Real Time Simulation Testing Using IEC 61850

Marc Desjardine, Paul Forsyth, Ralph Mackiewicz

Abstract--As IEC 61850 becomes more widely accepted in the electrical engineering community, it is important that the testing tools keep pace with this development. IEC 61850 presents new challenges to real time simulation and closed-loop testing of protective relays. Electrical interfaces used for binary signaling and voltage/current amplifiers must be replaced by an Ethernet connection and an IEC 61850 protocol stack. The electrical interfaces of a real time simulator are engineered to provide low latency and deterministic performance appropriate for a real time simulation. Similar attention must be given to IEC 61850 interfaces. Latency must be minimized so that the IEC 61850 interface does not add unacceptable delays to the operation of the simulator. Also, protocol processing must be deterministic to allow real time simulations to be repeatable and dependable. In addition, IEC 61850 specifies new configuration parameters and a new method for configuration called the Substation Configuration Language (SCL). These must be implemented in such a way that they fit within the typical modes of operation of the simulator.

The paper presents a successful hardware implementation for IEC 61850 messaging on a real time simulator and discusses the key design criteria. The software required to configure the IEC 61850 will also be addressed along with the advantages in using the IEC 61850 protocol. One of the biggest advantages is brought about by the realization of the IEC 61850-9-2 sampled values, removing the need for amplifiers as the standard interface to protection devices. Sampled values of the voltage and current signals can be sent via Ethernet, making it even more practical to perform testing on a protective relaying scheme rather than just individual devices.

Keywords: IEC 61850, GOOSE, GSSE, closed-loop testing, real time, power system simulation.

I. INTRODUCTION

REAL time digital simulation using systems such as the RTDS® Simulator are often used to perform closed-loop testing of power system protection devices such as relays and protection schemes. IEC 61850 is the international standard for substation automation systems. It defines the communications between devices in the substation and the related system requirements. IEC 61850 supports all substation automation functions and their engineering [1]. As IEC 61850 becomes more widely accepted and implemented by protection device manufacturers and power system utilities, it is important that the testing tools keep pace allowing these new devices to be tested. Using IEC 61850 for simulation testing also provides a number of benefits and advantages over traditional electrical interfaces such as the simplification of wiring and the potential to reduce the cost of the test setup.

When using IEC 61850, the electrical interfaces used for binary signaling and voltage/current amplifiers are replaced by an Ethernet connection and software implementing IEC 61850. Careful consideration must be given to the integration of IEC 61850 into real time digital simulators to ensure that the integrity of the simulation is not compromised due to non-deterministic or slow performance of the IEC 61850 interface.

This paper introduces real time digital simulation testing that includes the use of IEC 61850. A list of advantages for using IEC 61850 in simulation testing is presented along with key design criteria used when incorporating IEC 61850 into a real time digital simulator.

II. SIMULATION TESTING USING REAL TIME DIGITAL SIMULATORS

A. Common Applications

Real time digital simulators are commonly used for closed-loop testing of protection and control devices as well as for real time system studies. When conducting closed-loop testing, the simulator acts as the power system and interfaces to the test objects. For closed-loop operation protective relay testing, the simulator must provide real time data (i.e. voltage, current and breaker status) to the relay and sense trip and reclose status from the relay. Since the power system is being simulated, various faults can easily be applied under different network conditions to evaluate the performance of the protection and control. If the protection detects the fault applied, the trip signal will be sensed and the breaker in the simulation opened.

When evaluating the performance of a protective relay or protection system, exhaustive testing is often conducted. This involves applying thousands of faults while varying different system parameters (e.g. fault type, fault location, point-on-wave). Since so many tests are run, it is crucial to keep each test and the time between tests as short as possible.

