Real Time Simulation and Testing Using IEC 61850

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Abstract--As the IEC 61850 communication protocol becomes more widely accepted and applied in electrical engineering, it is important that the testing tools keep up with these developments. IEC 61850 presents new challenges to real time simulation and closed-loop testing of protective relays. The electrical interfaces used for binary signaling and the voltage/current amplifiers used in traditional test methods 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 testing. 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 will present a successful implementation for IEC 61850 messaging on a real time simulator using the GTNET card and will discuss the key design criteria. The software required to configure the IEC 61850 will also be introduced along with the advantages of using the IEC 61850 protocol. One of the significant advantages brought about through the realization of the IEC 61850-9-2 sampled value communication is the elimination of complex and expensive amplification equipment traditionally used as the interface between the real time simulator and the physical protective relay(s). Sampled values of the voltage and current signals are sent via Ethernet, making it simpler, more practical and less expensive to perform closed-loop tests.

As part of the IEC61850 communication standard the "quality" of information is contained within the transmitted data. As an example of the effectiveness of the RTDS simulator as a testing tool, tests were run in which the "quality" information contained in the IEC 61850 data was dynamically changed. The purpose of such a test is to show how various IEC 61850 IEDs would react to abnormal (and normal) IEC 61850 data. Understanding how a protection system responds to IEC 61850 data is important and will give engineers confidence that the system will behave in an acceptable manner.

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

I. INTRODUCTION

REAL time digital simulators such as the RTDS® Simulator are commonly used to perform closed-loop testing of power system protection and control devices including protective relays and integrated protection schemes. As the IEC 61850 communication protocol becomes more widely accepted and implemented, it is important that the testing tools keep pace allowing devices that adhere to the new standard to be properly tested.

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

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

As a practical example of the effectiveness of the RTDS simulator as a testing tool, simulations were performed in which the "quality" information contained in the IEC 61850 data was dynamically changed. The purpose this example is to show how various IEC 61850 IEDs would react to abnormal (and normal) IEC 61850 data and to show that the RTDS simulator can be used to produce such conditions.

A. Common Applications

Real time digital simulators are commonly used for closed-loop testing of protection and control devices as well as for other real time power system studies. When conducting closed-loop testing, the simulator represents the power system and provides the interface to the test objects. For closed-loop protective relay testing, the simulator must provide real time data (i.e. voltage, current and breaker status) to the relay and receive trip and reclose signals from the relay. Since the power system is being simulated mathematically, various faults can easily be applied under different network conditions to evaluate the performance of the protection and control devices. If the protection detects

the applied fault, the trip signal will be sensed by the simulator and the modeled breaker(s) will operate in response to the incoming signal(s).

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 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. In total there are 30 digital and analogue signal 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.
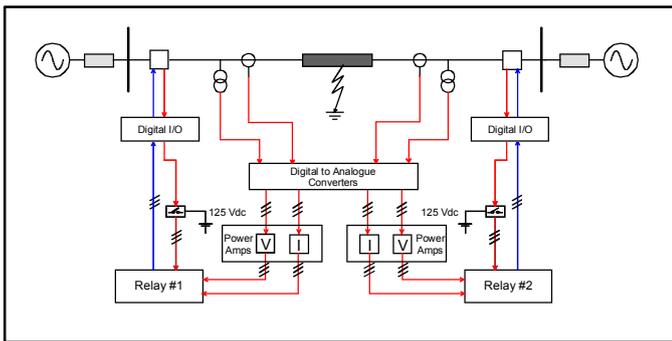

Fig 1. Test Setup with Standard Electrical Connections

B. Integration of IEC 61850 in Simulator 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. IEC 61850-9-2 sampled values replaces 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 [2].

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 [2]. 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 the initial implementations of 61850-9-2 send messages with instantaneous 3-phase plus neutral voltage and current samples (i.e. 8 signals) [1]. Arbitrary sample rates are permitted by IEC 61850-9-2, but initial implementations of MUs commonly referred to as IEC 61850-9-2LE used for protection typically send samples at 80 samples/cycle[2].

