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Utilizing possibilities of IEC 61850 and GOOSE

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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. Besides describing generic improvements in capacity, performance and reliability, the paper presents a practical GOOSE application, i.e. blocking based busbar protection.

INTRODUCTION

Horizontal communication, or GOOSE, as it is called in the IEC 61850 standard, 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.

Traditionally, the signal paths between protection and control devices have been hardwired. In these schemes, 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 busbar protection and co-ordinated arc protection.

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.

SIMPLIFIED WIRING

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

1. Signalling between switchgear bays. Typical signals include breaker, disconnector and earthing switch status signals, service and interlocking position information, and protection start signals.
2. Signalling to and from external systems, for example to RTUs or other automation systems. As well as most of the signals listed above, current, voltage and power measurement signals are also included.

Extensive signal wiring constitutes a significant cost over the entire life cycle of the switchgear installation. Table 1 reveals the extent to which hardwired I/O signal wiring is needed in a conventional 10-bay medium voltage switchgear installation.

Number of IO wires	From/To Protection and Control IEDs	From/To other Devices	Total
Intebay signalling	104	116	220
Automation system	85	47	132
Other externals, i.e. load management system	383	252	635
Total	572	415	987

Table 1. Amount of I/O wiring in traditional hardwired MV switchgear system

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. However, Table 1 reveals that 70% of the signal connections are to external systems. Though modern automation systems and load management controllers also incorporate GOOSE capability according to IEC 61850, thereby enabling high-performance integration without hardwiring, it has to be noted that most of the traditional fieldbusses and communication protocols, such as Modbus, and even the IEC 61850-8-1 client/server profile do not perform properly in demanding load management applications.

Significant savings can be achieved if only some of these signals are 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.

The use of GOOSE signalling over an Ethernet bus instead of binary signalling over hardwired cables decreases the number of wiring diagrams required, which enables the switchgear vendor to standardize the design and therefore streamline the production process. The nature of the Ethernet makes it possible to use automatic test tools to test the signal paths, whereas a hardwired solution would need significant manual intervention even in an automated approach.

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, late 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.

PERFORMANCE OF A 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.

Performance

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. This benefit is used in protection schemes described later in this document.

Testing the performance: blocking the incomer protection

Fig. 2 shows a typical distribution network primary substation with two protection and control devices. Fault currents are injected from a network simulator using recorded fault current patterns and a simple network model. The task is to measure how quickly the - incomer protection can be blocked in the event that the fault is on the outgoing feeder.

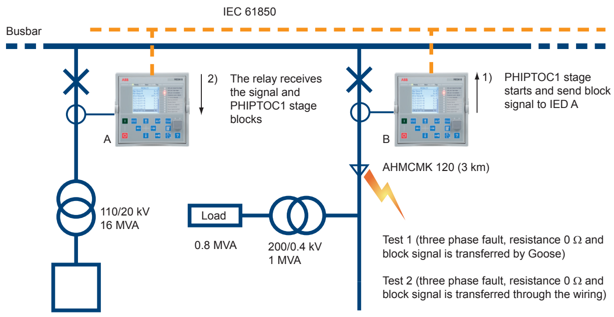

Fig 2. Test arrangement to study blocking performance

Using a GOOSE based setup, the time taken to block the protection stage on device A after the fault current was injected was 15…20 ms. In contrast, with the same protection settings and a reasonable input filter time of 5 ms on device A, and using wiring from device A to B, the time measured was around 47ms.

To achieve minimum operating time but maintain selectivity, the operation delay of the high-set overcurrent protection stage in device A needs to be set properly. Reduced signal propagation delay can be used to improve the protection scheme.

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. In the following diagram the GOOSE response time distribution is depicted under a communication loading of 2,000 GOOSE messages per second on the network. These messages were intended (subscribed by) for the devices under test. The response time was measured by two ABB REF615 devices.

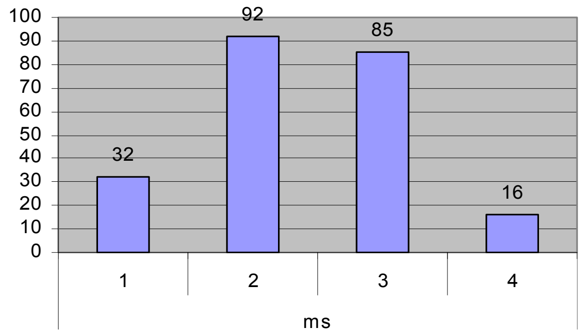

Fig 3. GOOSE response time at 2000 msg/s background communication load, a total of 225 test messages.

It can be seen that the response time performance fulfils the standard criteria (specified in IEC 61850-5, Type 1A, Class P2/3 messages, 3 ms) even under heavy load conditions. It must be noted that the times measured include up to 2.5 ms of the application processing cycle time of the REF615 device. This time is not accounted for in the performance measurements specified in IEC 61850-5, but has to be taken into account in actual applications.

SUPERVISING THE SIGNAL QUALITY AND STATUS OF HORIZONTAL COMMUNICATION

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. 4 . 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. 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 substations, as well as in switchgear factory and site tests.

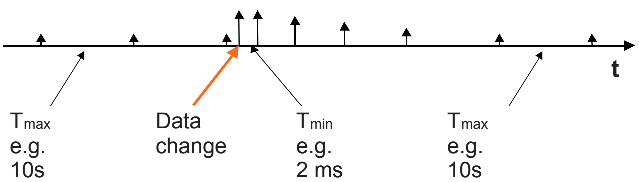

Fig 4. GOOSE Supervision

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.

