XIII SEPOPE
18 a 21 de Maio 2014
May – 18th to 21st – 2014
FOZ DO IGUAÇU (PR) - BRAZIL

XIII SIMPÓSIO DE ESPECIALISTAS EM PLANEJAMENTO DA OPERAÇÃO E EXPANSÃO ELÉTRICA

XIII SYMPOSIUM OF SPECIALISTS IN ELECTRIC OPERATIONAL AND EXPANSION PLANNING

Real Time Requirements and Closed-Loop Testing of Wide Area Protection and Control Schemes

C. PETERS, V. NAUMOV, P. FORSYTH, S. CAYRES

RTDS Technologies Inc., EKRA LLC, Cayres Pinto Engenharia Ltda

Canada, Russia, Brazil

SUMMARY
Wide Area Protection and Control (WAPAC) is an exciting new technology in the power systems industry. As with all new technological developments, it is critical that it is thoroughly tested before being deployed in the power network.

One important device, which is often an essential element of WAPAC studies, is the Phasor Measurement Unit (PMU). PMU's are typically placed at various locations in the power network to provide real time monitoring of the system frequency as well as the voltage and current phasors (i.e. magnitude and angle). Today PMU's are found as standalone units and are implemented as features within protection and monitoring equipment. Currently, most PMU data from Wide Area Monitoring Schemes (WAMS) is used for offline analysis, but research is being done to apply the data to protection and control in so called Wide Area Stability and Voltage Control Systems (WACS). Decisions based on the PMU data could be made by WACS schemes to perform many different actions such as the adjustment of generation set points, pick up or drop out transmission lines, shed load, etc. With the use of such actions, these schemes have the potential to be very powerful. At the same time, however, they have the potential to do great harm to the network stability if the wrong action is taken. Therefore an environment for closed-loop, real time testing is essential in developing these schemes so as to ensure they operate in a secure and reliable manner.

This paper will focus on the requirements of a real time electromagnetic transient power system simulator for closed-loop testing of WAPAC schemes. These requirements include simulation models as well as standard industry communication protocols. It is important to have comprehensive libraries of protection and control models in case the functions are not all represented in the equipment under test. Standard industry communication protocols should be available (IEEE C37.118, DNP3, IEC 61850, IEC 60870-5-104). Synchronization of a simulation to an external time reference is also critical to WAPAC testing and will also be discussed.

Finally the paper will present results of testing a Wide Area Protection (WAP) scheme created by EKRA, a Russian manufacturer of protection equipment, using an RTDS® Simulator. The testing conducted by EKRA will also show comparison of the same tests conducted using a hybrid analogue/digital simulator at the JSC "STC UPS" (formerly JSC "NIIPT") institute in St. Petersburg, Russia.

KEYWORDS - PMU, WAPAC, RTDS, WAP

1. Introduction

This paper will focus on the requirements for closed-loop testing of Wide Area Protection and Control (WAPAC) schemes. WAPAC schemes are an exciting new development in the power systems field. Phasor Measurement Units (PMU's) have been used for many years to collect data from the power network which is typically used for offline analysis. WAPAC schemes are currently being investigated as a means to control localized areas in the power network based on information received over a large area.

As it is critical for a power system to be reliable, it is important that new technology installed within it operates correctly. Wide Area Control Systems (WACS) and Wide Area Protection Systems (WAPS) must be thoroughly tested and verified to work in all possible scenarios. The only way to verify that control or protection equipment is functioning correctly is to test it with a real time simulator.

It is also important for the real time simulator to be able to have a common time reference with external equipment. A PMU is locked to a very accurate time signal (ie. GPS clock) and it is important the real time simulator can be synchronized to the same time source for testing. Finally, the real time simulator must be capable of using industry standard protocols in order to communicate with external protection and control devices.

2. Real Time Simulation

Prior to the early 1990's, analogue real time simulators were used exclusively. Analogue simulators consist of scaled down models of the power system (machines, transmission lines, etc). They are expensive, occupy a large area, and require significant expertise to operate. Nowadays, real time digital simulators are almost exclusively used by the world's manufacturers, utilities, and educational institutions.

Real time digital simulators use electromagnetic transient (EMT) algorithms such as the algorithm developed in the late 1960's by Dr. Hermann Dommel [1]. The Dommel algorithm uses the trapezoidal rule of integration to turn differential equations into algebraic equations. The algorithm is performed at discrete instants in time and if executed fast enough (~50 microseconds for typical power systems), provides the frequency range needed for testing physical protection and control equipment. This time is referred to as the simulation timestep.