With the implementation of IEC 61850 communications 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 64 binary inputs and 64 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.
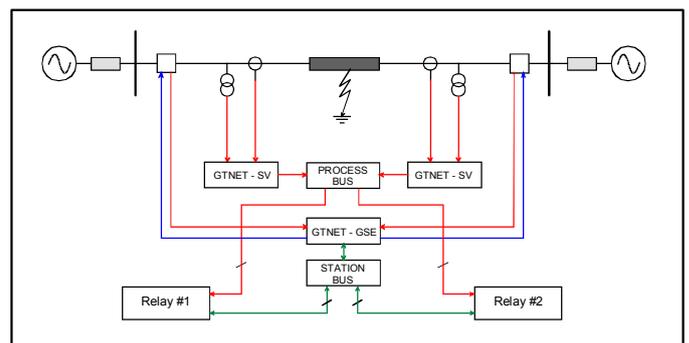

Fig. 2. Test Setup with IEC 61850 Connections

II. ADVANTAGES

There are a number of advantages in 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. Application of IEC 61850 in substations is increasing [3], and it is important to be able to test these new protection devices using the IEC 61850 interface.

Since one goal of IEC 61850 is to provide a comprehensive set of functions [2] 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.

III. IMPLEMENTATION OF AN IEC 61850 INTERFACE FOR SIMULATOR 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 configuration of the simulator is 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 of 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.

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.
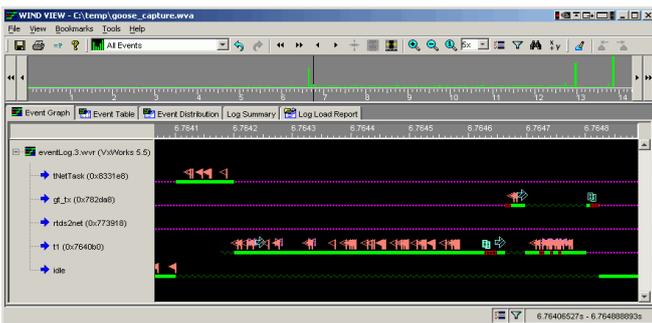

Fig. 3. GOOSE Reception analysis using RTOS Development Tool

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. IEC 61850 configuration of the simulator is easily accomplished using the IEC 61850 SCL features described in IEC 61850-6 [2].

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.

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.

IV. REAL TIME IEC 61850 DATA MANIPULATION

In order to illustrate the effectiveness and usefulness of the RTDS simulator as an IED testing system a series of simulations were run in which data within the communicated packets was purposely manipulated.

In earlier versions of the GTNET the data quality information was fixed to normal conditions, but has recently been enhanced to provide access to the "quality" information bits, "test" flag, and "needs commissioning" flag. The manufacturer's documentation, conformance statements, and IEC 61850 Standards must be consulted to determine the correct response of the IED to the affected IEC 61850 data during the simulation.

A. Quality Data

The IEC 61850 configuration of an IED will determine

which type of data attribute is included in the message. For example a device dataset may only contain the status value (stVal) and not contain any detailed quality (q) information. When a device is configured with quality bits, a bit string will be included for each dataset member. The following table for IEC 61850 Edition 1 shows the meaning of the quality bits of a message [2].

