HVDC Control and Protection Testing Using the RTDS Simulator

Yong-Beum Yoon, Tae-Kyun Kim, Seung-Tae Cha

Power System Research Laboratory,
Korea Electric Power Research Institute,
Korea

Rick Kuffel, Rudi Wierckx, Ming Yu

RTDS Technologies Inc.,
Canada

Abstract: Many advantages can be gained by integrating High Voltage Direct Current (HVDC) technology with conventional AC power systems. The widespread acceptance of HVDC technology is for a large part due to its fast and effective controllability. Fundamental control of an HVDC system is achieved through well coordinated, interdependent adjustment of valve firing instants at the respective converter terminals. Unlike AC systems, where a combination of relays and circuit breakers provide protection, the HVDC scheme relies on the quick and coordinated response of its controllers.

In order to gain a good and comprehensive understanding of HVDC and its control functions, a real time simulator can be used. In this paper the authors will describe how the RTDS Real Time Digital Simulator can be used to develop and study control strategies for HVDC systems. Control system modeling capabilities of the RTDS will be explained using typical or generic controls modeled internally. In addition, physical HVDC controls will be connected to the simulator and "closed loop operation" with external control will be illustrated and explained. Special aspects of the RTDS simulator for modeling HVDC schemes and for testing HVDC controls will also be discussed in the paper.

1) INTRODUCTION

Simulation is is one of the best ways to gain understanding and confidence of the complex phenomena associated with power systems. Modern computer simulation methods provide accurate representation of both power and control system components. When combined with specialized computer hardware, these simulations can be run in real time. When running in real time, the simulator can be connected to physical hardware such as HVDC or SVC controls, protective relays, generator controllers, etc.

The RTDS real time digital simulator [1] has been successfully applied to the detailed testing of controls for many different HVDC projects [2]. Tests have been performed using both internally modeled controls systems (i.e. the control system block set) and using interfaced physical controllers. Many aspects of HVDC system control and performance can be verified and fine-tuned using the simulation approach.

Benefits gained by detailed simulation studies include;

- increased confidence in system operation under normal and abnormal operating conditions
- decreased on-site commissioning time,
- increased security against unnecessary equipment stresses and failures during initial operation
- decreased risk of in-correct control settings and responses
- general reduction in time from design to in-service date

In this paper a fully digital real-time simulator is used to model both the power systems and the controls associated with HVDC systems. Various phenomena commonly encountered when dealing with HVDC systems was studied and shown. Control loops often included in commercial HVDC control systems are modeled internally to demonstrate their effect on the system performance. In addition, simulations were performed with a physical set of HVDC controls in order to illustrate the general methods of interfaced testing.

2) RTDS SIMULATOR OVERVIEW

The RTDS real time digital simulator utilizes customized hardware and software, designed to solve the Dommel electromagnetic transient algorithm [3] in real time. The hardware is based on parallel processing using a large number of floating point Digital Signal Processors (DSP's)[1]. 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.

The main processing power of the RTDS simulator comes from the specially designed triple processor cards (3PC). Each 3PC card includes three Analogue Devices AD21062 (SHARC™) DSP's. On-board analogue and digital I/O allows direct connection of the processing cards to external physical devices (like the HVDC controller). Up to twelve 3PC cards can be used together in one RTDS rack. One or more racks can be operated together in order to increase simulation capacity (i.e. for larger and more complex systems).

In addition to the 3PC cards, each rack also contains a Workstation InterFace (WIF) card and an Inter-Rack Communication (IRC) card. 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. Power systems larger than 14 3-phase buses require more than one rack for the simulation. The IRC card is installed in each rack to provide direct communication between racks for the purpose of data exchange.

The RTDS simulator also includes 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.

