Development and Testing of a Large Scale Digital Power System Simulator at KEPCO

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Abstract: This paper deals with the development and testing of a large scale, real time digital power system simulator for the Korean Electric Power Corporation. The so-called KEPS Simulation Center is to be located at KEPCO's research center (KEPRI) in Teajon, South Korea and is expected to be in full operation by September 2001.

The KEPS Simulation Center includes a wide range of off line power system simulation and analysis tools, as well as an advanced real time digital simulator for the study of large scale AC and DC system performance.

Because the application scope of the KEPS real time simulator is broad, and because the network models being considered are significantly larger and more complex than in traditional real time simulator applications, many developments and tests have been required during the course of the project. In this paper, the authors will describe some of these developments and will present results from various benchmark tests that have been performed.

Keywords: Real Time Simulation, Non Real Time Simulation, Electromagnetic Transient, Stability, Power System Analysis.

I. INTRODUCTION

In the next several years it is expected that the Korean power system will continue to experience widespread growth and expansion. Such growth will without doubt include the application of advanced power system technologies and techniques such as Ultra High Voltage (UHV) transmission, FACTS, HVDC and tie-line interconnection to neighboring and distant networks. In order to fully understand and take advantage of such techniques, the Korea Electric Power Research Institute (KEPRI) has undertaken a project that will see the development and installation of a large scale power system simulation and study facility [1].

KEPCO is expecting to use the real time aspects of the KEPS simulation facility to perform detailed digital simulation studies of electro-magnetic / electro-mechanical transient phenomena as well as dynamic phenomena in the power network. Interactions between equipment like protective relays, controllers and power electronic devices will be studied in detail. KEPCO will test and investigate the performance and correct operation of protection systems, regulators, stability control devices and various advanced FACTS systems.

It is also expected that the KEPS facility will serve as a training and education center for KEPRI & KEPCO engineers and operators.

II. POWER SYSTEM ANALYSIS TOOLS

A number of analytical tools are available for the study of generation, transmission and distribution systems. With the exception of the traditional analogue Transient Network Analyzer (TNA), most tools are based on digital computer simulation techniques. The most suitable tool(s) for any one application depend on the specific goal(s) of that particular study.

Although the actual number of simulation tools available for study of power systems is large, most can be grouped into one of a few general categories.

Loadflow (or Power Flow) programs are used to study the steady state operating conditions of an existing or proposed power system. Such studies address the power system under balanced three phase operating conditions. No negative or zero sequence phenomena (or parameters) are considered.

The basic purpose of the loadflow simulation is to determine whether proposed system operating conditions are within the capabilities of installed equipment. Under acceptable system operating conditions all generators must operate within their real and reactive power limits, all bus voltages must remain within specified limits and all equipment loading must be within acceptable limits.

Typically, the loadflow study includes a large network model (several thousand buses is common). Many simulation cases representing a wide range of operating conditions are examined.

Stability programs are used to determine whether a network will remain in synchronism following a significant disturbance.

Power system stability, by definition is the measure of a network's ability to return to an acceptable steady state operating condition following a disturbance.

Network instability can occur in one of two general forms: (i) steady increase in machine rotor angle due to lack of synchronizing torque, or (ii) machine rotor oscillation of increasing magnitude due to insufficient damping torque.

Depending on the type and magnitude of the disturbance being studied, the stability problem can be classified as either transient or dynamic.

Transient stability simulation is the most common method to study long term electromechanical behavior of power systems. It is the transient simulation result which is used to determine whether a network will return to acceptable operating conditions following the occurrence of major disturbances such as transmission system faults, loss of generation, sudden change of load, transmission line switching, etc.

Dynamic stability simulation (sometimes referred to as small-signal stability) is used to evaluate the ability of the network to maintain synchronism under small disturbances. Dynamic simulation is really a simple extension of the loadflow solution in which a slightly more complex representation of machines can be included. Since the disturbances considered in dynamic simulation studies are small, a linearized set of equations can be applied during the solution. As in the case of loadflow simulation, typical studies might include thousands of buses and hundreds of generators.

