Transient Stability Analysis using Large-Scale Real Time Digital Simulator

Yong-Beum Yoon, Tae-Kyun Kim, Jong-Ryul Won, Jeong-Hoon Shin, Yong-Hak Kim, Seung-Tae Cha and Jin-Boo Choo

Abstract - The KEPS(KEPCO's Enhanced Power system Simulator) Real Time Digital Simulator (RTDS®) is the largest real time power system simulator ever built. A power system which includes 320 (3-phase) buses and 90 generators has been modeled and run in real time. Since such large-scale systems were involved, it was not practical to validate them using non-real time electromagnetic transient programs such as EMTDC™ or EMTP. Instead, the results of the real time electromagnetic transient simulation were validated by comparing to transient stability simulations run using PTI's PSS/E™ program. The comparison of results from the two programs is very good in almost all cases. However, as expected, some differences did exist and were investigated. The differences in the results were primarily traced to the fact that the electromagnetic transient solution algorithm provides more detail solutions and therefore greater accuracy than the transient stability algorithm. After finding very good comparison of results between the RTDS Simulator and PSS/E, and after investigating the discrepancies found, KEPCO gained the necessary confidence to use the large-scale real time simulator to analyze and develop their power system.
Keywords - Power System Simulation, Large-Scale Real Time Simulation, KEPS(KEPCO's Enhanced Power system Simulator), Real Time Digital Simulator (RTDS), Transient Stability, Electromagnetic Transient Simulation

1. Introduction

The Korean Electric Power Corporation (KEPCO), LG Industrial Systems (LGIS), and RTDS Technologies have been involved in a research and development project to produce an advanced power system simulation and study facility, known as the KEPS Simulation Centre. Part of the project, undertaken by RTDS Technologies, was the design and supply of a large scale Real Time Digital Simulator (RTDS) [5].[1]

Although real time simulation of large-scale power systems has long been desired, the application of real time simulators was traditionally reserved for small to medium scale power systems (i.e. less than 70 buses). Analogue-hybrid simulators were physically too large and too expensive for these systems and fully digital simulators of this size were yet to be realized. As a result, large-scale simulations were left mainly to non-real time transient stability programs.

The project described above drew on recent advancements to realize the benefits provided by large-scale real time simulation of power systems. The real time electromagnetic transient simulation would add the following capabilities:

a) faster results through real time performance
b) physical protection and control equipment testing
c) more detailed time domain simulation
d) detailed analysis of power electronic controllers (e.g. HVDC, SVC, TCSC, etc.)
e) real time response for training and education of power system personnel

The KEPS RTDS Simulator is the largest real time power system simulator ever produced. As part of the acceptance tests, it successfully represented KEPCO's Largest Equivalent System (LES). The LES power system includes 160 3-phase buses, 41 generators, 131 single and double-circuit lines, 78 transformers, and more than 60 controlled load models. Continuous, real time operation was achieved for the LES with a simulation timestep of 50 microseconds. Subsequent to the acceptance tests, power systems of up to 320 buses and 90 generators were also simulated in real time, representing an even larger portion of the South Korean high voltage system.

KEPCO expects to use the real time aspects of the KEPS simulation facility to perform detailed digital simulation studies of electro-magnetic and electro-mechanical transient phenomena as well as other dynamic phenomena in the power network. Interactions between equipment such as 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.

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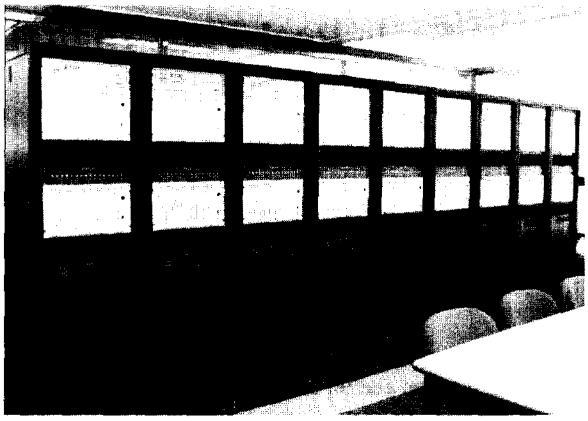