A real time simulator must provide an instantaneous value solution to the power network under test rather than a steady state phasor representation typical of Transient Stability Analysis (TSA) programs. It must also provide results over a wide frequency spectrum (from DC up to electromagnetic transients). Even though devices such as PMU's and relays operate at fundamental frequency (50/60 Hz), they may mis-operate when exposed to faster transients and other phenomenon. Physical devices can only be tested thoroughly by being exposed to a wide range of disturbances and transients over a wide frequency spectrum.

It is also important for the real time simulator to be able to operate for extended periods of time, while maintaining simulation accuracy and numerical stability. Tests may be required to run over many hours or over multiple days, requiring a reliable simulator. Furthermore, it is important that the simulation results be completely trustworthy. When debugging problems, it is important that the real time simulator is reputable so the simulation results are not called into question if the device under test mis-operates.

3. Simulation Requirements

There are several important requirements for a real time simulator. These range from accurate modelling of power systems and protection and control equipment, to providing communication to external physical devices as well as time synchronization.

3.1 Power System Components

A real time simulator should offer a wide variety of standard power system models. Some of the models necessary for simulating WAPAC schemes are as follows:

- Synchronous and Induction Machines
- Transmission lines and cables
- Transformers with saturation
- Instrument transformers (CT, CVT, PT)
- Faults and Breakers
- Smart Grid Technologies (wind, solar, fuel cell, battery, etc.)
- Power Electronics (FACTS, VSC HVDC, etc.)

Non-linearity's are difficult to model in real time. These include properties such as saturation in a transformer or the frequency dependence of transmission lines and cables. As such, extra care must be taken when modeling these types of components in order to ensure the stability and accuracy of the simulation results.

Often, WAPAC schemes require large power systems to be modeled. It is therefore important that the real time digital simulator be modular and scalable. Real time digital simulators which model many hundreds of three-phase buses are currently in operation [2]. It is important for the simulator to maintain its accuracy when simulating large scale networks and produce results over the entire frequency spectrum for the whole network

3.2 Control and Protection Components

In the same way that power system components must be available, control and protection components are required to simulate WAPAC schemes. Some useful software models include:

- Protective relays (differential, distance, overcurrent, generator, etc)
- PMU models
- Breaker control/synchro check
- Tap changer control
- Comprehensive libraries of logic, math functions, transfer functions, etc (for internal control)

Often, it is not possible to test all the physical devices in a WAPAC scheme using a real time simulator as it could require many hundreds or thousands of inputs and outputs. Therefore, is useful to be able to model devices normally installed in the power network, such as protective relays [3], PMU's or controllers as software components internal to the simulation. These models should be able to be programmed with settings that would typically be found in devices of their type. For example, the model of a PMU should operate according to the IEEE C37.118 standard in order to produce results in line with its physical counterpart.

3.3 Communication

The real time simulator must provide the capabilities for bi-directional communication with physical devices. This is called Hardware In the Loop (HIL) testing. The most basic form of communication is in the form of analogue and digital signals. For analogue signals, real time simulators often use A/D and D/A converters in the range of +/- 10V. Digital signals are typically in the range of 0-24V. Many controllers operate within these voltage ranges, however, protective relays typically receive secondary level voltages and currents as inputs. As such, power amplifiers are typically used to provide 64 Vrms and 1 or 5 Arms respectively.

As power systems become more complex, so do the methods of communication used within them. There are now many industry standard protocols that are used to communicate between devices. Network protocols needed to simulate WAPAC schemes include IEEE C37.118, IEC 61850 GOOSE messaging, DNP3, and IEC 60870-5-104. IEEE C37.118 is used to communicate PMU data. It is useful for the real time simulator to be able to stream PMU data from its simulated models onto the network to be available for a Phasor Data Concentrator (PDC) to analyse. Many modern protective relays are equipped with IEC GOOSE messaging, which allows a large amount of information about the relay and its status to be transferred over the Ethernet. In order for the real time simulator to interact with these relays, it must be capable of both sending and receiving GOOSE messages. DNP3 and IEC 60870-5-104 are useful as they are industry standard Supervisory Control And Data Acquisition (SCADA) protocols capable of exchanging large amounts of data.

3.4 Time Synchronization

One critical aspect to testing WAPAC schemes with a real time simulator is to make sure the real time simulator can be synchronized to an external time source (ie. GPS clock). The timestep in a real time

Figure 1: Oscilloscope capture showing analogue output jitter less than +/- 1 µs vs 1PPS signal

digital simulator is generated by an oscillator. Even though oscillators are very accurate, each one has an inherent error. The error will depend on the ambient operating conditions, such as temperature. One effect of this error is the constant phase angles generated by the real time simulator, will appear to drift with respect to an external time reference.

The time protocols most often used in power systems are 1PPS, IRIG-B, and IEEE 1588. It is important that the real time simulator have the ability to synchronize to all of these protocols. The end result is that a constant phase angle will be seen from the real time simulator by the external equipment without drift.

