Development of a Training Simulator for Power System Operation

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Abstract – A new type of simulation training system for power system operation is presented in this paper. It is based on transmission mimic board, double screen PC, mimic control panel, and real-time digital simulator, KEPS. The operating simulation includes the simulations of the control panel interface and the simulator. The mimic board displays transmission network summary information using a software view of the hardware based mimic board. The symbols, numbers and colors layout exactly match those of the KEPS draft case to provide operators a familiar and effective starting point. This paper describes the development of an innovative training system, utilizing the benefits of 3 dimension visualization s/w and communication-control s/w to create the appropriate operational environment and allow simulation of various power system operations without the restrictions of other training methods. Experiences gained in developing concepts and meeting considerable s/w challenges are outlined, and the potential of the simulator for future operations training discussed.

I. INTRODUCTION

Increased size and complexity of power systems have gradually changed the requirements for control and monitoring systems. The rising cost of labor and lack of trained personnel have both contributed towards the development of modern training system, for the supervision of their complete networks. Today they represent a valuable and often necessary aid for power system engineers involved in planning and operation in power systems. Simulation is perhaps the best way for both students and engineers to begin to understand the complex phenomena associated with power systems. There are two kinds of training for operators, one is simulator training and another is knowledge training related with the associated operation. Simulator training provides a real operating environment and excellent training effects have been obtained for the operating skill training. But, lacking the visualization of power system & component information, such as transmission line flow, power transfer, reactive power, overall system security status or PD curve, etc. In other words, if simulator training has no support with knowledge training then the trainee lacks opportunities for the real operating skill training. The need for enhanced power system visualizations has been increasingly acute over the last decade. Therefore, our new type of training system is supplemented with an essentially static mimic board where detailed state information is electronically displayed and the application of different colored lights to indicate the status of various system devices so as to combine the skill training and knowledge training. The included processes are controlled by map controller that drive the electronic displays and accept control inputs from and provide feedback to the simulator. The map controller will also interface with the simulator & 3-dimensional visualization s/w to display power being transfer & operating conditions of power system (i.e PD curve). Modern computer methods in both the modeling of the power system and control system components, as well as, the interface to the powerful KEPS simulator ensure that the trainee is able to make efficient use of time to study power system phenomena, actually perform the switching tasks themselves, not have to struggle with the nuances of the simulation tool and educating the next generation of power engineers.

In this paper a fully digital real-time simulator, KEPS is used to model both the power system and the controls associated with a simple two-area system. Our training system proposes a new mode of simulation system combining operation training and knowledge training. The case system is similar in structure to the one used in references [1] and [2] to study the fundamental nature of inter-area oscillations. Various phenomena commonly encountered when dealing with the two-area system is studied.

II. THE KEPS & TRAINING SYSTEM : AN OVERVIEW

The KEPS is a parallel processing based power system simulator capable of continuous real-time simulation of both power systems and control systems. The power system network is modeled using the well known Dommel algorithm first incorporated into the EMTP. The availability of a substantial number of both analogue and digital input/output ports on the KEPS, coupled with operation in real-time permits interconnection of physical control and protection equipment to the simulation. It is thus possible

for the user to study the performance of the external control and protection equipment under test in a closed loop manner. If the user does not have access to the physical control and protection equipment, that equipment can be modeled using the KEPS. This KEPS unit represents the world's largest and most advanced real-time digital simulator. It consists of 26 racks of modified RTDS hardware, each containing 13 Triple Process Cards, 1 Workstation Interface Card, 1 Dual Inter Rack Communication Card and various auxiliary components. In addition, many significant enhancements and improvements were made to KEPS hardware and software. A number of application software development were undertaken and many are also on-going projects. Data Conversion S/W converts existing PSS/E files to KEPS/Draft file including initial system conditions. System Reduction S/W, evaluate existing and create custom techniques used to reduce large systems, but maintain system dynamics. 3-Dimensional Visualization S/W helps display results from large simulations. It is also expected that KEPS facility will serve as a training and education tool for KEPCO/KEPRI engineers and operators.

Fig. 1 An overview of KEPS

A new type of simulation training system is based on transmission mimic board, double screen PC, control panel, control/communication s/w and real-time digital simulator, KEPS. The new training system provides a realistic power system control environment for effective operator training. The mimic board displays transmission network summary information using a software view of the hardware based mimic board. The symbols, numbers and colors layout exactly match those of the KEPS draft to provide operators a familiar and effective starting point. Trainees are therefore able to develop good decision making skills as they experience and respond to different operating situations.