Figure 1 shows a typical RTDS installation with hardware in the background and the computer based Operator's Console in the foreground. Operation and control of the RTDS simulator is accomplished through a Graphical User Interface (GUI), PSCAD® [4]. Figures. 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) MODELING HVDC ON THE RTDS

The RTDS based HVDC valve group model is shown in Figure 4 and includes six thyristors arranged as a Graetz bridge, snubber circuits and the converter transformer. Thyristors are represented as controlled switches whose state changes from low resistance to high resistance based on the status of the firing pulse signal and the voltage polarity. The firing pulse may be derived from firing circuits modeled within the RTDS simulator, or from physical controls

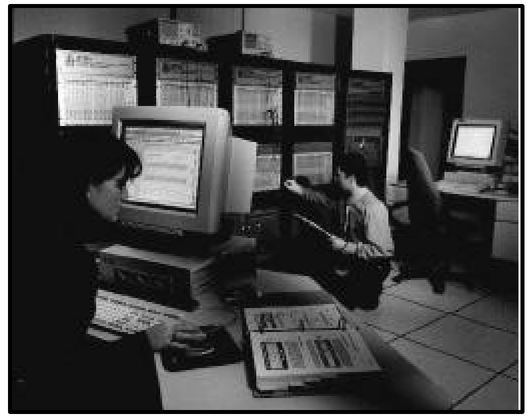

Fig. 1 RTDS Simulator Installation

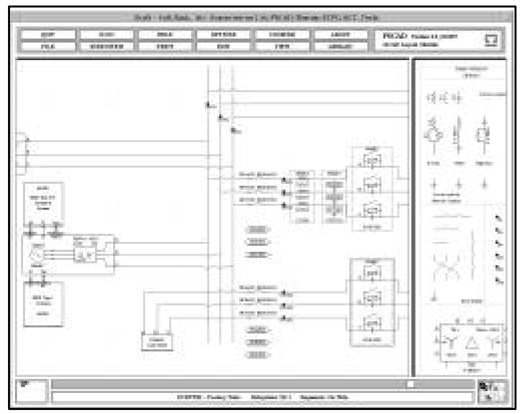

Fig. 2 PSCAD Draft Program Module

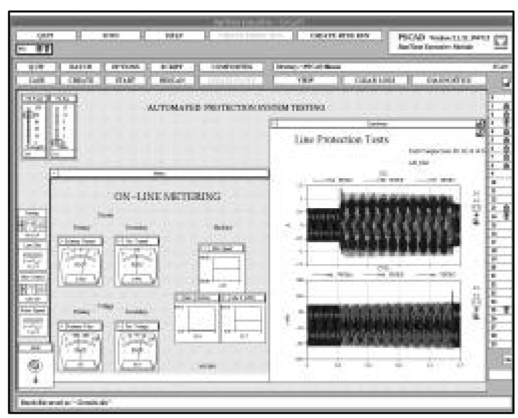

Fig. 3 PSCAD RunTime Program Module

interfaced through one of the RTDS digital input ports.

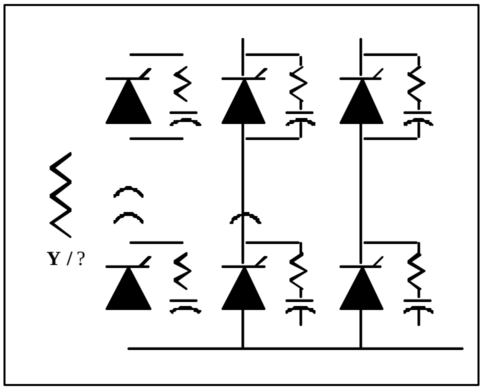

Fig. 4 HVDC Valve Group Model

The valve group model includes the option to have a thyristor return to the low resistance (on) state if positive voltage appears across the thyristor within a user specified time after turning off. This feature models a property of the physical thyristor. Inclusion of this feature will give more realistic response to a sudden change in the inverter AC voltage.

When the current through a thyristor becomes zero a pulse is generated which can be used as input to HVDC controls modeled on the RTDS, or can be sent to a digital output port for use by external controls.

