, Q, V and f) are not obtained when a fault occurs accurately, it is very difficult to compare exactly the simulation results of the training simulator with the data during an actual system fault. Therefore, we justified the power system simulation by studying the calculation result of the training simulator in case of past power system faults.

- The Substation controller model performs the VQ control function in the actual power system. The self-operation model performs the self-operations that power station and/or substation operators take independently in the event of blackout/restoration. This model reduces instructors workload very much.

- For the training session, it is necessary to set fault time, fault equipment, operated relays and tripped CB's for the training. Since the power system facilities/equipments are totally modeled, unexpected actions or poor judgment of trainee can be faithfully simulated in the power system.

- In Fig. 6, the low-speed models related to the frequency and power flows/voltages are executed in the positions of the intermediate-speed model (F) and the intermediate-speed model (P), respectively.

- The training in an extensive blackout restoration is conducted as one of the major training scenarios with great training effect.

- In the TEPCO, the system development period was about four years including the staff time of about fourteen man-years. The training simulator hardware and software are maintained by Mitsubishi Electric, as the manufacturer. The training staff consists of five persons who have experienced as dispatchers in dispatching centers or made operational plans in the head office and branches, and designed automated dispatching computer systems.

In reply to the remarks and questions from Drs. R. Ramanathan and H. Ramchandai:

- The items 1 and 2 were answered in the Prof. Anjan Bose's questions.

- Basic load capacities (P_{L0} and Q_{L0}) are determined as constant values for a minute, and effective loads (P_L and Q_L) are changed every 3 seconds by considering the frequency and bus voltage characteristics.

- When a large power imbalance occurs, the load flow is calculated first by interrupting the frequency deviation calculation. In this load flow calculation, the simulation time is not updated.

- A nuclear plant is modeled by BWR. Since the nuclear plant of an actual system is operated at the constant generating power, the reactor has the simplified model responding the sudden deviation of the system frequency.

- The item 6 was answered in Mr. James G. Waight's question.

Finally, we would like to thank again all the participants for their valuable comments. We hope that the training using the simulator will become increasingly important.

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