Real−Time Digital Simulator Testing of an On−Line Integrated Stability Control System

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***Abstract* − The paper describes the testing of an on−line integrated stability control system that is to be used to maximize the total power transfer capability of an existing transmission corridor in Japan. The prototype controller which includes the control algorithm of the integrated stability control system is interfaced to a real−time digital simulator for testing.**

I. INTRODUCTION

A 2380 MW thermal power plant located approximately 300 km from the interconnection into the main power grid is planned for the Chubu Electric Power System in Japan. Existing transmission facilities will be used to transfer the power from the generating plant into the grid. In an effort to maximize the total transfer capability of the existing lines and yet maintain security of the interconnection, a 450 MVA STATCOM and a special protection system (SPS) will be included. The SPS includes an on−line transient stability algorithm, details of which are included in [1][2].

The SPS is implemented using a central controller which communicates with terminal control equipment installed in remote substations. The SPS issues control commands to the power system elements under its control. The terminal control equipment also monitors local conditions and provides those measurements back to the central controller.

By installing the SPS and a 450 MVAr (3 x 150 MVAr units) STATCOM, it is expected that the total transfer capability of the twin circuit 275 kV line used to transfer the power from the new generation plant can be almost doubled.

Due to the complex nature of the controller and the number of system elements under its control, testing of the SPS was done by interconnecting the prototype controller of the SPS to an RTDS™ real−time digital simulator. The RTDS was used to model the new thermal power plant, as well as, the power system network between the plant and the grid. The interconnection between the controller and simulator is shown in Figure 1 and details of the power system modeled on the simulator are shown in Figure 2.

II. DIGITAL SIMULATION IN REAL−TIME

Digital power system simulators capable of sustained real−time operation may be used to test physical control and protection equipment. Digital simulators such as the RTDS use the electromagnetic transients (EMT) algorithm with time−steps in the range of 50 micro−seconds. Using parallel processing techniques permits detailed representation of significant portions of the power system.

Interfacing the simulator with external control and protection equipment, which controls or protects components located physically close to the device, is normally accomplished using digital to analog converters and digital input and output ports available on the simulator. The prototype control equipment uses network based packet communication to send and receive data. DNP3 is one of the communication protocols supported by the prototype controller. DNP3 is also supported by the RTDS, and as such, the DNP3 protocol was used for the communication medium between the RTDS and the prototype controller during the testing.

A protocol converter board, referred to as the GTNET, is available with the RTDS to handle the sending and receiving of data over a LAN connection using the DNP3 protocol. Figure 1 shows the arrangement of the hardware required to implement the LAN communications using DNP3 protocol between the simulator and the external control equipment. Measured signals from the power system are sent from processor cards on the RTDS to the communications card via a fiber connection. Firmware on the GTNET card forms the DNP3 packets and sends it over the LAN. Data coming from the controller is received by

