Utilization of IEC 61850 GOOSE messaging in protection applications in distribution network

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***Abstract*—IEC 61850 provides a standardized framework for substation integration. Following its introduction, the implementation of IEC 61850 has advanced at a remarkable pace. Perhaps never before has an industrial standard been accepted with such speed. Within few years of its release, a majority of the markets are demanding IEC 61850 as the preferred communication protocol.**

The savings that IEC 61850 delivers by way of substation design, installation, commissioning, and operation combined with new capabilities that are not practical or cost effective using legacy approaches, makes it a worthwhile investment.

This document describes the utilization of some new features offered by IEC 61850, Communication Networks and Systems in Substations. In particular, the paper looks at how horizontal communication, commonly known as GOOSE communication, between protection and control devices can be used to improve the reliability and performance of the system. A recent project involving various schemes built over GOOSE for India's one of the largeest petrochemical industry clearly illustrated this. Besides describing generic improvements in capacity, performance and reliability, the paper presents practical GOOSE applications, i.e. reverse blocking protection and auto transfer schemes.

I. Introduction

Early substation automation systems were acquiring the information from utility and industrial substations through remote terminal units (RTUs). In turn this information was provided to operator works station as well to upper level communication system like NCC / DCS / EMS. These conventional RTUs based systems typically were using transducers, interposing relays and hardwired contacts. The information update was also slow for these systems, on the order of several seconds to minutes.

With advancement in technology the substation's IEDs (numerical relays) are performing more system automation and control functions. The IED's apart from protection, provides the functions like control, measurement, disturbance recording and condition monitoring. Due to IED's built in logic building capability along with PLC functionality, substantial reduction in panel wiring / uses of auxiliary relays and timers can been achieved. These substation IED networks reduce or eliminate additional transducers, input and output contacts, and even RTUs. They are also able to provide data at a much faster speed. Almost all the information required by system operators and more is available from these IEDs once they are networked together.

The introduction of the IEC 61850 standard offers a range of features and benefits for protection and control applications, among them peer-to-peer communication using GOOSE. Apart from enabling fast and supervised communication, the use of GOOSE also enables simplified substation wiring.

The IEC 61850 standard is a future-proof, which promises longevity and interoperability between devices and applications and which relies on well-established Ethernet networking technology.

The GOOSE communication can be used to enhance existing medium voltage substation automation applications. The first way is by simplifying and decreasing the wiring inside medium voltage switchgear, which helps to reduce costs. The second is by implementing a completely new application using Ethernet and GOOSE because ignalling response times from device to device can be significantly faster than traditional hard-wiring from binary outputs to binary inputs.

In the traditionally hardwired system the response time is constrained by the auxiliary relay on/off delay of the sending device, and correspondingly by the input filtering on the receiving device. Both these delays can be avoided using GOOSE. Additionally, protection and control devices often have a limited number of binary inputs and outputs due to cost and space constraints. With GOOSE, a higher number of virtual inputs and outputs can be used without additional device or wiring costs.

Enhanced performance and capacity compared with the additional costs in traditional systems open up the possibility of introducing new and improved functionality, such as faster reverse blocking scheme and co-ordinated arc protection.

II. PROJECT BACKGROUND

The largest petrochemical Industry of India was looking for IEC 61850 compliant systems for distribution network of their expansion projects of 2 existing locations. The customer defined the following requirements for the system to be developed:

1. Modern, flexible, safe and reliable protection and control IEDs
2. Comprehensive functionality pre-configured and tested at factory, reducing commissioning time at site
3. Increased operational safety with reduction in hardwiring by utilizing GOOSE communication
4. Reduction in operation and maintenance cost
5. Demonstrate the functional testing at factory to test the performance and reliability of signal exchange over GOOSE communication.

III. IEC61850, THE CHOICE OF CUSTOMER

The evolution of numerical relays, intelligent metering and fault / disturbance recording functions built-in numerical relays has made the need to communicate these devices essential in order to extract the maximum possible benefit from the equipment. High speed communication infrastructure in substations has been needed for the same to support the same.

The customer has made the decision to implement the IEC 61850 standard in all new medium voltage and low distribution substations. This is a result of customers' interest in new technology and the company's orientation towards long-term stability and less dependencies of proprietary protocols.