Fig. 2 A view of training system

III. STRUCTURE OF SIMULATION TRAINING SYSTEM

The training system includes a transmission mimic board and its monitoring system supported by the 3-dimensional s/w module. The simulator-control panel supplies a similar operating environment as in the real buttons & switches, which simulates the dynamic procedure of power generator unit, transmission, load, circuit breaker, shunt/capacitor, transformer, PSS and its monitoring system and provides typical operation interfaces such as tripping, terminal voltage and frequency adjustment, accident and abnormal processing, loss of a generating unit, CB switching, relaying, sudden change of load, rescheduling generation to alleviate overload & frequency, change of generation to follow the load, blocking the governor frequency response of generation sources, etc. Three-dimensional module demonstrates knowledge and principles associated with the corresponding operation. This allows the overall contingencies analysis results for a system to be conveyed "at a glace".
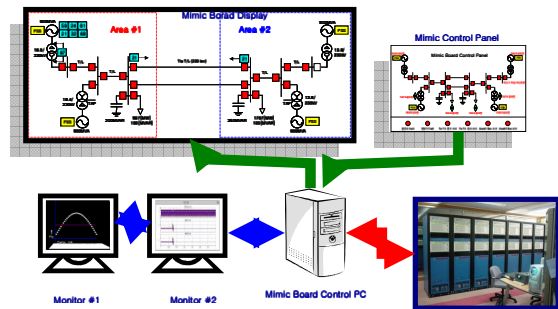

Fig. 3 Structure of simulation training system

A. Transmission Mimic Board

A physical transmission is being designed for both research and education needs. The large mimic board where detailed state information is electronically displayed. The symbols, numbers, colors and layout exactly match those of the KEPS draft case to provide operators & trainees a familiar and effective simulation environment.

Fig. 4 A complete view of transmission mimic board

Under the support of 3-Dimensional S/W, the left screen presents power-angle curves for tie-line shown in Fig. 4. This can enhance the training effect and the learning enthusiasm of the trainee. The related runtime graphs and the operating states are shown in the right screen which explains why to take such an action.
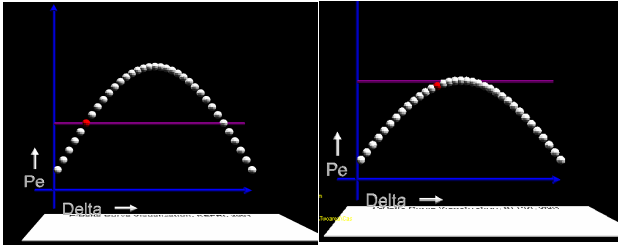

Fig. 5. 3-D Output Plot for Steady State. Fig. 6. 3-D Output Plot for Loss of transmission line.

B. Mimic Control Panel

The mimic control panel provides a realistic power system control room environment for effective training. Trainees are therefore able to develop good decision making skills as they experience and respond to different operating situations. The mimic control panel offers as set of control actions to create an almost endless array of different training situations. Some of these include:

- Loss of a generating unit
- Adjustment of terminal voltage & frequency
- Change of shunt & capacitor
- Transformer tap change
- Switching circuit breaker
- Sudden change of load
- Rescheduling generation to alleviate overloads
- Change of generation to follow the load
- Loss of a transmission line
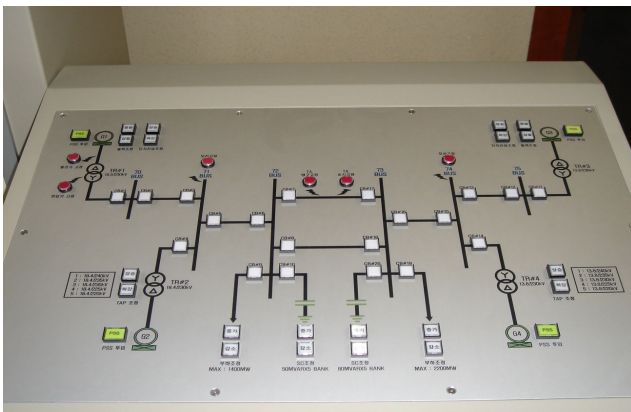- Relaying protection

Fig. 7 A complete view of mimic control board

C. 3-DIMENSIONAL SOFTWARE

In any visualization application, visual simulation is generally the most demanding process in terms of computing power. For our 3-D visualization, a Pentium IV machine 3.2GHz CPU and nVidia GeForce 6600 3-D accelerated graphic adapter is used in conjunction with a 17" 120Hz monitor to provide the operator with a "window on the world". The 120Hz monitor is used to present 15 frames per second, thereby providing a 3D view that has depth, rather than just a flat display. Fig. 5 & 6 show examples of power-angle curves for tie-line.