Electromagnetic transient simulation studies are concerned with fast transients on power systems. Network and component models include more detailed representation than in the case of loadflow or stability simulation.

Electromagnetic transient simulation is based on concepts introduced by H. Dommel in his 1969 publication [2]. According to the Dommel algorithm, all passive components within the network can be converted to an equivalent resistor in parallel with a current source. The equivalent resistance value is time invariant (except if switching occurs) and depends on the component type and its parameters. The current injection on the other hand is time and history dependent and must be updated each time a new system state is produced.

Most of the electromagnetic transient simulation programs apply the trapezoidal rule of integration. Trapezoidal integration is both numerically stable and accurate enough for practical purposes.

Unlike loadflow and stability, electromagnetic transient simulation includes unbalanced system representation. Fast transients such as those caused by switching or even lightning phenomena can be studied. The chosen simulation time step (?t) will directly effect the fastest transient that can be accurately represented. Smaller time steps allow representation of higher frequency phenomena. However, as the time step is decreased the computer time required to complete the required calculations increases. Typical electromagnetic transient simulations are performed using a time step in the order of 50 usec.

Electromagnetic transient simulation programs like EMTP and EMTDC are used to study system and equipment behavior over a very short period of time. In addition, because of the complexity of the solution algorithm, these programs generally deal with a reduced version of the original power system. Various reduction and equivalencing techniques exist which allow the user to retain important characteristics of original system in the simulation model.

Real time simulation can be performed using either analogue or digital technology.

Most analogue simulators are actually hybrid in that they are comprised of both analogue and digital components. The analogue/hybrid simulator represents a natural extension of the traditional analogue TNA, which has been applied in power system studies over the past several decades. Although analogue simulator studies have been widely applied by both equipment manufacturers and utilities, it is well known and well understood that several limitations and approximations are inherent in such studies. Perhaps the most significant difficulty with the analogue TNA relates to excessive damping.

The analogue TNA is essentially a scaled down replica of the actual power system. The simulator consists of various discrete analogue components that are connected together in a way that matches the actual network. Since the actual system includes various linear and non-linear components operating under high voltage and high current conditions, a scaled down model should accurately represent the response of these components at low voltage and current conditions. This is not trivial since the properties of the actual component don't necessarily scale linearly. For example, a transformer model on the simulator will contain a significantly higher resistance to inductance ratio than the actual unit. Special electronic components have been used to compensate for excessive losses, however the application of such techniques is difficult and can lead to erroneous results and even instability if not applied correctly.

The main advantage of the TNA is its ability to operate in real time and hence its usefulness in testing physical equipment. Because of complexity in system set-up and calibration, analogue TNA's normally include a relatively limited network model. Portions of the network that are considered distant from the main area of study are either ignored or represented as equivalents.

During the past decade several important advances have been made in digital computer hardware and in solution algorithms for the power industry. Perhaps the most significant evidence of this relates to the introduction of a fully digital real time power system simulator [3]. Real time digital simulation essentially combines the modeling accuracy and flexibility of computer based simulation programs with the real time operating aspects of the TNA.

III. THE KEPS SIMULATOR

At the core of KEPS simulation facility is the RTDS® Real Time Digital Simulator. The hardware architecture of the RTDS is based on parallel processing. A large number of Digital Signal Processors (DSP) participate in the simulation of the network solution as well as the individual power and control system components connected within the network. Each DSP is assigned specific computing tasks based on the topology of the network defined by the user. Timing and operation of all DSP's is synchronized to a single master timestep clock that ensures accurate coordination of both computation and data exchange (data transfer).

For the KEPS project, nearly one thousand high-speed digital signal processors (DSP's) are included in the RTDS hardware architecture. The Analogue Devices AD21062 DSP has been utilized in so-called triple processor Cards (3PC) used by the RTDS. Figure 1 includes a view of the KEPS simulator hardware. In total, 26 racks of hardware, mounted in 13 cubicles are used for the KEPS real time simulator.

