

SUBSTATION AUTOMATION EXPERIENCES BASED ON THE IEC 61850 GOOSE MESSAGES

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ABSTRACT

One of the main challenges of new technologies is to demonstrate in the real world the benefits they provide. Now that the implementation of IEC 61850 is a fact we have results from real projects that confirm the advantages of the new standard. This paper covers some substation automation experiences based on the IEC 61850 GOOSE messages for an specific automation function applied to a substation topology commonly known as 'H' and the use of the GOOSE messages in the communication between control and protection relays and remote I/O modules (RIO).

INTRODUCTION

There are a wide variety of mechanisms through automation functions can be achieved in a Substations Automation System (SAS). Functions performed in previous systems based on other communication protocols or on wiring can be implemented now using the GOOSE messages specified in the IEC 61850 standard.

This paper will focus on different real experiences regarding the use of this communication service based on the GOOSE messages. More specifically it covers the application of GOOSE messages in an specific automation function applied to a substation topology commonly known as 'H' and their application in the remote digital input/output modules.

The first application example of GOOSE messages presented in this article is an automatism implemented in IBERDROLA's substations with 'H' topology. This substation architecture known as 'H' is typical of distribution installations. The higher voltage switchyard has an H configuration while the lower voltage level switchyard has a single busbar configuration. The paper will describe an implementation of this automatism that uses the GOOSE messages for the required information exchange to execute the automatism and will explain the conclusions of this experience.

The other application example covered by this article is the use of GOOSE messages for the communication between the control and protection relays and remote digital input/output modules.

These applications have been tested in two real projects at 30/13kV GARDATA substation and 66/13kV SANGUESA substation, in the north of Spain.

THE IEC 61850 STANDARD

The IEC 61850 standard (Communication networks and systems for power utility automation) defines the peer-to-peer communication that provides services for the exchange of substation Events. These are the GOOSE messages (acronym for Generic Object Oriented Substation Events) based on multicast ethernet frames. The most evident use of this GOOSE messages is the replacement of the traditional wiring to exchange information between bay control and protection units, for example to implement the interlocking between devices. But once we have a fast and reliable data communication mechanism between devices, we can use these messages for other purposes as described in this paper.

GOOSE messages work in a model type known as "Publisher / Subscriber" [1]. In this model, the sending device "publishes" the desired data in a GOOSE message and any device in the same network interested in any of the data of the publishing message can be configured to "subscribe" to the publishing device's GOOSE message. This means that a single message can be received by several devices using a multicast mechanism. The content of the GOOSE messages can be not only binary data but any other data as measurements.

A newly activated device, upon power-up or after recovering from a communication failure, shall send the current value of the configured data as an initial GOOSE message. Moreover, all devices sending GOOSE messages shall continue to send the message with a long cycle time, even if no status/value change has occurred. This ensures that devices that have been activated recently will know rapidly the current status values of their peer devices.

In summary, some advantages of the GOOSE messages regarding the traditional hard-wired signals can be identified. There is a cost reduction due to the use of the

communication network instead of the hard-wired signals. This is especially important when we need to send a data to a large number of devices. And thanks to the continuous retransmissions of messages, a failure in the link can be immediately detected.

THE 'H' AUTOMATISM

The first application example of GOOSE messages presented in this article is an automatism implemented in IBERDROLA's substations with 'H' topology. This substation architecture known as 'H' is typical of distribution installations. The higher voltage switchyard has an H configuration while the lower voltage level switchyard has a single busbar configuration.

IBERDROLA has a large number of substations with 'H' type configuration, this is a particular configuration that differs from others in which the lines have no protection and transformer positions do not have high voltage breaker.

One of the characteristics of this configuration is that the three circuit breakers cannot be closed at the same time and that the lines are protected by the remote end of the lines. The mission of this automatism is to keep the voltage in the busbars of the substation through the opening and closing of circuit breakers from the lines and from the longitudinal coupling according to some configured preferences and with the detection of the presence or absence of voltage on the power lines.

This automatism is executed in the Substation Control Unit (SCU) with information received from other devices (IEDs) via communication. With the required information the SCU executes the automatism and sends the corresponding open/close commands to the IEDs.

