http://doi.org/10.35784/iapgos.6787

received: 02.11.2024 | revised: 20.04.2025 | accepted: 19.06.2025 | available online: 27.06.2025

SUBSTATION DIGITALISATION VIA GOOSE PROTOCOL BETWEEN INTELLIGENT ELECTRONIC DEVICES

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Abstract. *The article addresses the implementation of projects for new digital substations, as well as upgrading existing substations using digital intelligent electronic devices. The purpose of the scientific article is to implement the GOOSE protocol into the IEC 61850 standard, enabling all substation process equipment to be interconnected with a single information network. These technological advancements significantly influence the process of operating secondary equipment at substations and, at first, may pose certain challenges during its testing. The experimental analysis confirmed that the mechanism of cyclic transmission of GOOSE messages in REF615 and SEPAM T62 devices operates in accordance with the protocol. The repeated transmission mechanism ensures message delivery and enables detection of communication failures after the maximum period of transmission of GOOSE messages.*

Keywords: distribution substation, logical nodes, signal identification, control, monitoring

CYFRYZACJA PODSTACJI Z WYKORZYSTANIEM PROTOKOŁU GOOSE MIĘDZY INTELIGENTNYMI URZĄDZENIAMI ELEKTRONICZNYMI

Streszczenie. *Artykuł obejmuje zagadnienia związane z wdrażaniem projektów nowych cyfrowych podstacji, a także modernizacją istniejących podstacji przy użyciu cyfrowych inteligentnych urządzeń elektronicznych. Celem artykułu naukowego jest wdrożenie protokołu GOOSE do standardu IEC 61850, który umożliwia połączenie wszystkich urządzeń procesowych podstacji z jedną siecią informacyjną. Innowacje te znacząco wpływają na proces obsługi urządzeń wtórnych w podstacjach i początkowo mogą powodować pewne trudności podczas ich testowania. Eksperyment przeprowadzony w ramach pracy naukowej potwierdził, że mechanizm cyklicznej transmisji komunikatów GOOSE w REF615 i SEPAM T62 jest realizowany zgodnie z protokołem. Ta technologia wielokrotnej transmisji gwarantuje, że odbiorca otrzyma wiadomość, a wszelkie usterki zostaną wykryte po maksymalnym okresie transmisji wiadomości GOOSE.*

Słowa kluczowe: podstacja dystrybucyjna, węzły logiczne, identyfikacja sygnału, sterowanie, monitorowanie

Introduction

For the phased implementation of a 6 kV RP-140, dispatching, and implementation of the automated dispatch control system for power supply, it is essential to verify the compatibility of the operation of intelligent electronic devices REF-615 and Sepam 60 using the GOOSE (Generic Object-Oriented Substation Event) protocol.

A digital substation is a substation equipped with a set of digital devices that ensure the functioning of relay protection and automation systems, electricity metering, automated process control systems, and registration of emergency events using the IEC 61850 protocol. Currently, three distinct types of substation construction architecture have been defined:

- Type I architecture: Utilizes discrete and analog signals through control cables for data exchange between IEDs. Communication with supervisory systems (SCADA) is handled digitally via the MMS protocol, while currents and voltages are transmitted in analog form. Testing is straightforward due to compatibility with conventional analog test equipment [1].

Testing equipment for this architecture presents no significant challenges, since in this case, testing devices that are widely used in practice and that generate and receive analog and discrete signals, currents and voltages are used to perform tests.

- Type II architecture: Employs GOOSE messaging (IEC 61850-8-1) between IEDs while maintaining analog signal transmission for current and voltage measurements. SCADA communication continues via MMS. Traditional test tools are insufficient, requiring hybrid devices that can handle both analog and digital GOOSE messages [1].

Testing equipment at a substation of this architecture with traditional analog devices, similar to the architecture of type I, is no longer possible, since they are not capable of receiving information messages in digital form via GOOSE messages. For these substations, traditional test tools are insufficient, requiring hybrid devices that have analog current and voltage outputs and digital receivers of discrete signals in the form of GOOSE messages.