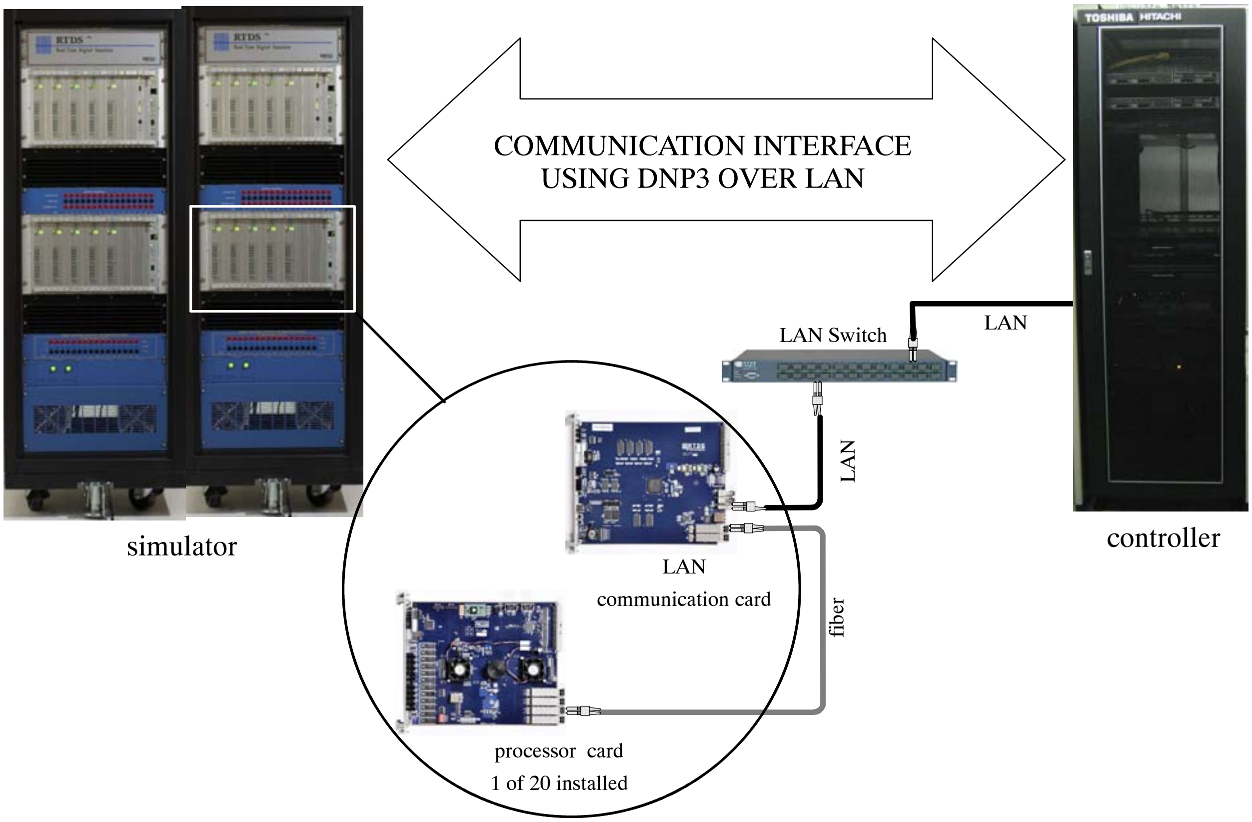

Figure 1: Communication between the Simulator and Controller

the GTNET card which then extracts information from the incoming packets and sends the data to the processor card.

III. SYSTEM MODEL DETAILS

The general structure of the power system representation used to test the SPS algorithm is shown in Figure 2. A simulator comprising 20 processor cards (40 processors) installed over four racks in two cubicles was required to represent the network and its components.

Detailed representation of the generator plant including models of 12 generators each with governor/turbine, AVR and stabilizer functions was included in the model. Models of the over and under excitation limiters (OEL, UEL) were also included for each generator. Four groups of three generators were connected to the transmission grid via a three winding transformer model. Individual generators could be tripped via a unit connection breaker included as part of the power system model.

Representation of loads was done using a dynamic load model where the loads are characterized according to the types of loads (eg. residential, industrial) found in the actual system. The amount of real and reactive load at each load location can be changed dynamically while the simulation is running. Data collected from the real system were used to vary the dynamic load model while the simulation was running so that realistic load cycles were represented. COMTRADE compliant files contained the recorded data used as input to the load models.

Elements of the power system which were under the control of the controller included –

- Transformer taps
- breaker operation
- switching of shunt reactors
- switching of shunt capacitors
- generator terminal voltage control (AVR)
- generator shedding