Prior to the advent of IEC 61850, the protection equipment was connected to the simulator using individual wires. The complexity of the wiring is evident even for the relatively simple double ended line protection test setup shown in Fig. 1. Twelve (12) signals have to be connected from the RTDS

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Simulator to the voltage and current amplifiers. After the signals pass through the amplifiers, twelve (12) more connections have to be made to connect the voltage and current signals to the relays. If the relays are set for single-pole trip and reclose, a minimum of twelve (12) contacts must also be connected to the simulator's digital input to control breaker operation. If internal relay elements are to be monitored, even more contacts have to be connected to the simulator. Finally, six (6) breaker status signals must be supplied to the relays at station level voltages (e.g. 125 Vdc) via potential free contacts. All told, there are 30 digital and analogue connections between the relays and the simulator when using traditional methods for the test setup illustrated in Fig. 1. This does not include the 12 signals that must be connected from the simulator to the amplifiers or the monitoring of internal relay elements.

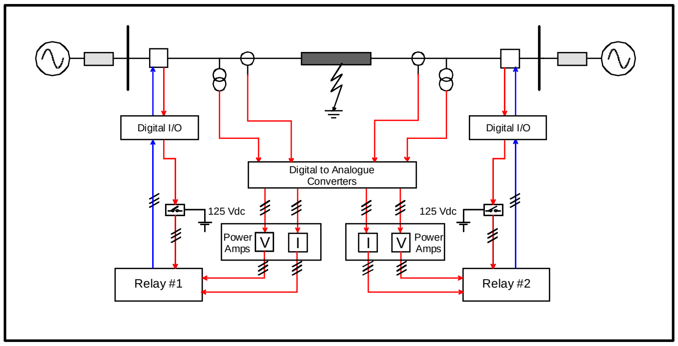

Fig 1. Test Setup with Standard Electrical Connections

B. *Integration Of IEC 61850 In Simulation Testing*

IEC 61850 can be used to replace the two types of interfaces between the RTDS Simulator and the devices being tested. IEC 61850 GOOSE/GSSE can replace the hard-wired binary inputs and outputs over what IEC 61850 refers to as a station bus and IEC 61850-9-2 sampled values can replace the hard-wired voltage and current signals from the power amplifiers over what IEC 61850 refers to as a process bus.

IEC 61850 GOOSE/GSSE replaces the hard-wired binary signaling with a message sent over an Ethernet based stations bus. All of the hard-wiring needed for status signals can be replaced by a single Ethernet connection between the simulator and the station bus LAN to which the protection devices are connected. The transfer of trip and breaker status through GOOSE/GSSE messages is very fast. Maximum end-to-end transfer time is typically specified between 3-10 msec [3].

IEC 61850-9-2 Sampled Values can be used for applying voltage and current signals to devices instead of using analogue current and voltage from amplifiers. Maximum sample to transmission time for an IEC 61850-9-2 sampled value message used for protection is typically specified at less than 3 msec for sample rates faster than 480 samples/cycle [3]. An IEC 61850 device referred to as a Merging Unit (MU) is used to transmit sampled values derived from transducers using IEC 61850-9-2 messages over the process bus. Messages sent by MUs may contain an arbitrary number of current and voltage channels/phases, but initial implementations of 61850-9-2 send messages with instantaneous 3-phase plus neutral voltage and current samples (i.e. 8 signals) [2]. Arbitrary sample rates are permitted by IEC 61850-9-2, but initial implementations of MUs used for protection typically send samples at 80 samples/cycle [3].

With the implementation of IEC 61850 communication for the RTDS Simulator, all signals are passed to and from the protective relays via a separate station bus and process bus both based on Ethernet. The IEC 61850 GOOSE/GSSE facility described in this paper allows up to 32 binary inputs and 32 binary outputs to be provided to as many as 8 different IED's (e.g. relays) from one device. Therefore the trip and reclose signals plus the breaker status signals for the double ended line protection tests can be provided by one Ethernet connection representing a single station bus. An added Ethernet connection is required for a process bus to pass up to 8 sampled value (analogue) signals to each relay. A double ended line protection test setup using IEC 61850 is shown in Fig 2. In the figure, the GTNET-SV is used for the IEC 61850-9-2 interfaces and the GTNET-GSE provides the GOOSE/GSSE interface.