Operation and control of the KEPS real time simulator is accomplished through user friendly graphical interface software, PSCAD® [4]. A number of developments were carried out to improve the applicability of PSCAD to real time simulation of *large scale power systems*. Figure 2 illustrates two of the available PSCAD modules; Draft, used to define the circuit and specify network parameters, and RunTime, used to operate and control the simulation case.

Figure 3 illustrates the basic layout of the KEPS RTDS simulator in Korea. Although the simulator can be operated as one large unit, its modular design also makes it possible to run several smaller simulators simultaneously, so that several studies can be carried out in parallel. From figure 3, it can be seen that the final installation of KEPS takes advantage of the inherent modularity and that separate study areas have been provided for protection development & testing, HVDC development & testing, SVC development & testing, FACTS development & testing and for power system development & analysis. With this approach, KEPRI is able to take full advantage of the real time simulator in all planned areas of application.

IV. THE KEPS REAL TIME NETWORK MODEL

The power system configuration upon which the size of the real time KEPS simulator (i.e. number of processors) has been based is a dynamically reduced equivalent of the expected Korean power system in the year 2010. The portion of the system with voltages of 154 kV and above has been considered in the specified Largest Equivalent

Figure 1 KEPS Real Time Simulator Hardware

Figure 2 KEPS PSCAD Software Modules

System (LES) model. For the LES at least the following components should be included:

?? 30 Generators c/w AVR & Gov/Turbine
?? 30 Generator Transformers
?? 15 Step Down Power Transformers
?? 6 Lumped Passive Loads
?? 66 Dynamic & Other Load Models
?? 8 Voltage Sources
?? 24 Three Phase Circuit Breakers
?? 17 PI Model Lines (short lines)
?? 11 Single Circuit Lines
?? 92 Twin Circuit Lines
?? 1 Triple Circuit Line
?? 1 Quadruple Circuit Line
?? 124 Buses
?? Multiple Movable Fault Branches

In addition to the LES, KEPRI will set up a large number of smaller networks in order to study behavior of various devices under various network and operating conditions. Additional components to be represented on the real time simulator of KEPS include:

?? HVDC Converters and Controllers
?? SVC Systems and Controllers
?? Measurement Transducers
?? Induction Machines
?? TCSC and Controllers
?? STATCOM/UPFC and Controllers
?? Power Plant Models
?? Protective Relay Models

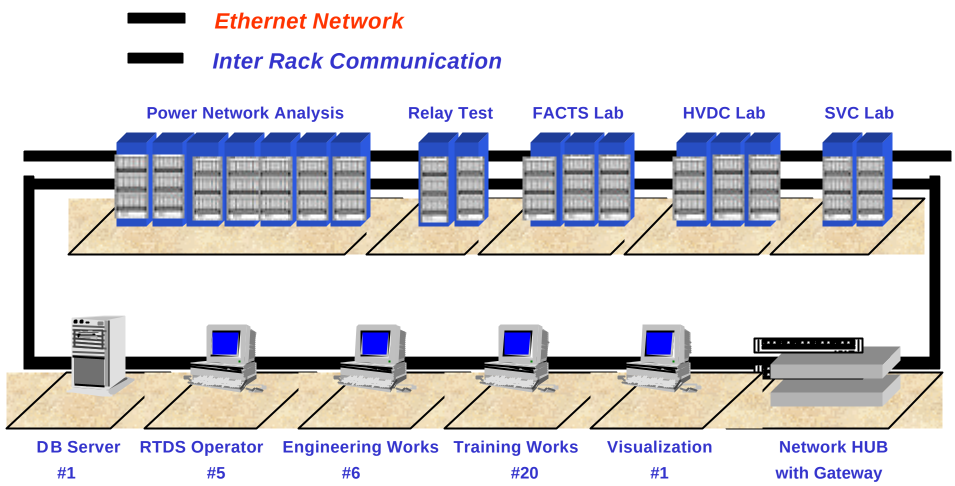


Figure 3 Final KEPS Configuration

V. RTDS RESULT COMPARISON

Because the KEPS real time digital simulator solves the electromagnetic transient equations on a continuous basis, it is well suited to study a wider range of phenomena than other traditional study tools. In fact, the RTDS can accurately represent the system under fast transient conditions (like emtp), under interfaced real time test conditions (like the TNA), under transient conditions (like stability simulation) and under steady state conditions (like loadflow simulation).