IV. NETWORK ARCHITECTURE

The power distribution system at MV and LV distribution level at both the customer locations were consisting MV / LV switchgear, IEC61850 compliant IED's, IEC 61850 communication network and connectivity to EMS system over IEC 61850. Being petrochemical industry the necessity was there to maintain the supply to processes under any power system disturbance situation.

The upcoming substation includes MV / LV air insulated switchgear equipped with the novel IEC 61850 compliant Relion® 615 series Feeder Protection and Control IEDs. The 615 series IEDs are applied for the protection and control of the various feeders.

All the process data including analog measurements, status signals, alarms etc. are acquired from the IED's. The various signals from switchgear required for interlocking and at EMS level are wired to digital inputs of IED which in turn made available for various interlocking schemes which is built in IEDs, resulting in substantial reduction in panel wiring / use of auxiliary relays. For building inter panel wiring GOOSE communication.

The function of the data communication network has been secured according to the same principles as the power system network. To assure a reliable operation the networks have been designed to a uniform entity, expressing the same implementation principles throughout the application, from the primary circuit to the data communication solution. The substation-grade Ethernet switches meeting the same requirement as protection and control IEDs have been selected. The connections from protection IED to switch are carried out with a dual SFTP data cable. Ethernet switches are interconnected in a fiber optic loop to ensure redundancy. The connection to the remote EMS system has been done using the IEC 61850 protocol.

Implementation of various interlocking schemes within substation like Reverse blocking, Auto changeover, Under voltage tripping have been done through GOOSE communication. Additionally the critical message exchange from substation to / from EMS including load shedding tripping achieved through GOOSE communication.

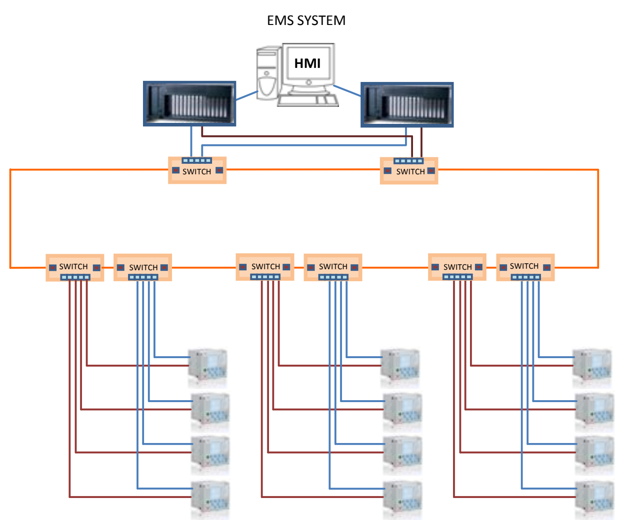


Fig. 1 System architecture for communication

V. SIMPLIFIED WIRING AND COST REDUCTION

Traditional hard -wired medium voltage switchgear systems contain extensive I/O wiring, connecting protection and control devices, for two main purposes:

- Signalling between switchgear bays. Typical signals include breaker position status, service and interlocking position information, and protection start signals.

- Signalling to and from external systems, for example. to RTUs or other automation systems as well as signals like current, voltage and power measurement.

Extensive signal wiring constitutes a significant cost over the entire life cycle of the switchgear installation.

Utilizing IEC 61850 and the GOOSE facility in modern protection and control devices, a vast number of signals can be transferred using ethernet instead of hardwiring.

In practice only one Ethernet cable is required between the IEDs of a substation and an Ethernet switch to enable communication between the protection and control IEDs. This can be compared with a hardwired solution where, for each signal, a copper wire is connected from each IED to all the other IEDs in the substation.

Significant savings can be achieved if signals are exchanged based on IEC 61850 GOOSE instead of traditional wiring. As well as the obvious reduction in material and direct labour costs, fewer wires result in savings from several other areas. Less wiring means reduced time spent on substation engineering and commissioning

Extensive wiring is not costly in the initial installation, but because the whole switchgear is split into separate panels for transportation, inter-panel wires have to be reconnected and possibly retested on site.

Furthermore, later stage or even on-site signal and logic additions are possible with GOOSE without having to install extra signal wires or use spare I/O channels in the protection and control devices.