D. KEPS DATA COMMUNICATION

The training simulator displays current power system operation data gathered from KEPS and controls operation parameters (circuit breaker status/fault apply/load & shunt change/generation change, etc.) of power systems simulated in KEPS. For those purposes, the training simulator has Ethernet communication channel for data exchange with KEPS. Actually communication occurs between main PC and WIF card (Workstation Interface Card) in KEPS using SIM Protocol which is exclusive RTDS data communication Protocol on UDP/IP. In the case of current operation data monitoring, every 0.5second main control PC gathers data required for Mimic board display(bus voltage, line flow, circuit breaker status, etc.) from KEPS. In the case of power system operation control, whenever a input command is applied via control panel, main control PC sends control signals to KEPS.

E. MAPDRIVER COMMUNICATION

The training simulator use mimic board and mimic control panel as user interface for overall system operation and each one has an exclusive communication channel for stable operation.(Fig. 10) In mimic board, there are 52 indicators, 35 lamps, and those are controlled by mimic controller. Every 0.5 second gathered operation data from KEPS are transmitted to mimic controller through serial(RS232) communication channel with exclusive Map Protocol, and mimic controller distributes data to proper indicators and lamps. In control panel, there are 50 push-buttons for control and small RTU(Remote Terminal Unit). RTU monitors status of each push-buttons, and detects changes in push-buttons. Whenever, push-button changes occur, RTU sends out the event data to Main Control PC through serial (RS485) communication channel with general DNP protocol.
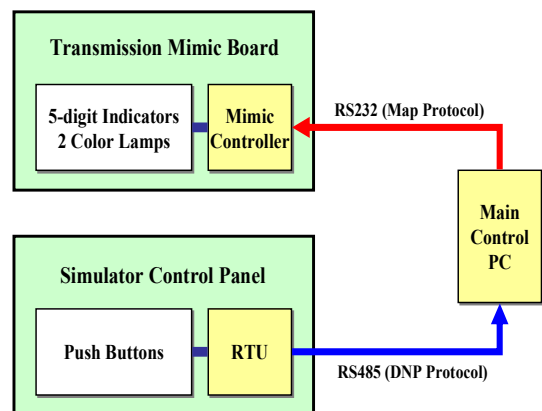

Fig. 8 Data transfer between control mimic & mapdriver

IV. TWO-AREA SYSTEM REPRESENTATION

The case system is similar in structure to the one used in references [1] and [2] to study the fundamental nature of inter-area oscillations. The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having a rating of 900 MVA and 20kV. The generator parameters in per unit on the rated MVA and kV base are as follows:

$$X_d = 1.8 \quad X_q = 1.7 \quad X_l = 0.2 \quad X'_d = 0.3 \quad X'_q = 0.55$$
$$X''_d = 0.25 \quad X''_q = 0.25 \quad R_a = 0.0025 \quad T'_{d0} = 8.0s \quad T'_{q0} = 0.4s$$
$$T''_{d0} = 0.03s \quad T''_{q0} = 0.05s \quad A_{Sat} = 0.015 \quad B_{Sat} = 9.6 \quad \psi_{T1} = 0.9$$
$$H = 6.5(for\ G1\ and\ G2) \quad H = 6.175(for\ G3\ and\ G4) \quad K_D = 0$$

Each step-up transformer has an impedance of per unit on 900MVA and 20/230 kV base, and has an off-nominal ratio of 1.0. The transmission system nominal voltage is 230kV. The line lengths are identified in fig. shown below. The parameters of the lines in per unit on 100MVA, 230kV base are

$$r = 0.0001pu/km \quad x_L = 0.001pu/km \quad b_C = 0.00175pu/km$$

The system is operating with area 1 exporting 400MW to area 2, and the generating units are loaded as follows:

$$G1: \quad P = 700MW, \quad Q = 185MVAr \quad E_t = 1.03\angle 20.2°$$
$$G2: \quad P = 700MW, \quad Q = 235MVAr \quad E_t = 1.01\angle 10.5°$$
$$G3: \quad P = 719MW, \quad Q = 176MVAr \quad E_t = 1.03\angle -6.8°$$
$$G4: \quad P = 700MW, \quad Q = 202MVAr \quad E_t = 1.01\angle -17.0°$$