Bit(s)	IEC 61850-7-3		Bit-String	
	Attribute name	Attribute value	Value	Default
0-1	Validity	Good	0 0	0 0
		Invalid	0 1	
		Reserved	1 0	
		Questionable	1 1	
2	Overflow		TRUE	FALSE
3	OutofRange		TRUE	FALSE
4	BadReference		TRUE	FALSE
5	Oscillatory		TRUE	FALSE
6	Failure		TRUE	FALSE
7	OldData		TRUE	FALSE
8	Inconsistent		TRUE	FALSE
9	Inaccurate		TRUE	FALSE
10	Source	Process	0	0
		Substituted	1	
11	Test		TRUE	FALSE
12	OperatorBlocked		TRUE	FALSE

Table 1. IEC 61850 Detail Quality Bits

B. Test and Needs Commissioning

The other two parts of a message is the "test" and "needs commissioning" flags. The IED documentation should describe the behavior of the message processing and help the user determine which bits should be manipulated and what the expected IED response should be. For example, Clause 15.2.3.8 in IEC-61850-7-2 Edition 1 standard states "The parameter **Test** shall indicate with the value of TRUE that the values of the message shall not be used for operational purposes."

C. Capturing and Analyzing Data

Software tools that can capture and display IEC 61850 messages are essential for all aspects of testing, development, and commissioning of substation automation schemes. MMS Ethereal and Wireshark are two such tools that are available free of charge.

Figure 4 shows a MMS Ethereal capture of a GOOSE message from the GTNET that is used to analyze the GOOSE information on the Ethernet. The following information can be observed. The "test" flag is set to FALSE, the "Needs Commissioning" flag is set to FALSE, and the number of dataset members is 36. The 36 dataset members are 16 binary values with StVal and Quality (16x2=>32 members) and 2 analog values with mag.f and Quality (2x2=>4 members). The "quality" information shows all 0s (default). The first Boolean item shows FALSE and the second Boolean item shows TRUE.

D. IED Documentation and Operation

The IEDs used during this testing were the AREVA P444 NCIT, RTDS GTNET-GSE, RTDS GTNET-SV and SEL421. The AREVA relay was GOOSE and SMV data capable. The RTDS GTNET cards were configured for GOOSE and SV data.
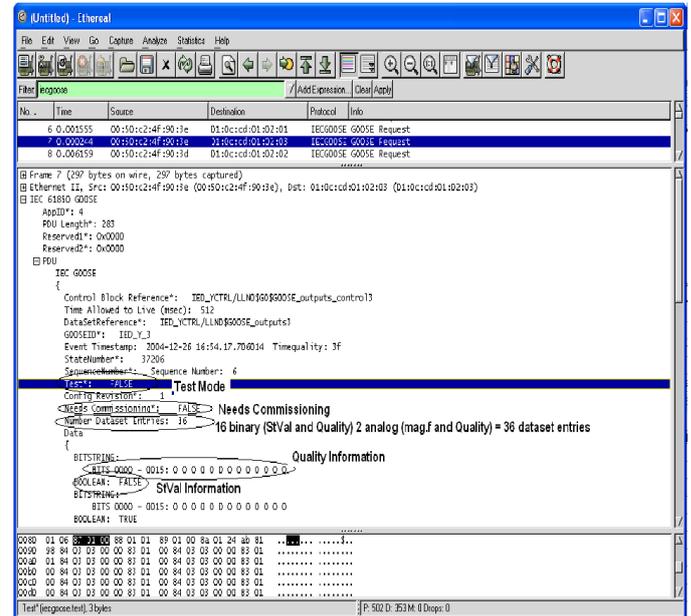

Figure 4. MMS Ethereal Capture of a GOOSE Message

The SEL 421 documentation shows that the relay will process GOOSE messages in the following manner. Reject all DA contained in an incoming GOOSE based on the accumulation of the following error indications created by inspection of the received GOOSE:

Configuration Mismatch -The configuration number of the incoming GOOSE changes.

Needs Commissioning - This Boolean parameter of the incoming GOOSE is TRUE.

Test Mode - This Boolean parameter of the incoming GOOSE is TRUE.

Decode Error - The format of the incoming GOOSE is not as configured.

This version of SEL relay did not allow control of the "test" flag and "needs commissioning" flag. Internal status indicators provide the information necessary for the device to set the validity and failure attributes. For example, if the device becomes disabled, as shown via status indications (e.g., an internal self-test failure), the SEL-421 will set the Validity attribute to invalid and the Failure attribute to TRUE. *Note* that this version of SEL-421 does not set any of the other quality attributes.