Signals required as input to the controller include –

- transmission Line P,Q
- generator P,Q
- generator terminal Voltage

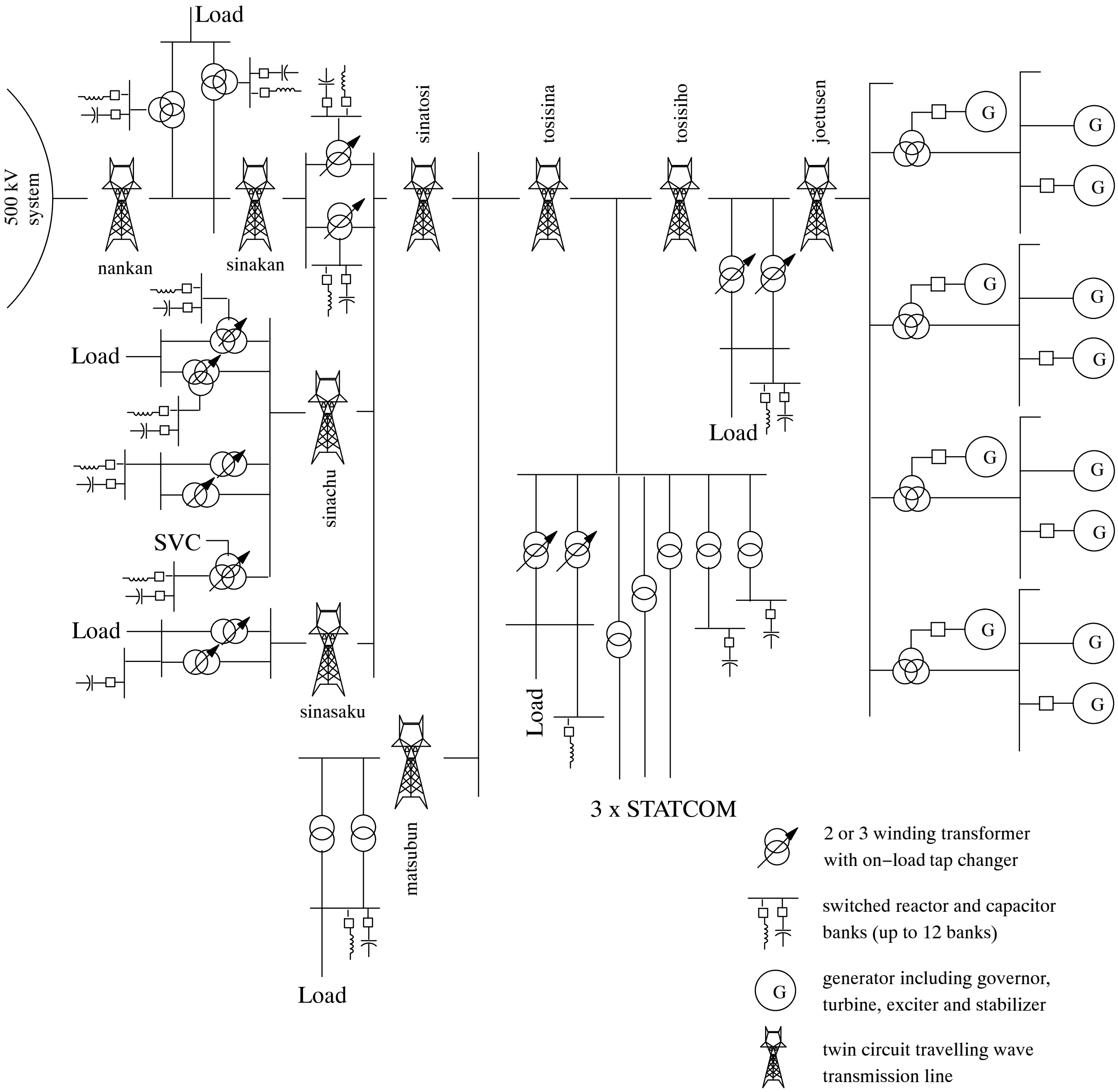

Figure 2: Structure of the Power System Model

STATCOM Q
substation Bus Voltages
transformer tap positions
breaker status

All of the above signals are sent from the simulator to the controller using the DNP3 protocol over the LAN connection.

Named signals representing those that need to be communicated over the DNP3 link are stored in a file accessed by the DNP3 component allocated on the simulator. In all 808 signals are exchanged between the RTDS and the special protection system,

164 Binary Status Signals
512 Binary Control Signals
132 Analog Status Signals

IV. RUNNING THE SYSTEM MODEL

Simulation runs are started from a pre−determined load flow condition, or with the system or portions of the system in a shutdown state. In order to test the full functionality of the SPS, the new generation plant was started in shutdown mode and brought online as the system loads increased. Simulation runs lasting an hour or more were run so that the response of the con-