The converter transformer model may be configured as Y_gY or Y_g? and include an algorithm for representation of saturation and hysteresis [5]. The transformer's tap position may be controlled dynamically from a tap changer control circuit modeled on the RTDS, or included as part of physical control connected externally to the RTDS. Tap up/down commands are taken as input and the converter transformer's present tap position is available as output from the valve group model.

It is possible to dynamically monitor the voltage across any thyristor, as well as, both the line side and valve side converter transformer winding currents (Figure 5). The DC Voltage and Current can be monitored separately as part of the power system DC side network.

By modeling the HVDC system and some portion of the surrounding AC system, the user is able to study the performance of the HVDC controller under various conditions.

The question of how much of the AC system to include is an important one. The performance

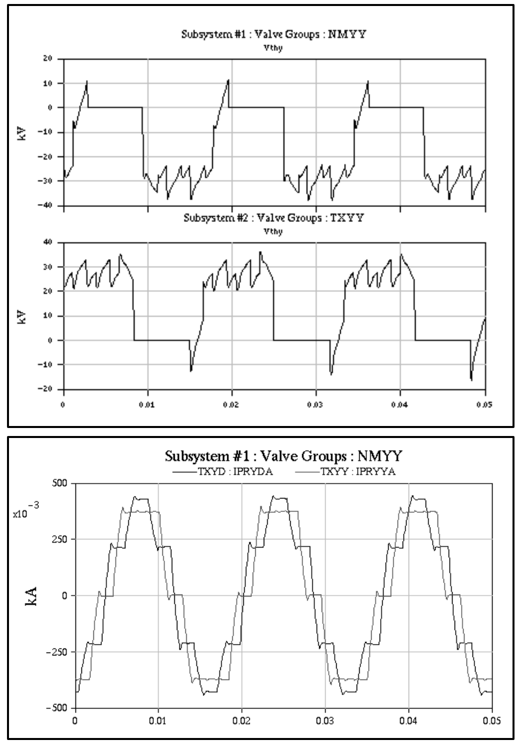

Fig. 5 Typical Waveforms from RTDS

of the HVDC system and in particular the configuration of its controls is very much dependent on the AC system.

4) HVDC CONTROLS MODELING

HVDC controls may be modeled internally as part of the overall simulation case. With the RTDS the user may choose to use a set of *generic* HVDC controls available from the library, or construct their own control system from basic control system function blocks. Figure 6 illustrates a typical control block configuration defined by the User in the Draft software module. The block shown deals with GAMA measurement.

The generic controls available from the library are based on published widely accepted control strategies. Such controls are generally divided in to distinct functional groups with the lowest level of controls (Group Controls) responsible for generating the firing pulses for the thyristors. The next higher level of controls (Pole Controls) produce the firing angle at which the thyristors must be fired and the highest level of control (Master Controls) is responsible for system level operation such as startup and shutdown sequences.

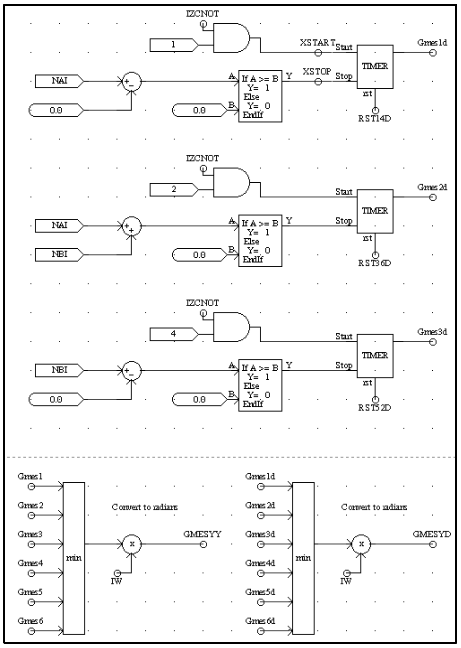

Fig. 6 Example Control Blocks from RTDS

Auxiliary control functions are often included to manage unique system requirements associated with the particular HVDC installation. Protection functions are normally integrated with the HVDC controls, as well. The generic control models available for RTDS include various control and protection functions.