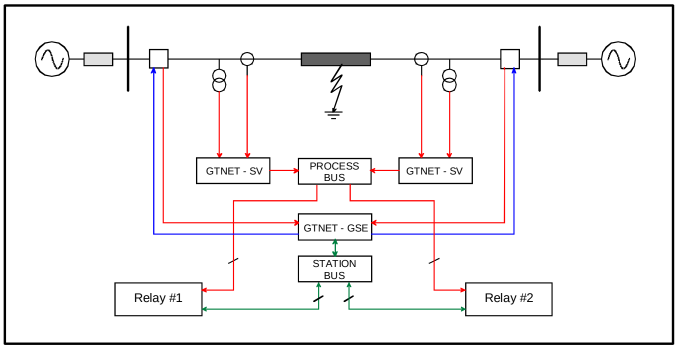

Fig. 2. Test Setup with IEC 61850 Connections

III. ADVANTAGES

There are a number of advantages to using an IEC 61850 interface for simulation testing compared to using traditional electrical interfaces. An obvious advantage is the ability to test IEC 61850 based systems that cannot be tested using traditional electrically interfaced simulators. The use of IEC 61850 in installations is increasing [4], and it is important to be able to test these devices using the IEC 61850 interface. Also, since a goal of IEC 61850 is to provide a comprehensive set of functions [3] to replace proprietary protocols, simulation testing can be performed on products from different vendors using only the IEC 61850 protocol without requiring a combination of industry standard and proprietary protocols.

Elimination of the often large and expensive voltage and current amplifiers commonly used in simulation testing reduces the size and cost of the test setup. This in turn makes it more practical to perform testing on larger protective relay schemes rather than on individual devices.

Another major advantage of using IEC 61850 for simulation testing is the reduction in electrical wiring between the simulator and protection devices. Fig. 2 illustrates that when using IEC 61850 for the same test system as shown in Fig. 1, the number of connections between the simulator and the relays is reduced to just 4. In addition, the connections are greatly simplified by using an Ethernet connection rather than individual wires and by eliminating the need for station level breaker status signals.

IV. IMPLEMENTATION OF AN IEC 61850 INTERFACE FOR SIMULATION TESTING

Implementation of an IEC 61850 interface for a power system simulator presents interesting challenges that are generally different than those present when implementing IEC 61850 in typical substation devices such as protection relays and circuit breakers.

A power system simulator must produce reliable, consistent results. The results must be consistent each time the same simulation case is run. There must be low variability in the input and output latency and the latencies must be well understood to allow the analysis of simulation results. The input and output latency must also be minimized to reduce the impact of the interface and allow the widest range of delay adjustment within the simulation, if desired. Although latency must be minimized, it should not be minimized at the expense of variability in latency. Any variation in latency affects the confidence in the timing measurements of DUT operations, which in turn affect the confidence in the simulation as a whole.

The start-up operation of a simulation test case also differs from other substation equipment. Whenever possible, the simulation should require only minimal time to start-up and initialize. This reduces the amount of time to run a single simulation test case and allows multiple simulation runs to be made in the shortest period of time. In addition, the start-up and initialization time should be as consistent as possible. This is because the worst-case initialization delay must be ‘out-waited’ in order to ensure consistent simulation results.

The configuration of the simulator is also different than most other substation equipment. The simulator is frequently reprogrammed to perform different simulations. In addition, the simulator is frequently started, stopped and restarted. In comparison, substation equipment is often set up during commissioning and runs continuously for many months without changes to the configuration other than automatic changes to the settings of the protection functions.

A. *Hardware*

The IEC 61850 interface for the RTDS Simulator was implemented using a dedicated processing platform. The only responsibility for this processing platform is to handle IEC 61850 communications. Using a dedicated processing platform for IEC 61850 communications allows maximum hardware and software optimization to be performed and allows control over input and output latency – both the amount and the variability from packet to packet. This is because there is no sharing of processing or communications resources between the protocol stack and other unrelated simulation activity as would be the case if the protocol processing was integrated into hardware that was utilized for other simulation functions.