4. Real World Application

Thus far this paper has discussed critical features that a real time simulator must have in order to test WAPAC schemes. Depending on the type of tests, one or more of these features will be used; PMU, time synchronization, communication protocols, etc. The following example highlights the real world use of a real time simulator to test Wide Area Protection (WAP) schemes.

An important part of WAP equipment development involves performing numerous test that serve to both prevent and react to emergency conditions in the power system. The JSC Federal Grid Company of Unified Energy System (FGC UES) Company introduced a standard in 2012 [4] which describes the main requirements for WAP schemes and their devices. It also outlines the tests that must be performed in order to certify WAP devices.

According to the standard [4], WAP functions such as out of step protection, overvoltage protection, underfrequency protection, etc. must be tested using electrodynamic models of the electrical power system that are identical to those used by the JSC High Voltage Direct Current Power Transmission Research Institute (previously JSC "NIIPT"). Under these circumstances, realistic test conditions (which are as close to possible as real operating conditions) are achieved using both a hybrid analogue/digital simulator and by the RTDS® Simulator.

The company EKRA, located in Cheboksary, Russia, recently tested a number of protection functions which are part of the EKRA 223 01 relay protection and automation terminal. Among the functions tested were ALAR (automatic elimination of asynchronous operation – out of step protection), overvoltage protection, line shunt reactor control, etc. These tests were carried out using the RTDS Simulator. The following provides more detail regarding the out of step protection testing.

Out of step operating conditions in a power system are found during emergency conditions and cause instability in the parallel operation of power plants and individual generators. For that reason, it is extremely important to provide early, selective, and reliable detection of out of step conditions in a power system. This will ensure quick elimination of instability and restoration of normal operating conditions. In light of this, stringent requirements have been laid out for the operation of devices to be used for automatic elimination of out of step conditions.

To estimate performance of microprocessor device-based out of step protection, a power system test circuit has been developed and its physical model has been created. NIIPT has significant experience testing out of step protection devices from multiple vendors. This enables them to draw conclusions that the hardware and software being tested is performing correctly as well as define the application area for the protection device [5].