Depending on the application at hand, either internal generic controls or specific user defined controls can be used in the simulation studies.

5) INTERFACED PHYSICAL CONTROLS

Simulation studies often involve verification and testing of real, physical HVDC controllers [2]. The real time nature of the RTDS simulation, coupled with the flexible I/O facilities, make it possible to interconnect physical controllers. In such studies, the physical controls typically monitor system quantities such as ac bus voltages, converter transformer winding currents, dc voltage and current, etc. These quantities are passed to the controls via the RTDS Simulator's analogue output ports. The physical controls in turn, produce firing pulses for the modeled valve group which are imported into the simulation using the RTDS Simulator's digital input ports and other auxiliary hardware. During such simulations, the simulator can also be used as a data acquisition and monitoring system by importing desired external control system signals and plotting them in RUNTIME. Figure 7 shows the typical connections between the simulator and the physical control hardware.

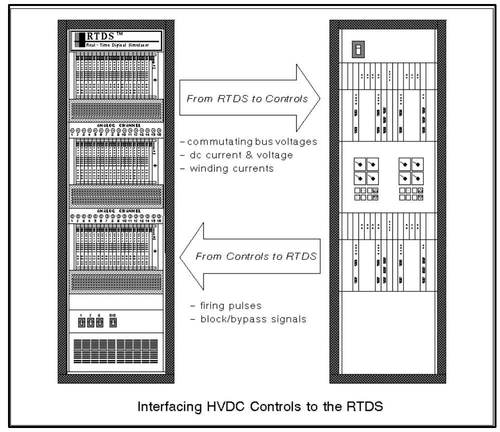

Fig. 7 Physical Controller Connection Method

The basic test set-up of figure 7 can be used when commercial HVDC schemes are studied prior to their installation in the actual power system.

6) PRACTICAL EXAMPLES & SAMPLE RESULTS

Many practical studies involving HVDC systems and controls have been carried out using real time simulation. Studies have been performed both for developmental purposes and for testing purposes. Developmental studies generally utilize the internal control modeling feature of the simulator while testing often involves physical connection of an actual controller to the real time simulator.

Example 1 – Internal Controls Modeling

Figure 8 shows the network and sample output quantities from the HVDC system and its controller captured during a SLG fault at the inverter end AC system. The power system used in this study included a Bipolar HVDC link with a parallel AC circuit. A generator model including AVR, PSS, Governor and Turbine was represented at the rectifier end. The HVDC system included both DC cables and four overhead DC lines. System equivalents were developed for lumped representation of the AC systems.

Many system disturbances were applied and investigated. Since the simulator is able to represent the network in detail and since the simulation is run in real time, many tests can be performed quickly in order to evaluate the performance of the controls and the subsequent response / performance of the overall network.