Figure 1 shows the substation configuration of these systems:

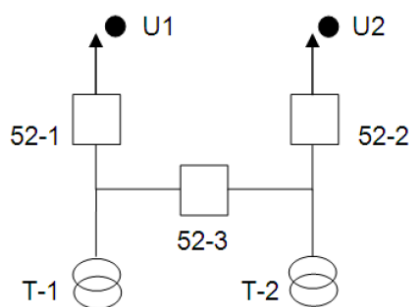


Figure 1.

Six devices are involved in this automatism, the two line relays (LINE1, LINE2), the bus coupler relay (BC1), the two transformer relays (T1 and T2) and the substation control unit.

The automatism has four different operation modes that can be selected from the HMI of the substation:

- Manual: The automatism is stopped and there is only manual operation.
- Preference 1: Line 1 is the preference to maintain the voltage in the busbars (52-1 and 52-3 closed).
- Preference 2: Line 1 is the preference to maintain the voltage in the busbars (52-2 and 52-3 closed).
- Preference 1-2: Both lines to maintain the voltage in the busbars (52-1 and 52-2 closed and 52-3 opened)

To illustrate the data modelling of this automatism according the IEC 61850 standard some of the inputs with their IEC 61850 mapping are detailed.

The automatism is modelled in the substation control unit with a GAPC logical node (HGAPC1). The GAPC (Generic automatic process control) logical node is defined in the IEC 61850 standard to model in a generic way the processing/automation functions that are not predefined by one of the other logical node groups.

For example, the commands received from the HMI to select the operation mode of the automatism are modelled with multiple instantiations of the SPCSO data (single point controllable status output):

- Preference 1: SCUCTRL/HGAPC1.SPCSO1
- Preference 2: SCUCTRL/HGAPC1.SPCSO2
- Preference 1-2: SCUCTRL/HGAPC1.SPCSO3
- Manual: SCUCTRL/HGAPC1.SPCSO4
- Blocked: SCUCTRL/HGAPC1.SPCSO5

Data from other IEDs, for example the circuit breaker positions, is modelled in the standard XCBR logical node:

- 52-1: LINE1CTRL/XCBR1.Pos.stVal
- 52-2: LINE2CTRL/XCBR1.Pos.stVal
- 52-3: BC1CTRL/XCBR1.Pos.stVal

The voltage presence that is calculated in a logic in line relays, is modelled also in a GAPC logical node in single point status data:

- U1: LINE1CTRL/LogGAPC1.Ind25.stVal
- U2: LINE2CTRL/LogGAPC1.Ind25.stVal

Some of the outputs of the automatism in the SCU, the operation commands for each involved IED, are also modelled in the HGAPC logical node extending its data with OpOpn/OpCls data objects for the Open/Close commands of the three involved circuit breakers. For example:

- 52-1 Open/Close commands:

- SCUCTRL/HGAPC1.OpOpn1
- SCUCTRL/HGAPC1.OpCls1

In this case, these commands will be sent via GOOSE message as will be explained later so this extended data class is SPS (single point status).

In previous IBERDROLA's substation automation systems where non IEC 61850 protocols were used, the SCU uses master-slave serial protocols (with pooling mechanism) to receive the information and commands to send the outputs of the automatism to the relays.

In this IEC 61850 based system the SCU can receive the information from the IEDs either with the Report model or with the GOOSE model. And the SCU can send the information to the IEDs either with the Control model (commands) or with the GOOSE model.

For the information that the IEDs send to the SCU both communication services (Reports and GOOSEs) were implemented during the project. Both were tested and validated but in the end the Report services were selected for two reasons. The time requirements of the automatism do not requires the use of GOOSE messages, and the SCU was already receiving that information via Report messages for the Sequence of Events (SOE) of the system.

For the information that the SCU sends to the other IEDs the options were the Control model (commands) or the GOOSE model. In this case the GOOSE messages were selected. The GOOSE messages have several advantages when compared to the Control model or with the master-slave serial protocols. One is the communication speed which is faster with the GOOSE messages.

In this case, the SCU sends a single GOOSE message over the network containing all the information required in all the IEDs involved in the automatism. This information is the following Boolean status (with quality) values:

- Automatic/Manual indication.
- U1 voltage presence.
- U2 voltage presence.
- 52-1 Open command.
- 52-1 Close command.
- 52-2 Open command.
- 52-2 Close command.
- 52-3 Open command.
- 52-3 Close command.