VI. MONITORING OF COMMUNICATION NETWORK

Furthermore, GOOSE enables a more comprehensive supervision of the system. With a hard-wired system, it is not possible to know if a wire really is connected and working, whereas all GOOSE connections are constantly monitored, and any anomalies are reported to the substation automation system. Thus, the receiving device can take corresponding actions, such as shifting into fail-safe mode or blocking some functionality. Additionally, devices in test mode can be indicated using GOOSE communication and therefore actions can be taken in the receiving devices. This makes testing easier and safer.

VII. PERFORMANCE OF GOOSE SOLUTION

One of the essential preconditions for using GOOSE is that it performs adequately compared with a hardwired solution. In addition, due to the non-deterministic nature of Ethernet, reliability has to be guaranteed under difficult communication load conditions. Both performance and reliability can be managed if the protection and control devices are properly designed to use GOOSE signalling in applications as critical as those of hardwired signals.

In a hardwired system, signal propagation delay performance is constrained by three main factors:

1. Output circuitry delay, e.g. “make or break” delay of auxiliary signalling relays, typically 8-10ms
2. Input handling and filtering time in the receiving device. Often there is an additional filter delay to suppress spikes etc. caused by electromagnetic disturbance. This is normally adjustable in the protection and control devices, but typical total values, including the input conditioning delay, are in the range 10-50 ms.
3. Application cycle time of the protection and control device, i.e. the frequency indicating how often the device processes its I/O signals. Typically 1-50 ms.

By using GOOSE and Ethernet communication, the delay types #1 and #2 can be omitted, but the communication propagation delay needs to be added. As a consequence, if GOOSE support is implemented properly and it fulfils the hardest criteria of IEC 61850-5, the total propagation delay can be significantly lower in GOOSE systems than in traditional systems.

The selected Relion 615 series IEDs comply to performance class P1, type 1A “Trip” for protection purpose using horizontal GOOSE communication. This performance capability of 615 series IEDs is used in protection schemes described later in this document.

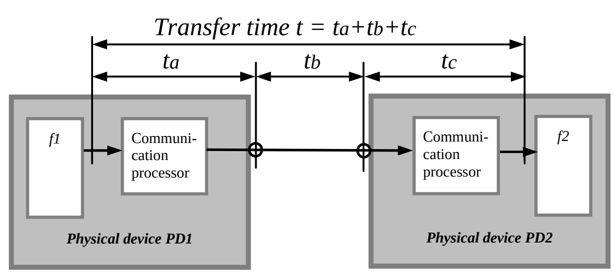


Fig. 2 Definition of transfer time

IEC 61850-5 classifies application types based on how fast the messages are required to be transmitted among networked IEDs. The standard also specifies the performance of each type of application, named as time duration of message transmission.

There are two independent groups of performance classes, one for control and protection, another one for metering and power quality applications. Since the performance classes are defined according to the functionality needed, they are independent from the size of the substation. Table 1 lists the message type, applications and requirement of transfer time.

TABLE I

MESSAGE TYPES AND PERFORMANCE CLASSES

Message type	Performance class	Applica-tion	GOOSE transmission time
1A	Fast Messages (Trip)	P1	10 ms
		P2/P3	3 ms
1B	Fast Messages (Others)	P1	100 ms
		P2/P3	20 ms
2	Medium Speed		100 ms
3	Low Speed		500 ms
4	Raw Data	P1	10 ms
		P2/P3	3 ms
5	File Transfer		≥1000 ms
6	Time Synchronization	T1 (time)	± 1 (Accuracy)
		T2 (time)	± 0.1 (Accuracy)

VIII. SUPERVISING GOOSE SIGNAL QUALITY

The strength of using IEC 61850 peer-to-peer communication compared to traditional hard wiring can be found in the supervision functionality and data quality handling. GOOSE supervision works as illustrated in Fig. 3. Data sending is event based and when a change in GOOSE data occurs, a message is sent multiple times to the network to ensure the data has been received. Message repetition starts at Tmin and continues with IED specific curve until the message sent goes to heart-beat cycle Tmax. If the receiving IEDs do not get the message within a certain time (e.g. 2*Tmax) the user is notified. The IED application can then handle the situation by changing the application values to fail-safe ones, for example. The signal flow between bays with hard-wired connections is, however, not supervised. Therefore GOOSE significantly improves safety.