The loads and reactive power supplied by the shunt capacitors at buses 72 and 73 are as follows:

$$BUS\ 7: \quad P_L = 967MW, \quad Q_L = 100MVAr \quad Q_C = 200MVAr$$
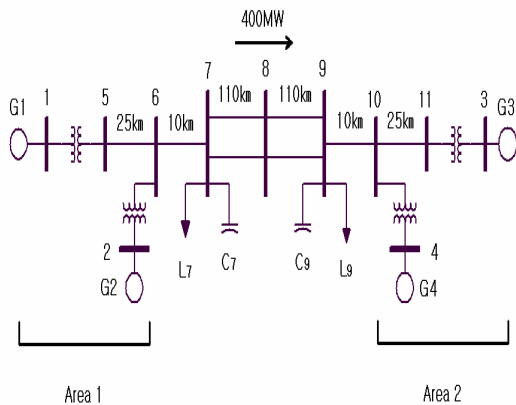$$BUS\ 9: \quad P_L = 1,767MW, \quad Q_L = 100MVAr \quad Q_C = 350MVAr$$

Fig. 9 Two-area system representation

V. TRANING SCENARIO

Under emergency conditions the operator, has to make quick decisions, with little concern for the optimality of the operating point. Hence an efficient and direct training scenario is always required. Details of these training scenarios are given in this section V. The two-area system is presented to show the effectiveness of the training method.
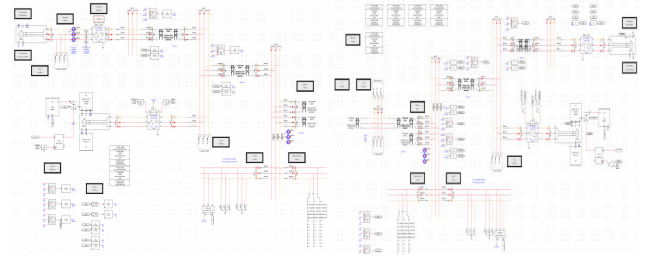
Fig. 10. KEPS Draft Area 1   Fig. 11. KEPS Draft Area 2

A. Effect of Power System Stabilizer (PSS)

Power System Stabilizers are used in the excitation systems of synchronous machines for the purpose of enhancing the dynamic stability of power generating systems. Such stabilizers using speed, power or frequency as input signal when applied with high initial response excitation systems are effective in damping low-frequency oscillations which may occur in the system. The straight forward steps are as follows.

(1) Identify phase angle, P & Q for Generator 1 & 2
(2) Switch off PSS # 1 ~ 4
(3) Apply Bus fault (0.2s duration)at 74
(4) Phase angle, P & Q oscillations
(5) Switch on PSS# 1 ~4
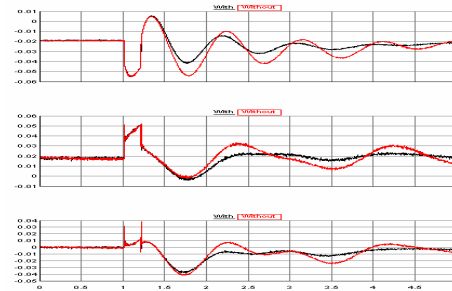(6) Repeat step (3)
(7) Observe 3-dimensional result

Fig. 11 Effective in damping low-frequency oscillations at G2, G3 & G4

As shown in Fig. 11, the degree of damping of power oscillation is greatly improved.

B. Rescheduling Generation to restore frequency

Modern power systems are heavily loaded or vice versa. In this case, a lightly loaded condition or at about 3 a.m serving predominately residential customers is assumed.

Then, decreasing load signals were sent to the 72 & 73 bus that reduced load at those areas by   MW within a few seconds. Frequency rise may occur as a result of a sudden decrease in system load. Manual action was taken to restore frequency. This was accomplished by pushing 5 times. System frequency during the event was reached at 60.73 before frequency was returned to normal. The straight forward steps are as follows.

(1) Assume off-Peak condition
(2) Identify load at bus 72 & 73
(3) Decrease load at 72 & 73 bus
(4) Check the generators output & frequency
(5) Rescheduling generation G1 & G3 to restore frequency
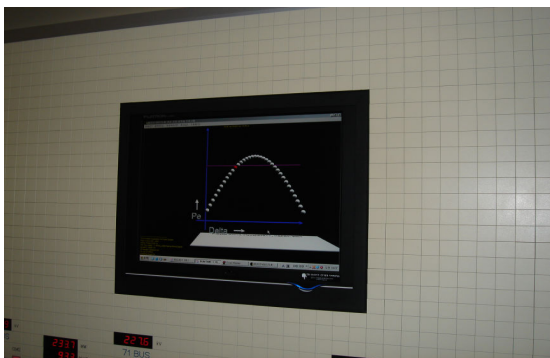(6) Observe freq, phase angle, P & Q

Fig. 12 Rescheduling generation to restore frequency

C. Loss of a Transmission Line

The system consists of two similar areas connected by a weak tie. An emergency may occur as a result of unexpected partial or total outage of a transmission line. Transmission line between 72 and 73, tie-line #1 & #2 were carrying 400MW at that time. Assume, one of the tie-line tripped, probably due to lighting and the opening of a breakers resulted in a voltage drop at 72 & 73 buses. The line opening led to a sudden increase, and finally stoppage of power flow on tie-line#1 from area 1 to area 2. These loading conditions were near system protection limits. With a tie-line out of service, remedial action scheme operated and reclosure at both ends. The straight forward steps are as follows.