The AREVA Non-Conventional Instrument Transformer (NCIT) relay provides access to control the "test" flag in outgoing GOOSE messages via the user interface. The relay

can force the "test" flag such that no state changes in the dataset members are transmitted or the relay can pass through the "test" flag such that state changes in the dataset members are transmitted with the "test" flag set. The user interface also provides the user a choice to optionally ignore the "test" flag of incoming GOOSE messages. The flags that are available in the signal acquisition part of the relay from the IEC 61850-9-2 data stream are:

1. Synchronized Acquisition Alarm
2. Test Mode
3. Validity Bit 0

The relay provides an alarm and gives access to these points in the programmable logic portion of the relay. Thus the user can create logic to customize the behavior of the relay when the SV data is unsynchronized, in test mode, or invalid. Figure 5 shows an example of some logic created to activate an LED when the SV data is abnormal.
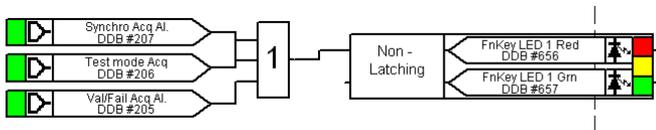

Figure 5. Sampled Value Data Flags in P444 Relay

The RTDS GTNET-GSE configuration provides access to the GOOSE transmit and receive "quality" bitmaps, "test", and "needs commissioning" flags. The RTDS GTNET-SV configuration provides access to the SV transmit "quality" bitmap and "SmpSynch" flag for the IEC 61850-9-2 data. The outgoing status on GOOSE and SV data can be dynamically changed during a simulation, thus the IED response to these flags can be verified. The status on incoming GOOSE messages are available to user configurable logic that will control the behavior of the simulation with abnormal IEC 61850 data from external IEDs.

V. TEST RESULTS WITH ABNORMAL IEC 61850 DATA

In the following examples the AREVA GOOSE, RTDS GOOSE, and RTDS SV datasets were manipulated such that the IED's would detect errors in the received GOOSE and/or SV data.

AREVA GOOSE Configuration:
TO RTDS: A,B,C trip, Carrier Send (CS), Auto Reclose (AR)
FROM RTDS: A,B,C status, CB healthy, Carrier Receive (CR),
AREVA SV Configuration:
FROM RTDS: IA, IB, IC, VA, VB, and VC

SEL GOOSE Configuration:
TO RTDS: A,B,C trip, Carrier Send (CS), Auto Reclose (AR)
FROM RTDS: A,B,C status , Carrier Receive (CR),

The diagnostic command via a telnet session to the SEL 2702 card was used to provide a snapshot of the GOOSE status.

1. Figure 6a shows the GTNET configuration revision was set different than what was used to program the SEL.
2. Figure 6b shows the GTNET "needs commissioning" flag was set.
3. Figure 6c shows the GTNET "test" flag was set.
4. Figure 6d shows the GTNET dataset format was not configured as previously defined.
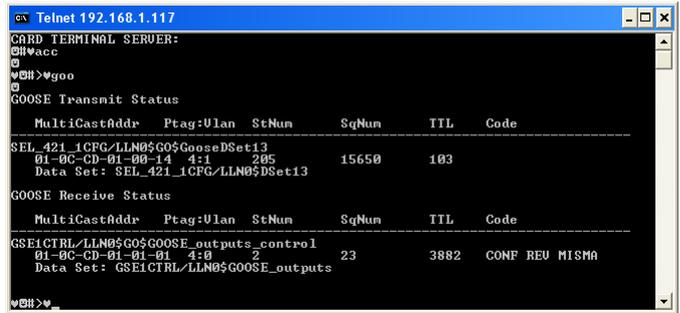