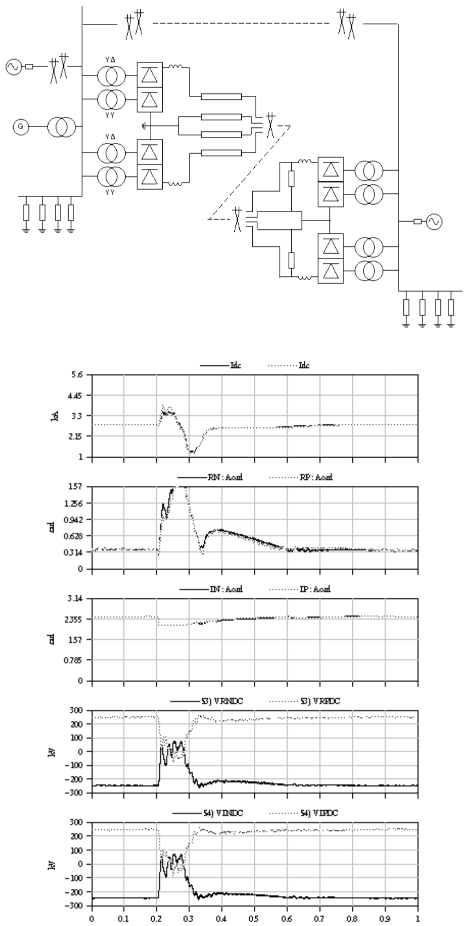

Fig. 8 Circuit & Sample Results
(Internal Controls)

For the case represented in Figure 8, the HVDC controls were modeled internally on the RTDS simulator. The sequence of events associated with the sample results is as follows:

- Wait for POW (400kV) at inverter bus
- Apply SLG on phase A
- Wait for 67 msec
- Open phase A breakers on parallel AC line
- Wait for 350 msec
- Re-Close phase A breakers on parallel AC line

Example 2 – External Controls Modeling

Figure 9 shows the network and sample output quantities from simulation studies involving a interfaced physical HVDC controller. The controller is a duplicate of a microprocessor unit currently in commercial use. The HVDC system is a 200MW monopolar back to back.

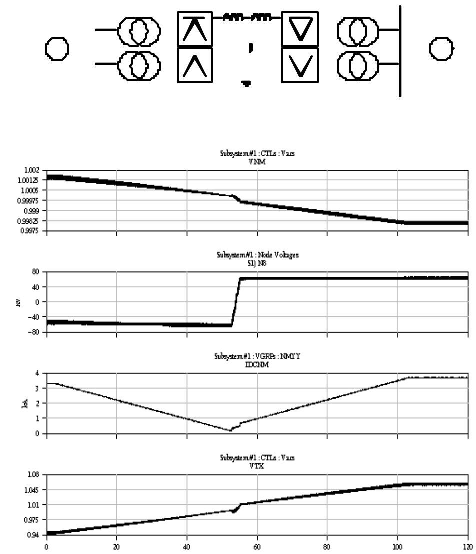

Fig. 9 Circuit & Sample Results
(External Controls)

For the case represented in Figure 9, a power reversal was initiated through the external controller. Plots of AC bus voltages (rms) as well as DC current and voltage are included. It should be noted that the plots shown for the power reversal are over a period of 120 seconds. *Real-Time* simulation is the only practical method available study a sequence of such duration when considering simulation studies.

The test configuration for the external control study included exchange of 48 digital signals between the controller and the RTDS (24 firing pulses and 24 current zero crossing signals). In addition, 15 analogue signals were needed by the controller from the simulator (including AC voltages, DC voltage and converter transformer winding currents).

6) CONCLUSIONS

The application of HVDC technology is widespread in todays modern power systems. The successful operation of integrated AC/DC systems is largely based on the proper performance of controllers associated with the HVDC systems. Although the basic concepts of HVDC control are well understood, a wide range of specialized functions can be seen in the industry. These specialized functions are generally influenced by system configuration and short circuit ratio.

Because specialized control functions can differ widely, detailed analysis and study is needed to evaluate and confirm performance of not only the HVDC link, but also the interconnected AC networks.

HVDC control schemes can be thoroughly investigated using simulation tools. Results from simulation studies are used to refine and adjust control system configurations and parameters so as to achieve the best overall performance of the network. In addition, extensive simulation testing significantly reduces the risk of problems during HVDC system commissioning and initial operation.

When real time simulator studies are considered the control systems can be either internally modeled or they can be physical controllers that are connected to the simulator. With such capability, the simulator can be used from the conceptual design phase of the control system right through to the testing of physical control devices that eventually are installed in the real system.

9) REFERENCES

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