It must be taken into account that in this project the Open/Close commands are boolean data values that are used in the subscribing IEDs to command the circuit breakers.

Another advantage is the information update when there

is a communication failure or in the start-up of the system. With the "commands" approach, the SCU must detect the lost and recovery of the communications and must send the required command to each IED.

For example, one of the information that each IED needs from the SCU is if the automatism is in automatic or manual mode, because the IED must not accept manual command over the circuit breakers if the automatism is working. With the GOOSE approach, once the communication link is restored, all the IEDs receive immediately the information without any special treatment in the SCU.

REMOTE I/O MODULES (RIO)

The remote digital Input/Output modules are not a new concept in substation automation although they have been used most frequently in industrial applications. Traditionally the RIOs have used field buses like CAN or PROFIBUS, or vendor private implementations. Not all the devices used in the substation automation systems have this field buses available and the vendor specific implementations do not allow interoperability. But now in the IEC 61850 based automation systems we have again a fast and reliable mechanism to exchange this I/O information with standard communication services that are already available in the IEDs.

Another important advantage is that this communication can use the same communication ethernet network already available in the substation.

IBERDROLA considered that these modules should not require an engineering effort similar to the rest of IEC 61850 IEDs and should not require even a CID configuration file. So in order to make the integration of these devices easier and mainly in order to guarantee a complete interoperability between vendors, IBERDROLA has written a specification for the RIO modules to be used in its IEC 61850 systems [2].

To some extent this specification can be compared with a Basic Application Profile (BAP) [3] [4], because defines a typical application of specific IEC 61850 domain and define a profile for this application. When this RIO specification was released the BAP concept was not in use in the IEC 61850 systems yet, and of course it is only the proposal of a utility. But based on this specification the E3 group in Spain [5] is now working to include in their minimum common specification for substation protection and control equipment in accordance with the IEC 61850 standard, the requirements for the use of the RIOs.

In this specification fixed configurations have been defined for these modules in the number of inputs/outputs and the information contained in the GOOSEs has also been specified. With this specification two mayor objectives have been achieved. The first is to reduce the

configuration of this communication to only two settings (the remote device address with micro switches in the RIO and with a setting in the relay) and the second is to allow the interoperability between different vendors without a specific configuration task.

Another important requirement of this specification is that each RIO can be associated with up to 8 devices, IEDs, which can receive the status of the digital inputs from the RIO module and any of them can activate its digital outputs. This activation of the digital is performed by an OR function of the signals received from each of the associated devices.

The communication between the Remote I/O modules and the other IEDs is based on GOOSE messages. The I/O modules serve a goose message on the network which include all the information related to the inputs and outputs status and the internal alarms and it subscribes to GOOSE messages from other IEDs that can activate its outputs.

The final objective of the specification is to allow the automatic GOOSE subscription in both the Remote I/O module and the associated IEDs with the minimum engineering effort.

To achieve this objective, of course, all the configuration values for the GOOSE messages must be specified, as is described in the following sections.

Fixed number of I/O

Fixed number of I/O as this determines the information included in the GOOSE messages (i.e. 12 inputs / 4 outputs).

Multicast address

Multicast address based on the identification number of the module. Each Remote I/O module in the network is assigned an identification number, like an address, which will identify the module in the network. So, the configuration of these devices is reduced to configure the number of the device in the Remote I/O module and in the IEDs, and to configure the values for the outputs of the module in the IEDs.

So a range of GOOSE multicast addresses is reserved for the Remote I/O communications.

The selected range of multicast address is :

01-0C-CD-01-XX-YY:

Where XX=01 indicates that the goose message is sent by the Remote I/O module and XX=00 indicates that the message comes from an IED.

Where YY indicates the module address configured in the

module switches.

GOOSE configuration parameters

The main attributes of Goose message are specified as follows:

- Control Block Reference: Vendor specific.
- Time Allowed to Live (ms): The standard values with a Maxtime of 2048 ms (the source supervision time or supervision heartbeat cycle time).
- Dataset Reference: Vendor specific.
- GOOSEID: Its format is RIO_W_XX_YY, where W is the manufacturer ID, XX is the number of digital inputs and YY is the number of digital outputs.
- Config Review: 1.