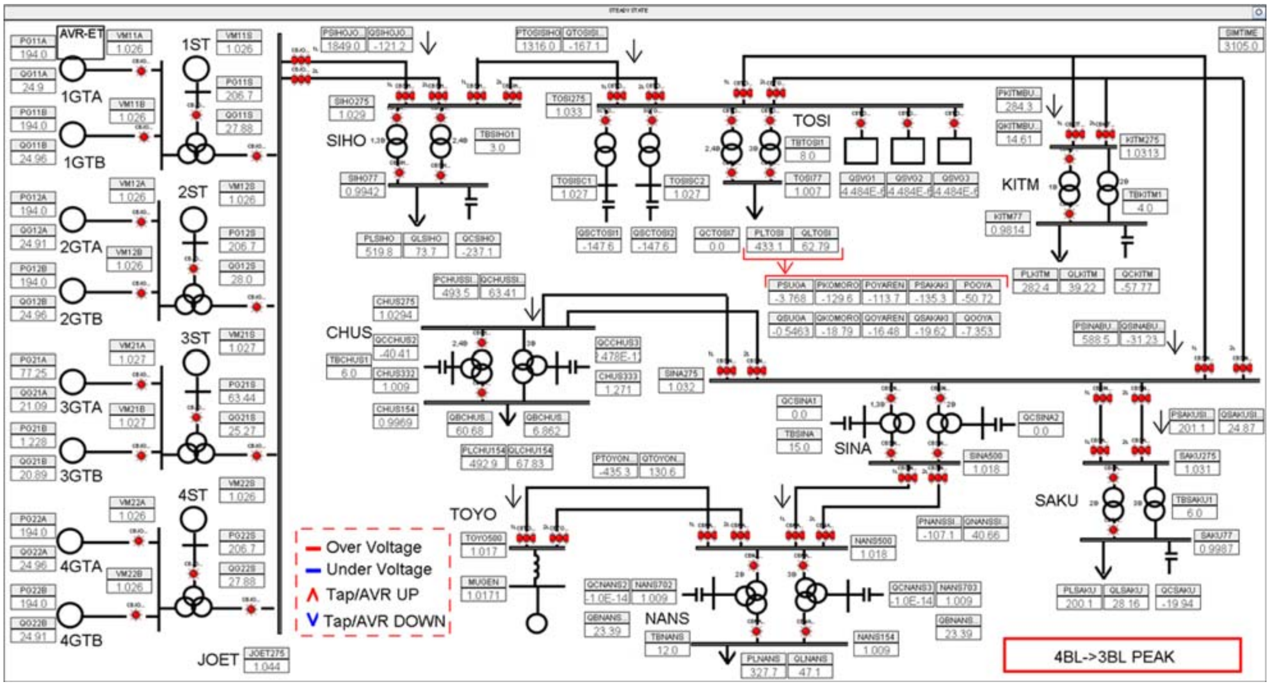

Figure 3: Operator's Console view

trol system to the changing generation and loading conditions could be observed.

Large voltage fluctuations can occur in response to significant load changes when the power is being transferred over long transmission lines. In order to control the voltage fluctuations, the SPS monitors all of the associated substation voltages and determines which of the 45 shunt capacitor and 20 shunt reactor branches should be switched in or out. Set–points for the generator's voltage regulators are also adjusted based on system conditions.

System quantities such as bus voltages, power flows and the state of controlled elements are monitored using the the simulator's operator's console (Figure 3). Both directly monitored quantities, as well as, computed quantities such as positive sequence values are available. Visual and audio cues are provided from the operator's console to indicate when the controller initiates a control change. Over or under voltage conditions in a particular area of the system are indicated by changing the color of the icon representing the bus so that the operators can more easily understand system conditions and corresponding control actions.

Two instances of the operator's console were created, one used for direct monitoring and interaction with the simulation and the second to record events for later evaluation.

In order to test the response of the SPS to severe disturbances, various fault conditions with associated breaker operation sequences were simulated. Faults at various locations in the system with varying fault types and point–on–wave inception points were applied.

The large number of simulation runs required to thoroughly test the SPS were managed using the simulator's script file feature. Script files contain C code which control sequences of events such as fault application and removal, breaker operation etc. FOR and WHILE loops can be placed around the control sequences to cycle through a large variety of conditions. Script files may include instructions to capture, record and analyze data produced by the simulation. In this way the simulator may be set to operate in an automated mode and the operator alerted to results that fall outside of a pre–defined set of criteria. Such simulation cases can then be re–run for closer inspection.