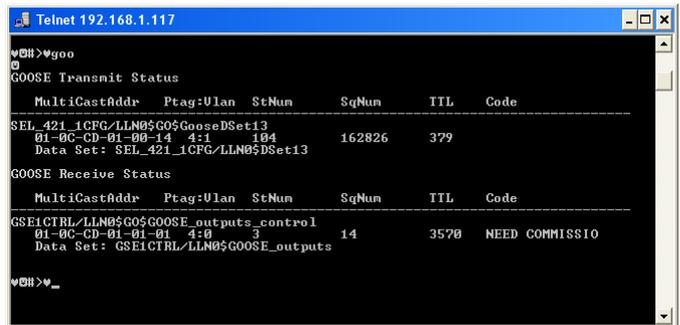Figure 6a. Configuration Mismatch Detected in Dataset

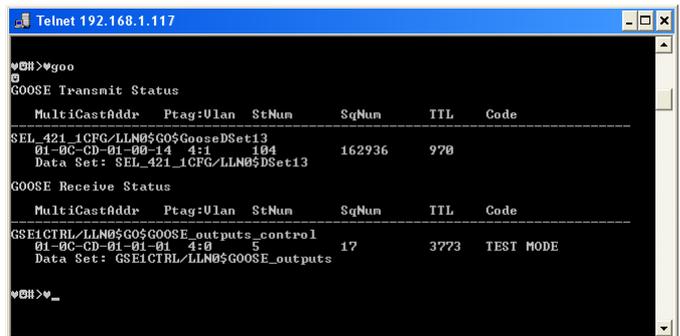Figure 6b. Needs Commissioning Detected in Dataset

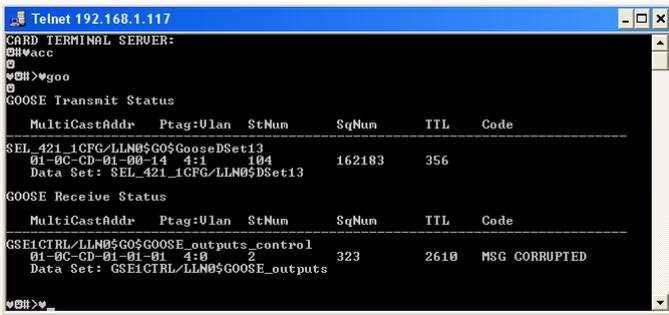
Figure 6c. Test Flag Detected in Dataset

Figure 1d. Decode Error due to Mismatched Dataset

Figure 7 shows the result of an A phase to ground fault applied to the line protected by the AREVA and SEL relays. The black trace "GOOSEIN" was configured with inputs 0-7 externally referenced to the SEL GOOSE message and inputs 8-15 externally referenced to the AREVA GOOSE message. The red trace "BI1GT" shows the "test" status for each of the 16 inputs. Black trace number #0 is the A phase trip and number #3 is the communication scheme permissive trip carrier send signal from the SEL. Black trace number #8 is the A phase trip and number #13 is the communication scheme permissive trip carrier send signal from the AREVA. The AREVA relay GOOSE dataset was configured to "pass through" state changes with "test" status set to TRUE. Red trace numbers #8 though #15 shows that the GTNET recognized the status of the "test" flag and logic in the simulation would prevent operation of the breaker.

The RTDS GOOSE message received by the AREVA and SEL was sent with the "test" flag set to TRUE. The AREVA "Ignore Test Flag" was set to NO. 8 shows the result of an A phase to ground fault, both relays tripped A phase but no AR occurred and A phase stayed open in the simulation.