(1) Assume case b step (6)
(2) Loss of a transmission line
(3) Check the bus voltage at bus 72 & bus73 & frequency
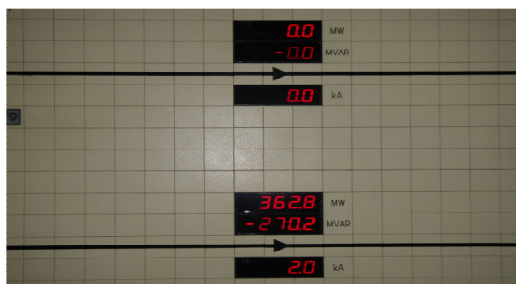(4) Apply remedial action, reclosing the open line

Fig. 13 Loss of a transmission line

VI. CONCLUSIONS & FUTURE WORK

We believe this training system has made significant advances in the area of power system training, education and visualization. Through simulator and mimic board training the operators have obtained related knowledge concepts and deepen their understanding about their operation. At the same time they can also enhance and sophisticate their operation skill. It has been demonstrated that new training system have worked coordinately and is an effective training method. Visualization can also play a crucial role in reducing the risk of future blackouts by helping operators to quickly assess a potentially rapidly changing system state, and by helping them to formulate corrective control actions. Nevertheless, significant challenges remain. Key challenges include the problem of wide-area visualization of all pertinent system quantities, the incorporation of new system measurements into the visualizations such as those from phasor measurement units and substation IEDs, the visualization of time-varying system information, the integration of enhanced visualization into existing KEPS applications. Hence, more research is certainly needed to develop better methods for visualizing these data. In future, more training courses will be coordinated to establish a more comprehensive education & training programs.

VII. REFERENCES

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VI. BIOGRAPHIES

Seung-Tae Cha has a B.S degree in Electrical Engineering from Illinois Institute of Technology, Chicago in 1992, and a M.S degree in Electrical Engineering from Yonsei University, Korea in 1997. Upon graduation, he joined the Korea Electric Power Research Institute where he was actively engaged in the development of KEPS, a fully digital real-time simulator, other various research projects and instruction of utility personnel in technical & software training courses. He is a senior researcher and his present interest includes real-time simulation of power systems, model development, studies involving load flow, system planning & operation.

Tae-Kyun Kim received his B.S, M.S and Ph.D. degrees in Electrical Engineering from Hanyang University, Korea, in 1986, 1989 and 1993 respectively. He is a principal member of the Technical Staff in the Power System Analysis Center at KEPRI which is a research center of Korea Electric Power Corporation(KEPCO), Korea. He has been project leader in several simulator studies related to development of various models and software for KEPS. His research interest includes real-time digital simulation, transient & dynamic stability, power system planning and operation.

Chul-Kyun Lee received his B.S and M.S degree in Electrical Engineering from Kwangwoon University, Korea in 1995 and 1997 respectively. He has been a research engineer of LS Industrial Systems Co. Ltd since 1999 and he performed several projects related to Real Time Digital Simulation of power systems. His major research topics are large power system simulation and power system modeling in real time simulation environment and FACTS, HVDC analysis with digital simulation.

Jeong-Hoon Shin received his B.S, M.S and Ph.D. degrees in Electrical Engineering from KyungPook National University, Korea, in 1993, 1995 and 2006 respectively. He is a senior member of the Technical Staff in the Power System Analysis Center at KEPRI which is a research center of Korea Electric Power Corporation (KEPCO), Korea. His research interest includes real-time digital simulation, transient & dynamic stability, power system planning and operation.

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Su-Chul Nam received his B.S and M.S degree in Electrical Engineering from Korea University, Korea in 2001 and 2006 respectively. He has extensive experience with transient and dynamic stability. He has performed and directed load flow, short circuit, railroad electrical system, and protective relaying studies. Mr. Nam joined KEPRI's Power System Analysis Center as a researcher in Feb 2006 where he is developing an integrated optimization scheme for reactive power management system for KEPCO and also participating in several transmission power system studies.