- Type III architecture, in which interaction between relay protection and automation devices is performed using object-oriented messages (GOOSE protocol), according to IEC 61850-8-1; information from current and voltage measuring devices is transmitted using the instantaneous value (SV) transmission protocol according to IEC 61850-9-2; information exchange with the upper level (SCADA) is performed using the digital MMS protocol [2]. Substations with this architecture are intended to be equipped with digital current and voltage measuring transformers.

When testing equipment of such substations, a full-fledged digital device is required that allows for the output and reception of both GOOSE messages and SV selective data streams. When testing analog signal converters, it is also necessary to use a hybrid device or a set of devices that allows for the output of analog currents and voltages, the reception of SV streams with the ability to compare them to assess the performance of analog signal converters.

1. IEC 61850 communication interface in intelligent electronic devices

IEC 61850 facilitates flexible function allocation across system components. With efficient means to communicate, functions can be located in any part of the system, meaning that the interconnect function can be implemented at both the intelligent device (IED) and substation levels. In addition, the standard provides flexibility in system implementation by supporting different levels of integration and distribution of functions between different devices. It can adapt for specific requirements, ensuring optimum use of resources and efficient operation [1, 4].

The communication protocols used in IEC 61850 are Ethernet and TCP/IP. A wide range of standard communication functions, defined in parts 8-1 and 9-2 of the standard, are enabled by the use of Ethernet and TCP/IP [1].

Separating the functionality defined in the data model from the method of communication implementation is an important feature of IEC 61850. This means that the protocol does not bind the automation system of the substation to a specific technology or to a specific hardware.

Consequently, using Ethernet and TCP/IP in IEC 61850 ensures efficient and compatible communication between different substation automation devices and systems, and allows easy future adaptation to new technologies and communication principles (Fig. 1) [2].

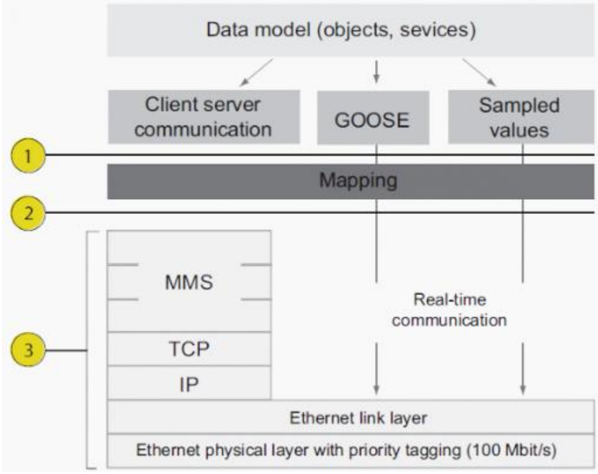

Fig. 1. IEC 61850 communication stacks and communication mapping: 1 – Abstract Communication Service Interface (ACSI); 2 – stack interface; 3 – ISO/OSI stack [2]

Protocols included three main data transmission in the IEC 61850 standard [3]:

1. MMS (Manufacturing Message Specification) protocol – used to transmit real-time data and dispatch control commands between network devices and/or software applications. It provides for the exchange of information about the state of devices, management and control of operations in the power system.
2. GOOSE (Generic Object Oriented Substation Event) protocol – used to transmit event data at a substation. This protocol replaces copper cable connections designed to transmit discrete signals between devices. GOOSE allows for the transmission of event information at high speed and reliability, reducing dependence on wired connections.
3. SV (Sampled Values) protocol – used to transmit digitized instantaneous values from measuring current and voltage transformers (CT and VT). This protocol allows replacing AC circuits that were previously used to connect relay protection and automation devices with CT and VT. Digitized values of instantaneous measurements are transmitted with high accuracy and update rate.

The functional blocks of intelligent electronic devices (IEDs) are designed taking into account the requirements and advantages of the IEC 61850 standard, which means that there is a clear correspondence between the functional blocks and the types of logical nodes. This correspondence is automatically handled by special tools [4].