VI. CONCLUSIONS

As IEC 61850 becomes implemented in more substation automation and control systems there is a growing need to test the behavior of each IED against normal and abnormal data. Understanding how an individual relay will react when subjected to abnormal IEC 61850 data is a critical part in the design of an IED and plays an important role in the whole system integration.
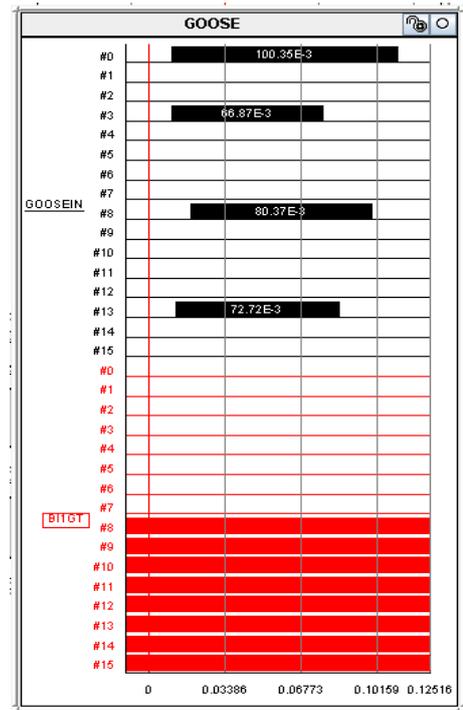

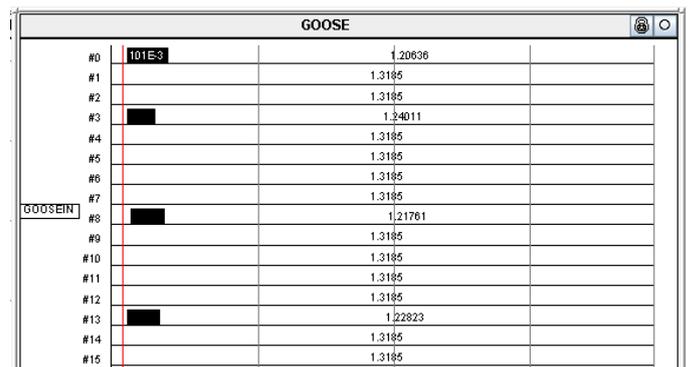Figure 7. Test Flag in GOOSE (red) from P444 Relay

Figure 8. Test Flag set in GOOSE from RTDS

IEC 61850 messaging capability has been 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.

It is important to have proper tools to work with IEDs that use IEC 61850 and it is also important to read the standards, conformance statements, and manufacturer's documentation. Response to abnormal GOOSE and SV data is not identical in different IED's and should be checked prior to installation. It is important to understand how the system will respond with

abnormal IEC 61850 data. Knowing which items affect an IED and knowing how to test for this is a key part of implementing and using a system with IEC 61850.

This paper has shown how such tests can be achieved with the help of a real time digital simulator interfaced to physical relays with dynamic control of IEC 61850 GOOSE and SV data.

VII. REFERENCES

Periodicals:

[1]   UCA International Users Group, "Implementation guideline for digital interface to instrument transformers using IEC 61850", R2-1.

Standards:

[2]   *IEC 61850 Communication networks and systems in substations* –All parts, Reference number IEC 61850-SER

Papers Presented at Conferences:

[3]   C. Hoga, G. Wong, "Utilities and industries of today: leading by following IEC 61850," presented at the 15th Power Systems Computation Conference, Liege, 2005.

VIII. BIOGRAPHIES

Rick Kuffel graduated from the University of Manitoba with, B.Sc. EE and M.Sc.EE in 1984 and 1986 respectively. After graduating he worked at BBC in Switzerland and Teshmont Consultants in Winnipeg before moving to the Manitoba HVDC Research Centre in 1989. There he worked mainly on the development of the real time digital power system simulator. In 1994 he co-founded RTDS Technologies where he currently holds the position of Director.

Dean Ouellette graduated from Red River Community College with a diploma in EE Technology in 1986 and upon graduation has spent the past 24 years working in the field of protective relaying. His employment experience includes time with Manitoba Hydro (1986-89), British Columbia Hydro (1989-1999), Schweitzer Engineering Labs (1999-2001), Nxtphase Corporation (2001-2003) and RTDS Technologies, Inc. (2003-present). Dean is currently a Research and Development Supervisor at RTDS Technologies, Inc.

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.