Throughout the KEPS project, the authors have been investigating the extent to which the RTDS simulator can be used within the planned simulation center. As part of this investigation a number of studies have been performed and the results compared with other well known and well accepted programs. In fact, as part of the validation work, RTDS simulator results wer e compared with:

?? Non-real time electromagnetic transients programs
?? Real time analogue/hybrid TNA
?? Transient/Dynamic Stability programs
?? Loadflow programs

In general, RTDS results for each of these types of simulations gave an extremely good match when compared to results obtained from the more traditional programs/tools. The following sample study cases show how well the real time simulator was able to match results from other programs/tools.

***Study Case 1**: SSR Benchmark Validation*

One of the benchmark cases considered for validation of RTDS results was the published IEEE Benchmark for SubSynchronous Resonance [5]. For this case a comparison with the widely used non-real time simulation program EMTDC [4]. Results from EMTDC and the KEPS RTDS are illustrated below.

As can be seen from the plots, results between RTDS and the EMTDC program match nearly exactly.

A comparison against published results also gives a near exact match.

***Study Case 2**: Generator Unit and Controller Validation*

Since KEPCO engineers often use the PSS/E simulation program and since much of the KEPCO network is already available on PSS/E, equivalent models for generator controls were implemented in the RTDS during the KEPS project. More than 24 exciter, governor and turbine models were developed and tested. In addition, several Power System Stabilizer models were considered.

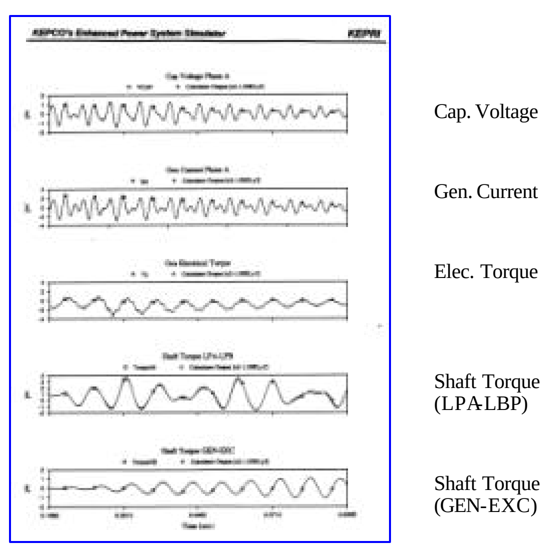


Figure 4 SSR Benchmark Comparison

All RTDS based controllers were initially implemented using the KEPS control system modeling software and tested against PSS/E simulation cases. Once proven to have the correct response, the controllers were collapsed into individual models in order to make them compatible with conversion software that was developed for KEPS. The conversion software allows KEPRI to directly port PSS/e files to the PSCAD/Draft program for use with the KEPS RTDS real time simulator. This conversion software was also one of the deliverables for the KEPS project.

Fig. 5 shows a comparison between PSS/E and RTDS results for a simulation including a generator, exciter and a power system stabilizer. During the simulation a 0.2 sec, 3-phase fault was applied on the generator high voltage bus. The specific generator controllers were chosen from the list of available PSS/e models. In this case the generator includes an IEEE Type 2A exciter, a GAST governor model and an IEE2ST power system stabilizer model. Both the response from the RTDS simulator and from PSS/E program are shown in the figure. As with all other cases, very good correlation is seen.

A number of observations were made during detailed testing and comparison. One of the more interesting points relates to generator representation and response.