Fig. 1 KEPS RTDS Simulator

2. Simulator Technology

The KEPS RTDS Simulator utilizes customized hardware and software, designed specifically to solve the Dommel electromagnetic transient algorithm [1] in real time. The hardware is based on parallel processing using a large number of floating point Digital Signal Processors (DSP's)[6]. The DSP's 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 depending on the topology of the network defined by the user. The function of each processor is defined completely by software and thus can perform different tasks during different simulations.

For the KEPS project, over 1000 high-speed DSP's were included in the Simulator. Three Analogue Devices AD21062 (SHARC™) DSP's were used on each of the triple processor (3PC) cards installed in the system. The 3PC cards were mounted in 19" racks, each containing thirteen 3PC cards. Fig. 1 includes a view of the KEPS simulator hardware. In total, 26 racks were mounted in 13 cubicles.

In addition to the 3PC cards, each rack also contained a Workstation InterFace (WIF) card and two Inter-Rack Communication (IRC) cards. The WIF card is responsible for coordinating the timing of the calculations performed and the exchange of data between DSP's in its rack. During a simulation involving more than one rack, one WIF card provides the master timestep clock for all racks. Thus, the timing and operation of all DSP's is synchronized to ensure accurate coordination of computation, data exchange between processors, and Input / Output (I/O). This is achieved by linking all of the WIF cards in the simulator to the Global Bus Hub (GBH) via optical fiber. The WIF also provides Ethernet (100BaseT) communication to a Local Area Network (LAN). Each WIF card has an IP address to facilitate the connection. From a computer workstation the user can run, retrieve data, and interact with the power system via the LAN at anytime during a simulation. For all intents and purposes, the user operates the power system.

Power systems larger than 14 buses require more than one rack for the simulation. Normally, one six channel IRC card is installed in each rack to provide direct communication between seven racks. Because of the scale of the KEPS RTDS, two IRC cards were installed in each rack to provide a direct communication link between each rack and 12 others. Although only one IRC card per rack was required to implement the LES, the additional communication channels made general implementation of large-scale systems easier.

The simulator also included vast amounts of both digital and analogue I/O. The I/O, which is serviced in real time, facilitates the connection of external equipment for closed loop operation with the real time simulation.

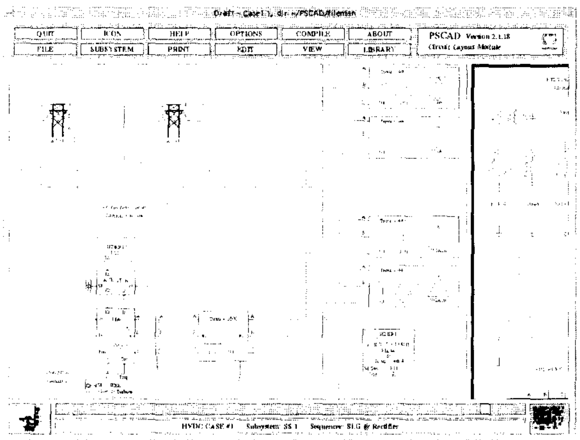

Fig. 2 PSCAD Draft Module

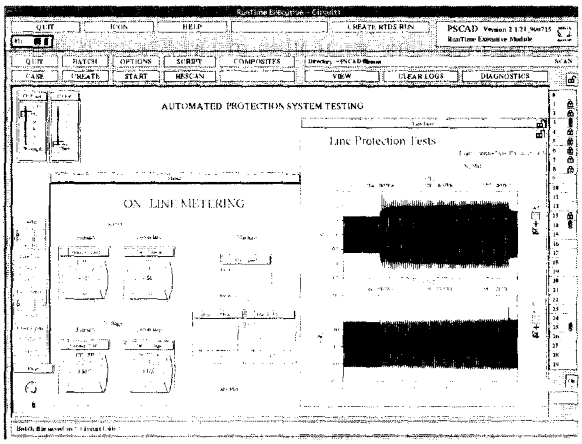

Fig. 3 PSCAD RunTime Module

Operation and control of the KEPS real time simulator is accomplished through a Graphical User Interface (GUI), PSCAD® [2]. A number of developments were carried out to improve the applicability of PSCAD to the real time simulation of *large-scale power systems*. The initial load flow values (e.g. V, P, and Q) were marked on the Run-