All other values of the GOOSE header will be the default values defined in Annex C of Part 8-1 of the IEC61850 standard:

- APPID: 0.
- VLAN-PRIORITY: 4.
- VLAN-ID: 0.

With all this predefined information, both Remote I/O modules and the associated IEDs are able to make automatically the subscription to the corresponding GOOSE messages.

Ethernet ports

The specification also includes a requirement for the Remote I/O communication ports. This modules must provide two ethernet ports with a built-in switch which must allows the connection in cascade of multiple modules, as is shown in figure 2.

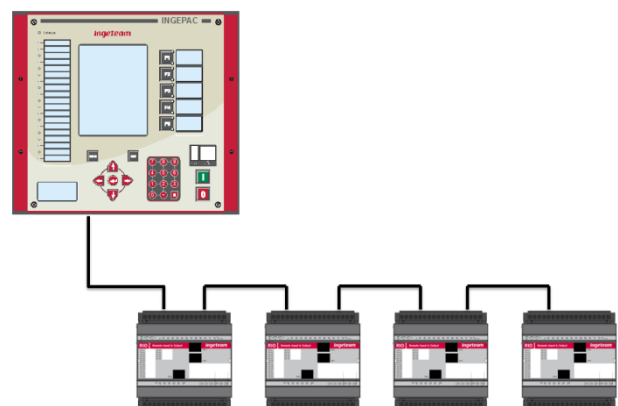


Figure 2.

The objective of this requirement is to reduce the installation cost of these modules avoiding the use of independent ethernet switches.

This communication topology does not provide redundancy. To achieve this redundancy the High-availability Seamless Redundancy (HSR) protocol could have been defined.

The HSR is a redundancy communication protocol defined in the IEC 62439-3 standard and it is one of the redundancy mechanism recommended in IEC 61850 networks. In the HSR protocol the device use two redundant ethernet ports and the protocol is based on the simultaneous transmission and reception of data via both independent ports. In the HSR networks no external switches are used, instead each device has two ring ports, and all the devices are connected in a ring topology, with one port of the device connected to the previous device and the other connected to the following device

This redundancy protocol was not considered due to two main reasons. When IBERDROLA's specification was defined the redundancy protocols (PRP or HSR) were in definition phase. And at this moment, this redundancy options represents an additional cost in a solution that require to be as economic as possible.

In this project the RIO modules have been applied in two applications related with the transformer bay. One is to get the required digital inputs information from the transformer and the other is the tap changer control. In both cases the RIOs are mounted outdoor nearby the primary equipment.

Other applications of these modules can be the extension of the I/O number of the relays, the mounting of the I/O boards in the process bus close to the primary elements, or to transfer the digital input/output information in the substation over a fiber optic media.

CONCLUSIONS

This paper analyses different implementation examples of the IEC 61850 standard and try to share the practical lessons learnt during the project used to validate the proposed solutions. The use of the IEC 61850 standard for substation automation and specifically the use of the GOOSE services offer additional options for those functions that need the information exchange between devices.

In the case of the application of GOOSE messages for the implementation of centralized automatism, as the described one applied to substations with 'H' topology, one of the advantages is the simplification of the required treatment in algorithms that requires sending information from one device to several devices. In addition the use of the peer-to-peer communication provides an improvement in the response time of the actions compared with other implementations based in master-slave protocols with pooling data acquisition or even

compared with IEC 61850 client-server communications.

The use of the GOOSE messages in the communication between control and protection relays and RIO modules can reduce the configuration effort, reduce the cost of installation due to the replacement of the traditional wiring and the use of the communication network and allow the interoperability between different vendors.

With the IBERDROLA's specification two mayor objectives have been achieved. The first is to reduce the configuration of this modules and the second is to allow the interoperability between different vendors without a specific configuration task.

As a conclusion, with this experiences the application of the peer-to-peer communications, based on the IEC 61850 GOOSE messages have been implemented, tested and validated in a real installation, for two applications different from the most common bay control unit's information exchange.

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- [4] Cigré Paris 2014 - Paper 207 – Increasing interoperability by IEC 61850 profiling – requirements and experience from end-user and vendor prospective
- [5] Minimum common specification for substation protection and control equipment in accordance with the IEC 61850 standard - <https://sites.google.com/site/e3groupiec61850/>