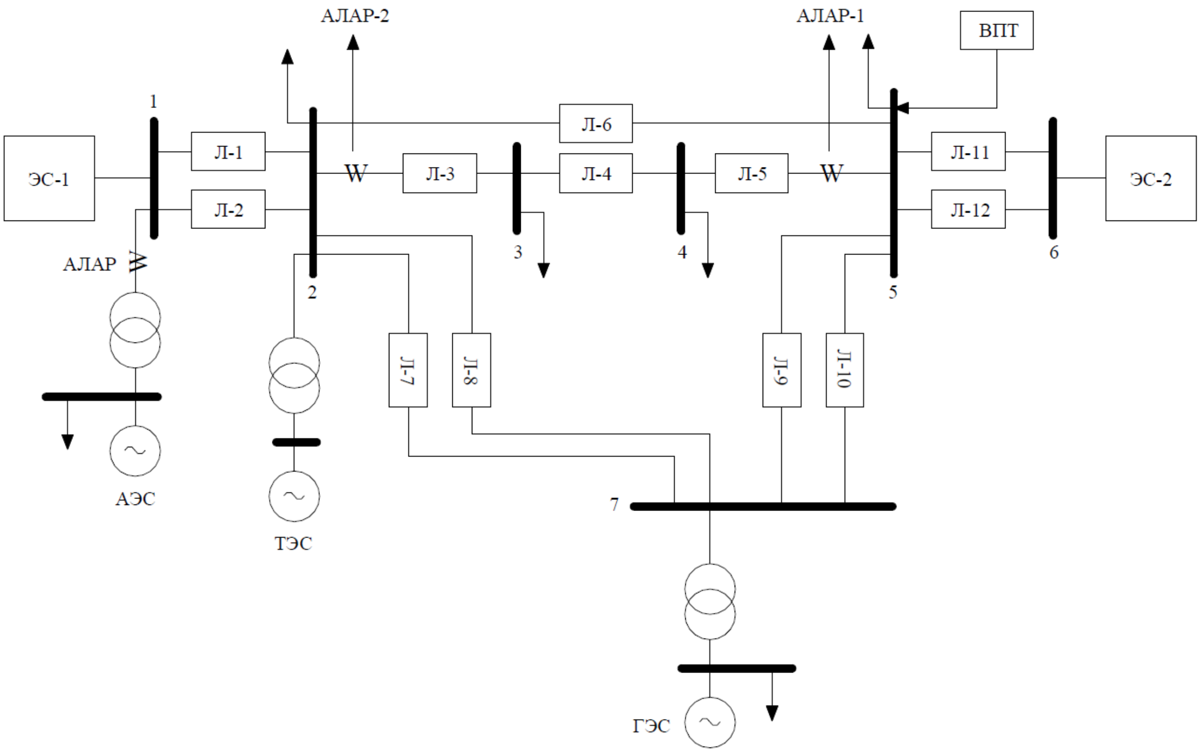

Figure 2: Multi Machine Test System

The qualification test program for out of step protection specified in the standard [4] contains a test circuit similar to the one established at NIIPT. When carrying out tests in the research and production departments at EKRA, the above-mentioned test circuit was implemented using the RTDS Simulator. Disturbance records taken from the hybrid analogue/digital simulator made it possible to achieve comparable results for normal and emergency operating conditions using the RTDS Simulator. In Figure 3, for example, one can see a comparison of the disturbance records obtained with the hybrid analogue/digital simulator model and the RTDS Simulator model.

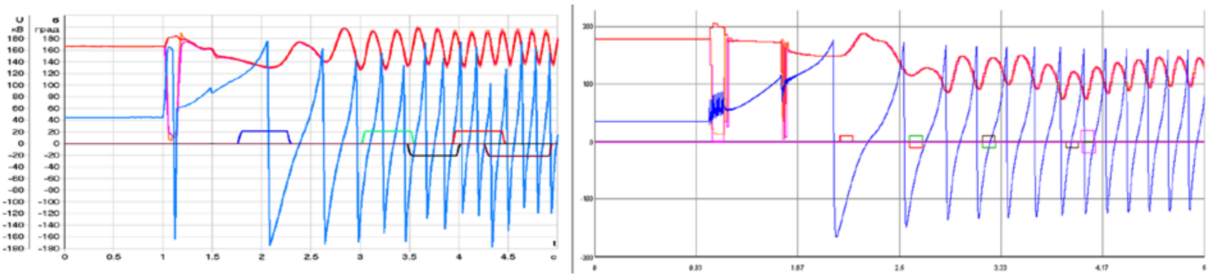

Figure 3: Transient disturbance records (red trace – rms voltage in kV, blue trace – machine angle in degrees) for double phase-to-ground faults in section 2-3-4-5 close to bus 5 with successful three-phase autoreclosing received from: left) digital-analogue-physical complex; right) RTDS Simulator.

While testing out of step protection algorithms, all of the functions contained in the WAP terminal were put into operation. Two terminals were used simultaneously during the tests. Outputs from the protection devices (ie. breaker trip signals) were connected to the RTDS Simulator, making it possible to illustrate the selectivity of out of step protection devices. With proper calculations, it is possible to test first and second level load shedding or generator overexcitation, in order to establish resynchronization conditions.

The RTDS Simulator-based out of step protection functions tests using the EKRA 223 01 relay protection and automation terminals proved that all the functions operate correctly, in accordance with the requirements of the standard [4]. The use of the RTDS Simulator to model different power systems allows full-scale out of step protection testing to be carried out. Accurate simulation of emergency conditions using the RTDS Simulator has been proven by the world-wide long-term service experience of such simulators around the world. In addition, the close agreement of the disturbance records obtained with the ones from the hybrid analogue/digital simulator at NIIPT shows that the RTDS Simulator is a useful tool for simulating WAP functions.

5. Conclusion

This paper has described requirements for testing WAPAC schemes using a real time simulator for closed loop testing. These are:

- Modular and scalable real time simulator, enabling simulation of hundreds of buses
- Comprehensive model libraries containing power system, protection and control components
- Communication methods and protocols to communicate with a wide variety of physical devices
- Time synchronization with an external time source (ie. GPS clock)

A real world example of testing out of step protection using a WAPAC scheme has also been discussed. WAPAC schemes have the potential to increase the reliability and security of our power networks which is why it is imperative that they are fully tested before being implemented in the real power network.

BIBLIOGRAPHY

[1] H. W. Dommel, "Digital computer solution of electromagnetic transients in single- and multiphase networks", IEEE Trans. on Power Apparatus and Systems, vol. pas-88, no. 4, April 1969, pp. 388-399.

[2] Defense Schema Against Large Distrubances in China Southern Power Grid, Electra No. 257, August 2011

[3] Using a Multi-Threaded Time-Step to Model a Multi-Function Relay in a Real Time Digital Simulator, IET 9th International Conference on Developments in Power System Protection, 2008. DPSP 2008

[4] Organization Standard JSC «FGC UES». Verification requirements for emergency control devices (PA). CTO 56947007-33.040.20.123-2012. Date of Introduction: 24.05.2012

[5] A.A.Kuzminova, D.A.Kabanov, Testing digital automation devices on the elimination of asynchronous digital-analogue physical complex. Procedures of the Direct Current Research Institute. Scientific publication № 64. St. Petersburg – 2010