Time meters so that the expected power system operation could be verified quickly and easily. The software was adapted to allow display on multiple monitors to increase the operating flexibility. A feature was also added whereby a simulation could be operated from two independent computer workstations (i.e. one for an instructor and one for a trainee). This feature is intended for operator training and allows the instructor to make changes in the system (causing disturbances) to which the trainee should react.

Fig. 2 and 3 respectively illustrate two of the available PSCAD modules, Draft and RunTime. Draft is used to define the circuit and specify network parameters. RunTime is used to operate, control and retrieve data from the simulation.

3. Data Conversion

Traditionally, the simulation of large-scale power systems has been performed using transient stability programs. For this reason, many utilities have already built up models of their systems for programs such as PSS/E. In many instances, as was the case at KEPCO, much time and effort has been invested to produce these models and to keep them up-to-date. Additionally, KEPCO's SCADA system was capable of generating a "snap shot" of the system conditions and storing them in PSS/E data format. A powerful feature to enable simulation of actual network conditions.

To take advantage of this work, the KEPS project included development of a software program to convert PSS/E transient stability input data to RTDS Simulator format. The conversion program utilized the PSS/E ASCII files to create an equivalent PSCAD-Draft graphical file of the system. After the conversion process, the file was available to be modified in Draft if required. The resulting Draft file contained the graphical image of the power system as well as the parameters of the different power system components.

Before the conversion software could be implemented however, all of the components used in the PSS/E simulations had to be made available for the RTDS Simulator. With an extensive component library already available, only specific generator controls and controlled loads needed to be developed.

As described above, all simulations with more than 14 buses were split into multiple RTDS Simulator racks. This is achieved by splitting the large-scale system into subsystems using traveling wave transmission lines. For this technique to be used, the travel time of the lines must be greater than one timestep (corresponding to approximately 20 km). Otherwise, the line can not be used to split subsystems and must be represented as a pi-section. The conversion software was designed to define the different subsystems and allocate them to the different racks. The software also had to determine which lines had to be represented using pi-sections.

In addition to converting the power system data, the software also incorporated the load flow from the PSS/E files to initialize the RTDS components. This feature made the start up of the large-scale simulations virtually seamless.

The conversion software proved to be very practical (i.e. advantage could be taken of the data entry already performed for PSS/E simulations) and efficient for making comparison of results for numerous cases.