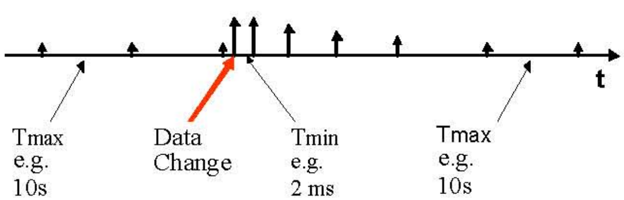


Fig. 3 GOOSE supervision

Additionally GOOSE data is sent with quality attributes which are used when interpreting the input value at the receiver side. This information is used in the running of substations, as well as in switchgear factory and site tests.

In running substations the quality attributes are used to detect failures in other IEDs and to act accordingly. For example, if an IED sending GOOSE data has an oscillating input, the data from this input is marked as oscillating and the IED receiving the data does not update the application due to invalid data. Instead the preconfigured fail-safe value is used, thus making the system safer.

XI. RELIABILITY UNDER COMMUNICATION LOAD

Even in a well-designed system the devices might experience background Ethernet traffic, such as sporadic queries by engineering tools. And most significantly, every untargeted device on the same LAN segment will "see" all the multicast/broadcast traffic - generated, for example, by GOOSE messages - intended for other devices. The effect of this additional communication load on GOOSE response times should be minimized. With modern designs and technology, e.g. using message filtering on the hardware level, even high communication loads can be managed.

The Relion 615 series IED architectures designed to support IEC 61850 from the start need to ensure that the delay in communicating control signals, analog values and other time critical data between the process and the IEDs is as small as possible.

The fast GOOSE performance of a Relion IED is critical in a native IEC 61850 implementation to allow control signal processing as if it were a traditional hardwired IED. During IED algorithm execution or task cycle, the data values of a protection function (eg, the protection start in PTOC) can change if an overcurrent is detected on a feeder, and this in turn updates the database supporting the particular LN structure. After a protection task cycle completes, the IED processing subsystem performs a signal comparison to identify new data in the IEC 61850 connected datasets. In the IEC 61850 data model, most data change driven activities are based on the datasets, for example, event reporting and GOOSE data publishing. The IED change detector identifies changes in the datasets and if a new value is detected, the dataset and its connected functionality are triggered. In an IED using GOOSE, the internal high-priority subsystem executing the GOOSE function is triggered. Subsequently, the modified data is sent as quickly as possible through the IED communication interface to the SA system station bus using a GOOSE multicast message. GOOSE multicast messages are unsolicited broadcasts which do not require any cyclical data polling mechanism. Data structures used in GOOSE include direct access to the IED internal database, and because the internal data model exactly matches the IEC 61850 standard, no data conversions are required.

In the same way, the IED's IEC 61850 native design yields high-performance subscribing GOOSE datasets from other IEDs in the local sub-network. As GOOSE messages are processed in the data link layer in the Ethernet stack, this does not require additional processing through the TCP and IP layers. This type of Ethernet communication is very fast since the data is retrieved directly from the IED communications hardware interface.

The IED's GOOSE processing capabilities can decode the message in less than 1 ms and deliver only the modified subscribed GOOSE data to the IED's internal database, which makes it immediately accessible to the next execution of the protection and control algorithms. A "put" operation is a single data value copy from a GOOSE frame to the internal LN structure database. No conversion is required as the data in both the IED database and incoming GOOSE message comply with IEC 61850 data types. The next application execution checks for new input values and processes them accordingly.

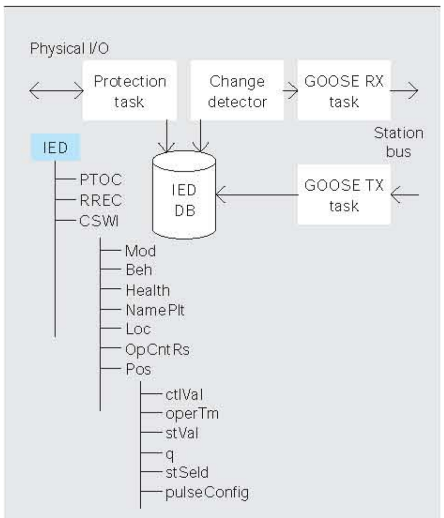


Fig. 4 GOOSE data and message handling in 615 IED

XII. PROTECTION APPLICATIONS BUILT OVER GOOSE COMMUNICATION

1. REVERSE BLOCKING INTERLOCKING SCHEME

In this scheme, the Incomer relay will use definite time overcurrent element and the outgoing feeder relay will use time overcurrent element. The Incomer relay selectively is allowed to trip or block depending on location of faults as identified from outgoing feeder relays.