Scripts were also used to initialize the power system model to the many different power flow conditions under which the SPS was tested.

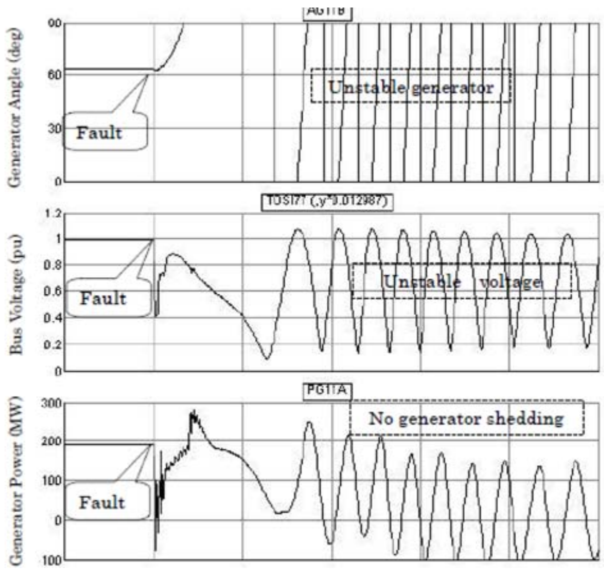

Figure 4a: Response to fault with SPS Off

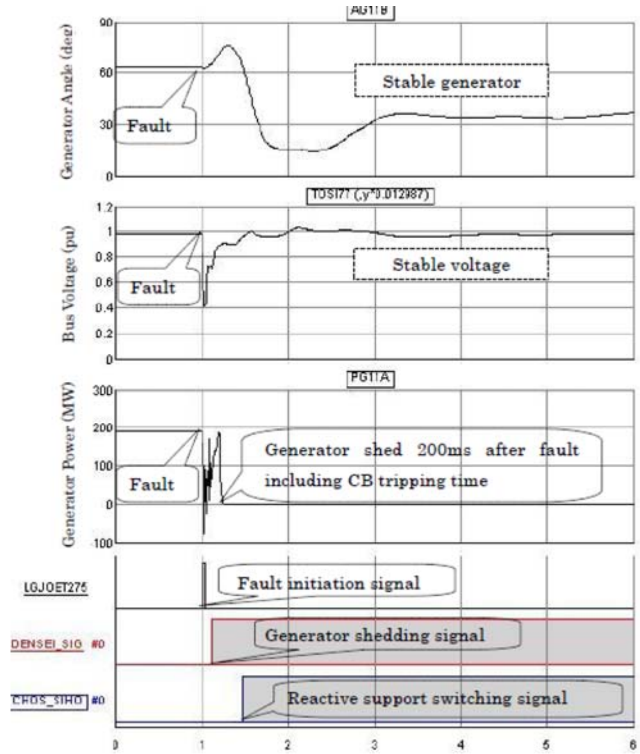

Figure 4b: Response to fault with SPS On

V. SIMULATION RESULTS

Figure 4 shows the unstable simulated system response to a fault in which 3 phases of one circuit and one phase of a second circuit on a parallel line are grounded. The SPS is not active for the results shown in Figure 4a. The fault is repeated with the SPS active and the results shown in Figure 4b. In response to the fault, the SPS issues signals to shed generation and adjust reactive power support. As a result of the SPS action the system remains stable.

VI. CONCLUSIONS

Digital simulators can be used to model power systems with enough detail to verify the operation of complex power system control and protection equipment prior to its installation into the field. Communication protocols such as DNP3 may be used for communication between the external controller and simulator. Large numbers of simulation cases may be run over extended periods in order to validate the operation of the equipment under test.

VII. REFERENCES

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VIII. BIOGRAPHIES

Rudi Wierckx received B.Sc 1983 and M.Sc 1985 degrees from the University of Manitoba. Between 1985 and 1993, he was employed by the Manitoba HVDC Research Center, working on the development of the Real−Time Digital Simulator (RTDS). In 1993 he left the Research Center to form RTDS Technologies Inc. and is currently a director of that company.

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