When using a dedicated processing platform, overhead due to communications between the platform and the rest of the simulator must be fast and efficient so that total input and output packet latency is minimal. This can be achieved by utilizing a high performance FPGA for the interface between the protocol hardware and the simulator. Buffering and filtering are easily implemented in an FPGA and provides an efficient interface for the processor and allows more CPU time to be spent processing packets.

The accurate time-stamping required for IEC 61850-9-2 is realized by distributing a 1 pulse per second (1 PPS) to the communicating devices. Implementing the 1 PPS input time synchronization functions within an FPGA eliminates processor overhead and dependency on processor interrupt latency. This allows the processor to spend more time processing packets rather than synchronizing to the 1 PPS input.

A key to minimizing the variability in input and output packet latency is to reduce the amount of extraneous, unexpected processing. The LAN can be a source of significant unnecessary processing, but can be minimized in most circumstances. The selection of the Ethernet media access controller (Ethernet MAC) is crucial in minimizing the impact of processing unrelated network activity. The Ethernet MAC must be equipped with the capability to perform packet filtering based on a set of configured addresses. Without hardware-based address filtering, each packet on the network must be read by the CPU to determine if the destination address in the message matches the filter criteria. With hardware address filtering, only packets with selected destination addresses are passed to the processor. Although IEC 61850 does not use Ethernet broadcast packets, such packets can be present on networks and might affect overall network performance. Disabling broadcast traffic during simulation runs can provide further optimization. The combination of hardware address filtering and disabling broadcast traffic reduces the network traffic entering to only those packets that are directly addressed or requested – there is no extra processing even when the network is very active.

B. *Software*

The RTDS Simulator implements IEC 61850 GOOSE, GSSE and 61850-9-2 Sampled Values under an off-the-shelf real time operating system (RTOS). By utilizing a RTOS with a rich suite of development tools, performance can be easily assessed and optimized. Fig. 3 shows a capture by one of the

RTOS tools and shows the processing of a single received GOOSE message. From this capture the approximate processing times, the number of context switches, and all operating system calls such as semaphore and message queue activity can be determined. This type of capture can be used to analyze and optimize the processing of packets.

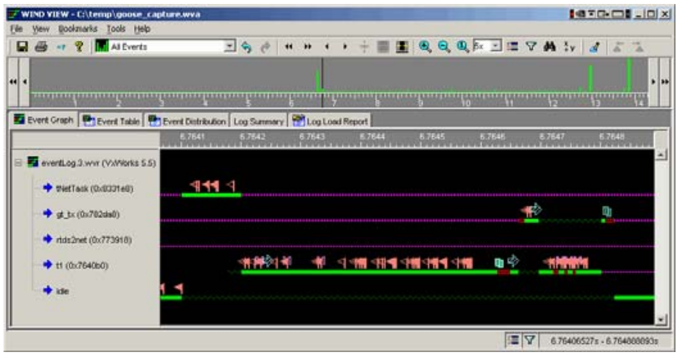

Fig. 3. GOOSE Reception analysis using RTOS Development Tool

A third-party IEC 61850 protocol stack was chosen to allow development time to be spent on integration and optimization rather than the implementation of intimate details of the protocol. Full source code was provided with the protocol software so that it was possible to verify the protocol processing was implemented efficiently.

The IEC 61850 protocol covers a wide range of functionality from relatively interface related station level reporting of system values and status to the very fast process related station level GOOSE/GSSE messaging and the process bus transmission of sampled values. Implementing multiple types of messaging at the same time can cause slight unexpected latencies. Since variability of latency must be minimized in a real time simulator, each IEC 61850 interface device only runs one type of messaging at a time. For example, a single IEC 61850 interface device can run GOOSE/GSSE or 61850-9-2 sampled values, but not both at the same time. No interface related station level messaging is supported while running GOOSE/GSSE or 61850-9-2 sampled values to avoid any possibility of affecting latency. If required, multiple IEC 61850 interface devices can be simultaneously connected to the simulator to provide the different types of messaging, while still providing excellent protocol performance.