For a fault on an outgoing feeder or an "out of zone" fault, the corresponding outgoing feeder will send blocking signal to the Incomer relay after its time instantaneous overcurrent element picks up. The relay on the faulted feeder will operate only and clear the fault. For a fault on the bus or an "in zone" fault, the corresponding outgoing feeder will not send a block signal to the main relay and the main relay will be allowed to trip and clear the bus fault after a short time delay.

Information exchange between bay level devices is conventionally realized by hardwiring. This means that any information which should be transferred to another IED is assigned to an output contact. The terminals of this output contact are then wired to an input in the receiving IED. Figure 5 indicates an example of a hardwired solution.

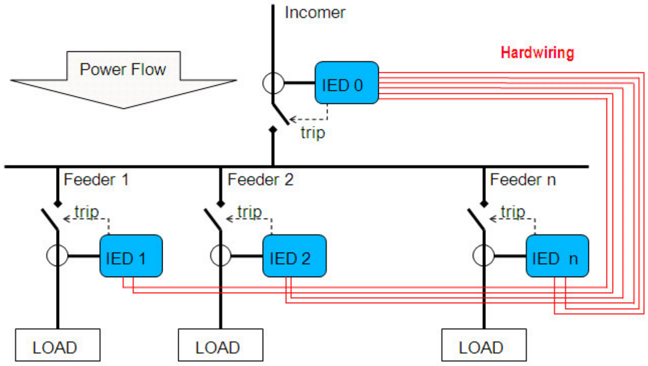


Fig. 6 Conventional hardwired reverse blocking scheme

By means of GOOSE communication the traditional interlocking scheme can be speeded up considerably. At the same time the new technology offers an increased operational reliability and flexibility of the protection. By transferring GOOSE messages between the relays interconnected with a local area network (LAN) the blocking signals can be sent directly from relay-to-relay without additional delay from auxiliary relays or input filters.

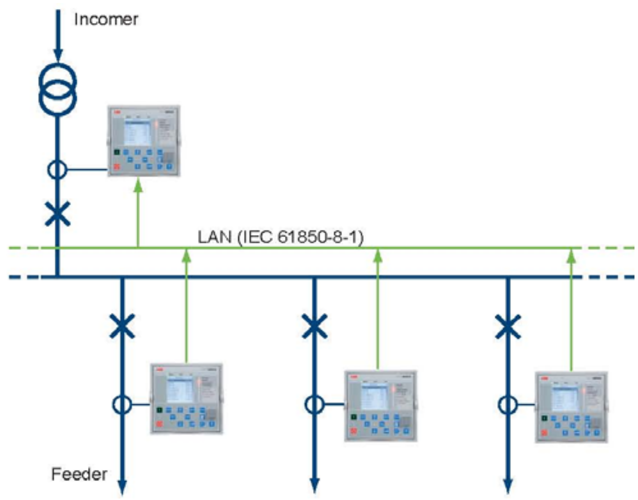


Fig. 7 IEC 61850 GOOSE communication based reverse blocking scheme using Relion 615 series IEDs

The operational reliability of a busbar protection scheme based on interlocking and GOOSE messaging is significantly enhanced by the inherent supervision of the GOOSE messaging. The supervision function of the GOOSE service generates an alert, should the message not get through, allowing appropriate repair measures to be taken immediately.

By using GOOSE messaging an operational speed gain of about 30% can be achieved by comparison with the operating speed of the classic, interlocking-based busbar protection schemes. The speed advantage is entirely attained from the speed and reliability of the GOOSE service.

Fig. 8 shows the comparative outlining the parameters affecting the speed of interlocking based reverse blocking protection schemes.