Generator representation in the RTDS includes the effect of stator transients on speed deviation while PSS/E ignores this effect. The difference in response can be seen in some of the observed results. In general the PSS/E gives more optimistic response. This effect is well explained in Kundar's text book "Power System Stability and Control"[6], Section 5.1.

Study Case 3: *Large-Scale Simulation Validation*

As part of the final validation and acceptance test procedure, a number of large-scale simulation cases have been studied, and comparisons between the KEPS RTDS and the PSS/e program have been made.

Large scale test cases included in the final validation procedure are based on KEPCO's actual power system.

Several reduced network models were prepared by KEPRI for comparison purposes. Different regions within the KEPCO network were considered in order to gauge both the applicability (and limitations), as well as the accuracy of the RTDS simulator when used for simulation studies of large, complex networks. The results presented below are from the LES system described in section IV above. A large number of individual test cases were run and quantitative comparisons were made between RTDS and PSS/e. The overall comparison includes monitoring of all bus voltages as well as real & reactive power flows at generators, load points and on transmission lines. The acceptance criteria for the KPES project requires very close match between PSS/e and RTDS results for various steady state, dynamic and transient conditions. Whenever differences were noted between PSS/e and RTDS, detailed analysis was carried out to determine and explain the cause of such differences.

In general, the results obtained from PSS/e and RTDS were found to be remarkably close. Criteria for measured bus voltages for example, is 0.05% difference between PSS/e and RTDS. All measured voltages were within this required limit.

Figure 6 shows a result from the LES for one of the operating scenarios defined by KEPRI to validate *Power System Dynamics in Transient State.* The case considers Critical Clearing Time for temporary system faults. The specific sequence of events for the case shown in Figure 6 is as follows:

- ?? Apply 8 cycle 3-phase fault at the selected bus
- ?? Temporarily open selected lines to clear the fault
- ?? Re-apply fault after line re-close
- ?? Open lines permanently
- ?? Capture 10 sec. from initial fault for comparison

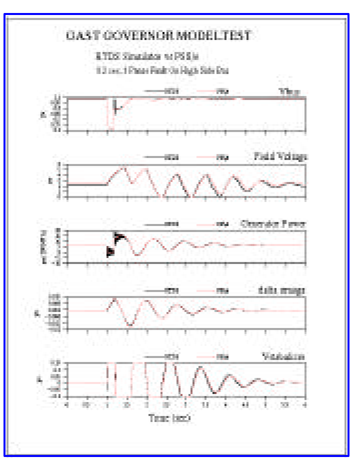
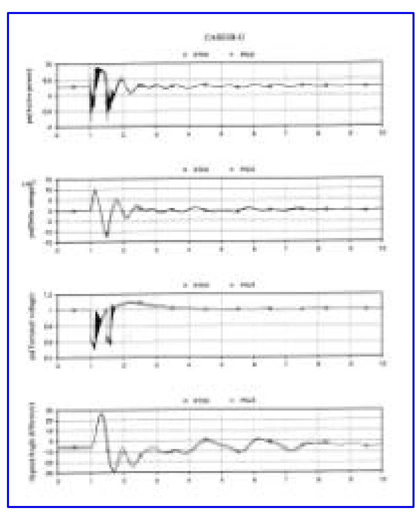


Figure 5 PSS/E vs RTDS Generator Response



Active Power

Delta omega

Terminal Volts

Delta Angle

Figure 6 Comparison of LES test results

VI. CONCLUSIONS

KEPCO/KEPRI, along with other industry leaders have undertaken the development and installation of what is clearly one of the world's most advanced power system simulation and analysis centers. State of the art real time digital simulation methods along with other well known computer based study tools have been applied in the implementation of KEPS.

Extensive verification of the RTDS simulator has been performed as part of the KEPS project. The purpose of the detailed testing is two-fold; first to validate the results of the RTDS simulator and secondly to gauge the applicability and limitations of real time simulation in the context of an advanced power system simulation center.

Based on observations made by the authors, real time digital simulation will undoubtedly play an increasingly important role in the development, study and understanding of power systems.

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