Quality handling can also be used in the switchgear factory and site testing phases by setting the IEDs to “Test” or “Test/Blocked” mode. See Table 2.

	IED in Test mode	IED in Test/Blocked mode
Outputs to process	Yes	No
GOOSE output	Sent data quality is flagged with test. If IED logic is set to Test mode, GOOSE message header Test bit is activated	Sent data quality is flagged with test/blocked. If IED logic is set to Test mode, GOOSE message header Test bit is activated
GOOSE input	Outputs to process are active only if received GOOSE data is flagged with Test quality mode	Received GOOSE data updates the IED application but the output from process to process is not activated

Table 2. GOOSE Test and Test/Blocked quality handling

When testing GOOSE connections between IEDs in Test mode it is assumed the connections to physical processes are not active as IED outputs to processes are activated according to the application. In Test/Blocked mode the IED outputs are not activated. Both the sender and the receiver IEDs must be set to Test mode to be able to utilize GOOSE signal testing between bays.

BLOCKING-BASED BUSBAR PROTECTION USING GOOSE

The GOOSE service of the IEC 61650 standard can be used in blocking-based busbar protection schemes. In this new approach the conventional hard-wired blocking signal paths between the switchgear cubicles are replaced with a substation-wide Ethernet LAN.

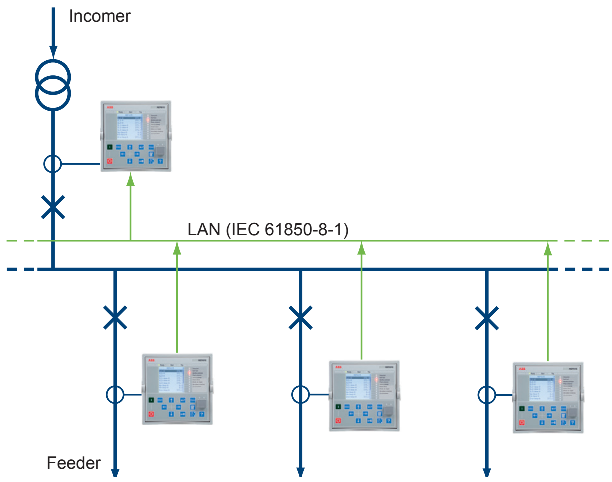

Fig 5. A fast busbar protection scheme based on ABB’s new 615 series of protection and control IEDs, a station-wide Ethernet LAN and GOOSE services

Fast and reliable busbar protection

By using GOOSE messaging an operational speed gain of between 30 and 50% can be achieved when compared with the operating speed of classical hardwired, blocking-based busbar protection schemes. This advantage is entirely attributed to the speed and reliability of the GOOSE service.

Blocking based protection schemes are well-known and widely accepted. When a fault occurs on an outgoing feeder, the protection and control IEDs of both the incoming feeder and the faulty outgoing feeder start. On starting, the IED of the outgoing feeder, however, blocks the fast-acting stage of the incoming feeder IED. On the contrary, should a fault arise on the busbar system, the outgoing feeder IEDs will not start and the incoming feeder IED is allowed to operate after a short coordination time delay and trip the CB of the incoming feeder.

By transferring GOOSE messages between the IEDs interconnected with a local area network (LAN), the blocking signals can be sent directly from IED to IED without additional delays from the auxiliary relays or input filters. In complex busbar systems the blocking signals have to be routed to several objects. For hardwired schemes this means inserting auxiliary relays, which delays the blocking circuit. This additional delay must be considered when the total operating time of the protection is determined.

By applying GOOSE messaging, blocking signals can be transferred to all the involved IEDs at once, and the ones to be blocked pick up the signal from the message stream. When using GOOSE messaging the total operating time of the busbar protection is independent of the number of protection and control IEDs involved and the complexity of the busbar system.

Adaptive and flexible protection

Applying GOOSE services to flexible REF615 feeder protection and control IEDs allows the busbar protection to benefit from the multiple protection stages of the IEDs. REF615 contains separate protection stages for the individual protection functions. In this way compromises stemming from conflicting requirements on a certain stage can be avoided when determining setting values for the protection functions. These circumstances are particularly beneficial in busbar protection applications based on the blocking principle. The settings of the IED stage issuing blocking signals can be freely determined from the magnitude of the short-circuit current, switching inrush current and the starting current of the feeder. The reach of the protection stage in a fault situation does not need to be considered when the protection settings are determined. These features make blocking schemes a useful and effective means of implementing high-speed busbar protection in distribution substations.

REF615 application with GOOSE

Issues affecting the operating time of blocking-based busbar protection systems

- Not affected by the applied communication technology
- Function gaining speed from GOOSE
- Significant technolgy-related delay
- Delay eliminated in GOOSE application

FACTOR	HARDWIRED APPLICATION	IEC 61850 AND GOOSE
Safety margin allowing for a possible saturation of the current transformers	Not affected by the applied communication technology	Not affected by the applied communication technology
Delay originating from possible interposing relay	Significant technolgy-related delay	Delay eliminated in GOOSE application
Start delay of relay sending out blocking signal / Overcurrent stage sending out GOOSE message	Significant technolgy-related delay	Function gaining speed from GOOSE
Retardation time of overcurrent relay providing busbar protection	Not affected by the applied communication technology	Not affected by the applied communication technology
Input and blocking circuit delay / Overcurrent stage receiving GOOSE message	Significant technolgy-related delay	Function gaining speed from GOOSE
Circuit breaker operating time	Not affected by the applied communication technology	Not affected by the applied communication technology

Fig. 6. Comparative table outlining the parameters affecting the speed of blocking-based busbar protection schemes.

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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