Reverse blocking scheme based on GOOSE communication		
Issues affecting the operating time of interlocking-based Reverse blocking scheme ■ (grey) Not affected by the applied communication technology ■ (orange) Function gaining speed from GOOSE ■ (purple) Significant technolgy-related delay ■ (green) Delay eliminated in GOOSE application		
FACTOR	HARDWIRED APPLICATION	IEC 61850 AND GOOSE
Safety margin allowing for a possible saturation of the current transformers	■ (grey)	■ (grey)
Delay originating from possible interposing relay	■ (purple)	■ (green)
Start delay of relay sending out blocking signal / Overcurrent stage sending out GOOSE message	■ (purple)	■ (orange)
Retardation time of overcurrent relay providing busbar protection	■ (grey)	■ (grey)
Input and blocking circuit delay / Overcurrent stage receiving GOOSE message	■ (purple)	■ (orange)

Fig. 8 Comparative outlining the parameters affecting the speed of interlocking

2. AUTO BUS TRANSFER AND UNDER VOLTAGE TRIPPING SCHEME

In a typical 2 Incomer and Bus coupler arrangement (Figure 9), the automatic bus transfer scheme is used to minimize the effect of outages on one of the incoming supplies by opening the normally-closed incoming breaker connected to that supply, and then reenergizing the decaying bus by closing the normally open bus tie breaker after the voltage of the decaying bus voltage drops to a predetermined level. This method is called Residual Voltage bus transfer.

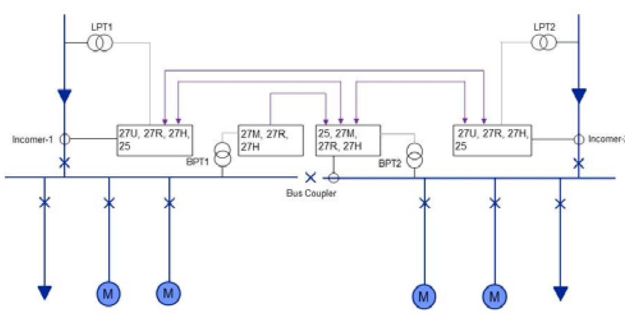


Fig. 9 Two Incomer and bus coupler arrangement

Various signals like breaker status, trip selector / auto-manual switch status, line / bus under voltage and healthiness status etc. are exchanged over GOOSE communication. Similarly the under signals from bus PT relay extended to all motor feeders to achieve under voltage tripping scheme.

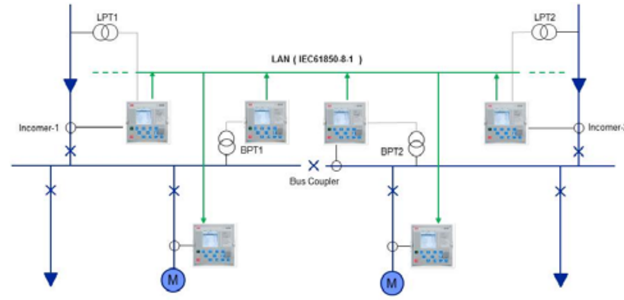


Fig. 10 IEC 61850 GOOSE communication based Auto bus transfer and under voltage tripping scheme

Both auto bus transfer as well under voltage scheme configured over GOOSE communication lead to below advantages:

- Significant reduction in hardwiring as compared to conventional bus transfer schemes.
- The use of programmable logic controller functions such as timers and control logic within the protective relay provides for the flexibility to implement a custom bus transfer scheme to best meet the needs of the
- Reconfiguration of scheme without time and expense of additional wiring.
- Ability to easily duplicate for additional bus transfer systems
- Less number of IED I/Os are needed for the transfer of data between the IEDs

XIII. TESTING PERFORMANCE OF GOOSE

The Factory Acceptance Testing (FAT) to prove the performance of complete system fulfilling the customer requirement has been carried out at ABB works. The FAT was carried out on engineered schemes of one of board having all the IEDs of that switchboard connected to Ethernet LAN as per the real system architecture. Missing parts like switchgear or DCS were simulated.