C. *Configuration*

Digital simulators are commonly programmed for an application every time a simulation case is downloaded. For this reason, all details for the IEC 61850 interface must be determined prior to downloading a test case. When using simulators in batch mode, it must be possible to easily change all simulation parameters from a script file. IEC 61850 configuration of the simulator is easily accomplished using the IEC 61850 SCL features described in IEC 61850-6 [3].

SCL is an extensible markup language (XML) based description language used to describe IEC 61850 IED configurations and communications. A single SCL file can contain a configuration and description of each IED so that the overall simulation configuration can be stored in a single SCL file. An IEC 61850 system engineering software package is used to modify the system configuration and generate an SCL file to be read by the configuration software for each connected IED. The system configuration function can be performed by many different system engineering tools since SCL is not proprietary. The compiler for the RTDS Simulator reads SCL files to determine the configuration and connections for the IEC 61850 interface. An SCL file can be generated for each test scenario and can be selected through simulator scripts. This allows compatibility between IEC 61850 and the simulator batch mode operation.

Some IEC 61850 stacks provide advanced features such as the automatic discovery of multicast destination addresses used by remote IEDs to simplify configuration. These features should be avoided for simulation testing if they affect the deterministic operation of the IEC 61850 interface or if they increase initialization time at the beginning of simulation. Automatic discovery of multicast addresses requires the IEC 61850 interface to process all multicast traffic on the network until a multicast message is received from the designated remote IED. This increase in processing can cause undesirable variations in input and output latency, and must be avoided in a simulation testing environment

V. CONCLUSIONS

An IEC 61850 messaging capability was successfully developed for the RTDS Simulator. The hardware implementation, referred to as the GTNET, is capable of providing both binary input and output as well as sampled value output for voltage and current signals. Great care was given to ensure that the system was deterministic in nature and able to operate error free in conjunction with real time simulations. Both the hardware and software used were optimized to ensure that unacceptable delays were not introduced when starting and stopping simulation cases.

A number of advantages were realized through the development of the IEC 61850 messaging capability for the RTDS Simulator. First it created the capability for closed-loop testing of newly compliant protection devices. Second it greatly reduced the number of physical connections that had to be made between the simulator and the protection system. For the example illustrated in Fig. 1 and 2, the number of connections was reduced from 30 to just 4. Third, it was no longer necessary to provide breaker status signals using potential free contacts. Finally when using IEC 61850-9-2 sampled values, the need for power amplifiers was eliminated, simplifying the test setup and greatly reducing the cost.

VI. REFERENCES

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VII. BIOGRAPHIES

Marc Desjardine received his B.Sc. degree in Computer Engineering from the University of Manitoba, Canada in 2000. He began work at NxtPhase T&D in 1997 where he developed firmware for protective relays and recorders. In 2004 he joined RTDS Technologies where he has focused on developing firmware and protocol interfaces for the RTDS simulator.

Paul Forsyth received his B.Sc. degree in Electrical Engineering from the University of Manitoba, Canada in 1988. After graduating he worked for several years in the area of reactive power compensation and HVDC at ABB Power Systems in Switzerland. He also worked for Haefely-Trench in both Germany and Switzerland before returning to Canada in 1995. Since that time he has been employed by RTDS Technologies where he currently holds the title of Marketing Manager / Simulator Specialist.

Ralph Mackiewicz obtained a B.Sc. degree in Electrical Engineering from Michigan Technological University in 1977 and worked at Westinghouse Electric's PLC division as engineering manager prior to joining SISCO in 1985. SISCO is a Sterling Heights, MI developer of standards based real-time communications and integration products. Ralph has been an active participant in MMS, UCA and ICCP-TASE.2 standards activities, conducts IEC 61850 training programs, has authored chapters for several well-respected industry handbooks, holds two patents on PLC technology and is currently the chairman of the UCA International Users Group marketing subcommittee.