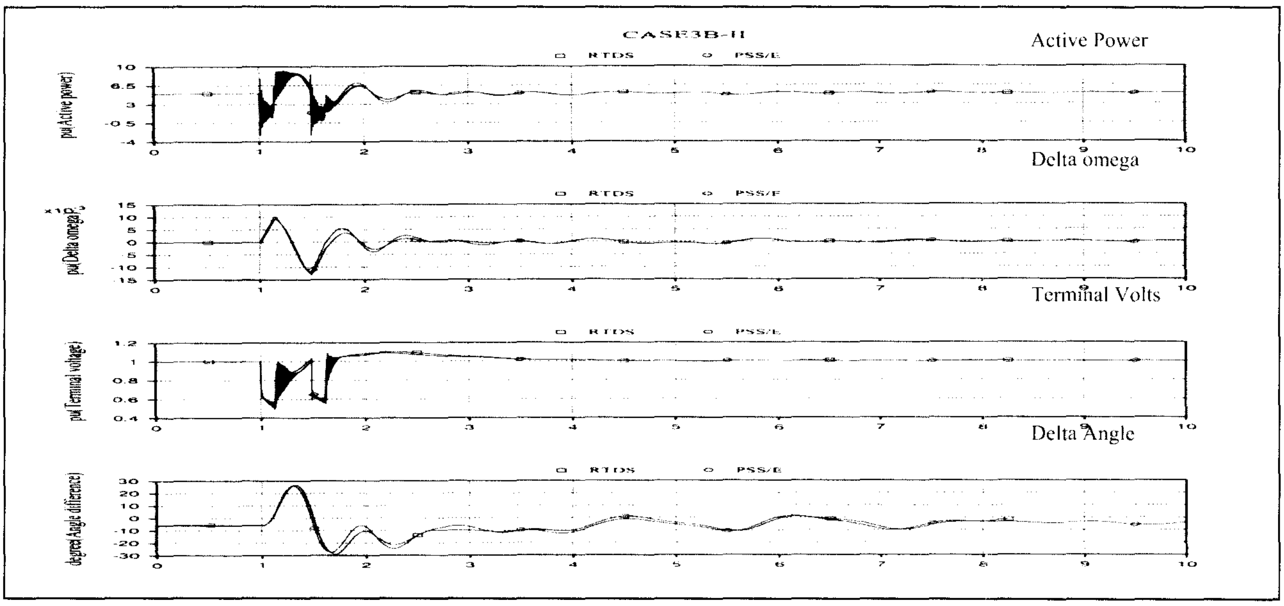

Fig. 4 RTDS Simulator vs. PSS/E Simulation Results

4. Transient Stability vs. Electromagnetic Transient Simulation

For the most part, the results provided from the RTDS Simulator and PSS/E were very similar. Fig. 4 shows a typical result where the comparison was very good. However some differences were observed and investigated.

The following were identified to be the main contributors to the differences observed in the simulation results.

4.1 Phasor vs. Time Domain Solution

The dynamic simulations performed by transient stability programs are based on fundamental frequency calculations. The RTDS Simulator on the other hand uses trapezoidal integration to solve differential equations representing the power system and provides an accurate representation of the power system from DC to a few kHz (with a typical timestep of 50 microseconds). Through its time domain solution algorithm, the RTDS simulation includes phenomena not represented in transient stability programs (e.g. traveling wave transmission lines, transformer saturation, switching of power electronic devices, etc). Additionally, the time domain representation allows the point-on-wave of faults and other events to be controlled.

4.2 Machine Modeling

A more subtle difference between the two programs is the way in which they represent synchronous machines. Both programs use the following d-q equations as part of their synchronous machine representation:

$$e_d = p\psi_d - \omega_r\psi_q - R_a i_d \quad (1)$$

$$e_q = p\psi_q + \omega_r\psi_d - R_a i_q \quad (2)$$

However, the representation used by transient stability programs is simplified by neglecting the terms $p\psi_d$ and $p\psi_q$ in eq.(1) and (2) respectively. These terms represent the stator transients and by neglecting them the stator quantities contain only fundamental components [4]. The simplification greatly reduces the calculations required and allows large-scale systems to be simulated more easily.

On the other hand, the electromagnetic transient simulation technique used by the RTDS Simulator represents eq.(1) and (2) completely as part of a full d-q-0 representation. Thus, the RTDS synchronous machine more closely represents the actual behavior of the machine.

Fig. 5 illustrates the effect of neglecting stator transients on the speed deviation of a machine. Note that the speed deviation calculated by PSS/E is larger than that calculated by the RTDS Simulator and does not include the higher frequency transients. In some instances, it was found that the difference in the two representations tipped the balance between stable and unstable operation of the power system.