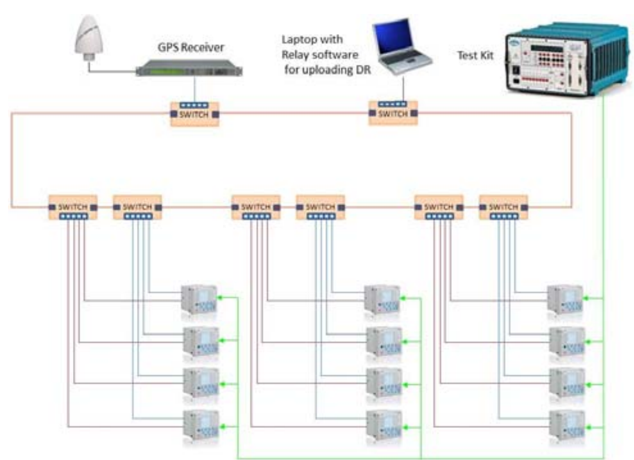


Fig. 11 Factory acceptance test set-up

The IEDs analog inputs were connected to Doble test set which can inject precision analogs signals. Inputs and outputs also wire back from each IED for monitoring circuit breaker position, triggering the test set, and allowing for input triggering on all IEDs simultaneously. Due to the multiple IEDs used to gather results in these tests, precision timing was critical. To support these requirements, a GPS clock with an SNTP (simple network time protocol) output connected to the network. The IEDs synchronized to the main system clock source within 1 ms time accuracy. The overall system configuration replicates the substation's field configuration in a lab environment (Figure 11).

Various tests were carried out to ensure the correct operation of the IED and scheme operation along with performance of GOOSE timings.

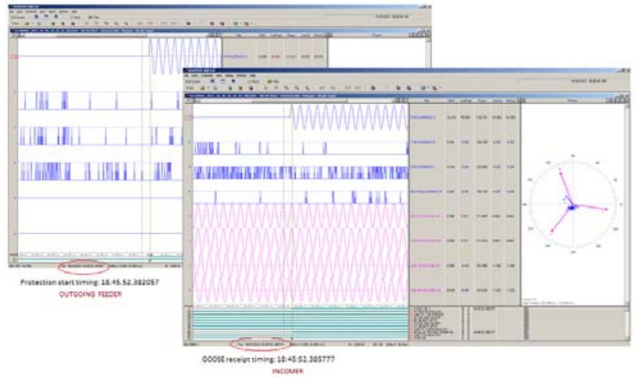
Fig. 12 Factory acceptance test set-up

The performance validation used the SOE (Sequence of Events) records and fault recording data from the IEDs. The first test involved the simulation of reverse blocking scheme with protective relays. The equal current injected in all outgoing and Incoming IEDs. In addition to protection, control, and metering, each IEDs has many standard features. These include graphical user-programmable logic, digital fault (waveform) capture, SOE and fault recording, monitoring, and advanced Ethernet communications supporting IEC 61850-8 with GOOSE (peer-to-peer) messaging.

Test measured three events: (1) The time for the outgoing relay to sense protection and send start signal to Incomer as well to trip its own breaker after set time delay. (2) The time for the Incomer relay to receive the GOOSE message the outgoing relay has started on protection. (3) The time for the Incomer relay to block instantaneous protection upon receiving the GOOSE trigger.

The relay's digital fault recorder was set to sample at 32 samples per cycle and record for 50 cycles. Recordings began on rising edge triggers.

After triggering events in both relays, the recordings were combined for analysis.



In summary, the text executed with : Protection blocking data exchange time between Relion® *615* IEDs using IEC 61850 GOOSE (max) including protection activation time *was 15 ms and Signal transfer time between Relion® IEDs using IEC 61850 GOOSE (max) was 7 ms. The test team conducted this test several times to ensure consistent results. GOOSE time stayed very consistent.*

The above is possible due to a native implementation of IEC61850 in the Relion product technology. This performance capability of the Relion product family allows the customer to fully exploit the benefits of the IEC 61850 standard in SA systems.

XVI. CONCLUSIONS

With IEC 61850 and GOOSE cost-efficient solutions can be built, as hardwired signal paths are replaced by a LAN network.

Utilizing IEC 61850 and GOOSE boost signalling performance and speed which surpass those of traditional hardwired systems. Additionally, the use of IEC 61850 and GOOSE provides increased operating reliability of the protection through continuous supervision of the communication and the data integrity of the GOOSE messages.

Furthermore, flexible protection schemes can be implemented through software configurations rather than hardwired signal paths. This makes the system easily extendable and reconfigurable on demand to meet the needs of protection system changes, as well as changes in substation configurations and network topologies.

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