4.3 Load Modeling

Typically in the modeling of large-scale power systems, simplified models are used to represent different types of loads. For instance, constant P and Q loads are commonly provided in transient stability programs. Such components were also developed for the RTDS Simulator. However due to the nature of the solution, the components have a controller associated with them. The controller ensures the proper response of the load with respect to varying system

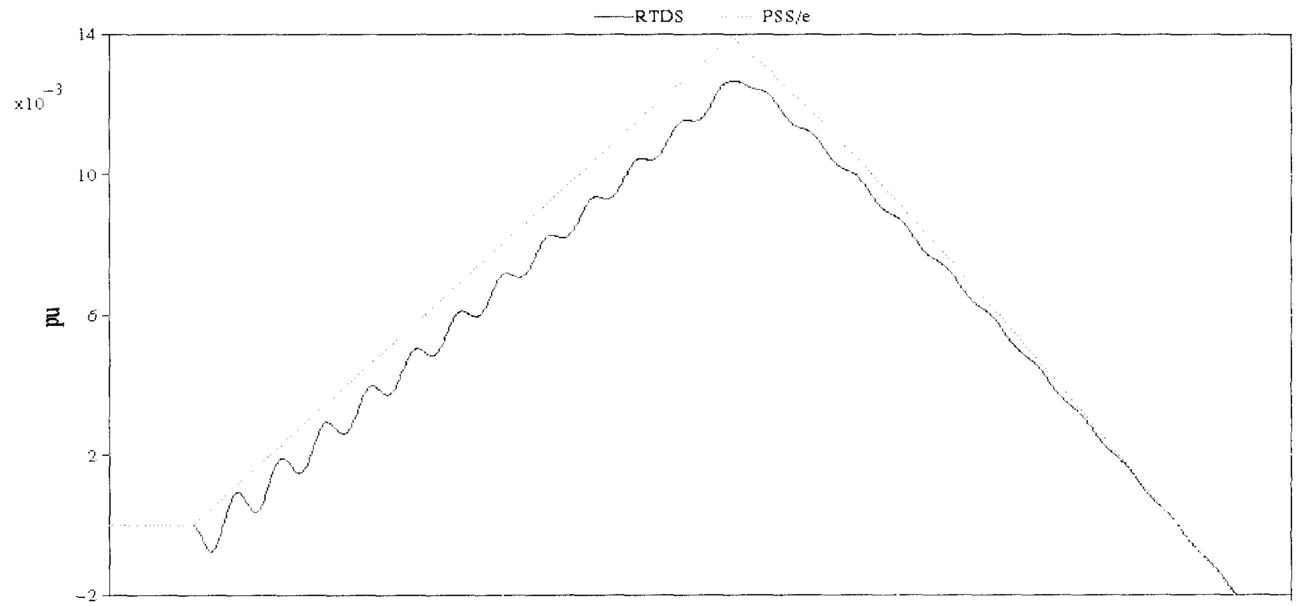

Fig. 5. Effect of neglecting stator transients. RTDS vs. PSS/E

conditions (i.e. ΔV and Δf). Furthermore, the controller is designed to revert to constant impedance when the bus voltage falls below a certain level (typically 0.4 pu), an approach adopted in the industry [3].

No such controller is required for the transient stability load representation. Therefore, a small variation in the simulations will be seen during dynamic conditions as a result of the time constants associated with the RTDS controller.

It was also found in some of the cases investigated that load flow results provided by the transient stability program did not take some details of the generator controls (i.e. limits within the excitation systems) into consideration. In these cases, the load flow provided by PSS/E was not realistic and could not be achieved using the RTDS Simulator.

All of these effects combined resulted in what were usually small differences in results between the two solution techniques. Investigation revealed that the time domain solution provided the more accurate representation of the power system.

5. Conclusions

In some cases, noticeable differences were observed in the results provided by transient stability analysis and the large-scale real time simulation. Investigation showed that the differences could be attributed to the different algorithms used for the two simulations.

The large-scale real time simulation performed by the RTDS Simulator provides a time-domain solution by solving differential equations that represent the power system (and controllers). As such, it provides more accurate results than transient stability analysis. Furthermore, by comparing results obtained from two significantly different solution algorithms, a high degree of confidence was gained that the RTDS simulation results were valid.

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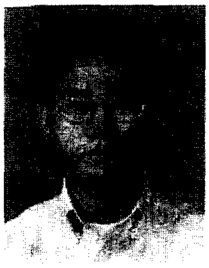

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