According to the IED device concept, the 61850 data for each function implemented in the "configuration tool" editor is automatically created. This means that the user does not need to manually process any information or configure the IEC 61850-related function instances.

Figure 2 shows the protocols of the IEC 61850 standard.

Thus, IEC 61850 contains requirements for the information model that must be implemented in devices, for the configuration language and the system engineering process. A clear description of the information model of devices is one of the important features of the IEC 61850 standard, which distinguishes it from other standards for information exchange in the electric power industry [4].

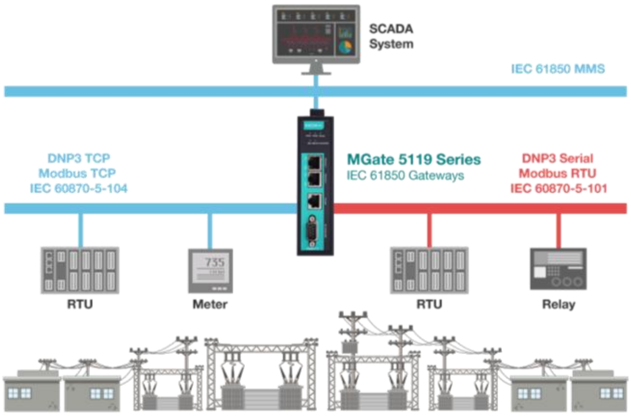

Fig. 2. IEC 61850 protocols [4]

Standardization of the storage structure and naming of data is extremely important, since this is what allows for compatibility in data exchange between devices from different manufacturers, as well as in parameterizing data transfer between devices using software from independent developers [5].

A method of identifying all the signals associated with functions in a substation automation system is provided by the IEC 61850 standard. The means for this is the use of logic nodes, which are functional blocks or elements of the system.

The logic nodes contain information about the control and monitoring signals that are associated with a particular function. Within a logic node, each signal and its properties (such as data type, description, units, etc.) are defined and identified. In this way, the logic node is a container in which all the necessary information about the signals associated with a specific function is stored.

Clear and unambiguous data exchange between different devices and systems in the substation is achieved by identifying signals and their properties within the logic node. This simplifies the design, configuration and operation of the substation automation system by making it easy to identify and understand which signals are associated with which functions [5].

By using logical nodes and unambiguous signal identification, IEC 61850 provides a consistent and structured approach to describing functions and associated signals in substation automation systems. This helps to make the system more understandable, reliable and flexible, and simplifies integration and interfacing with other systems such as SCADA or communication gateways.

The GOOSE configuration can be easily imported from Configured IED Description (CID) files of the various equipment under test. Messages support native complex data objects and attributes with digital and analog values (Fig. 3).

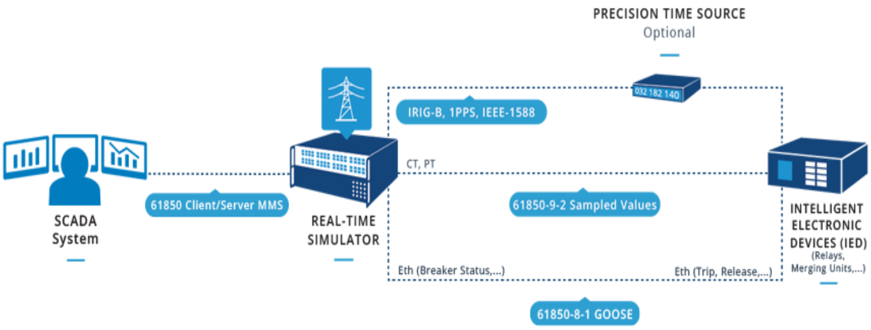

Fig. 3. IEC 61850: Horizontal coupling principle [4]

The principle of transmitting GOOSE messages

The retransmission technology not only guarantees that the recipient receives the message, but also ensures that the communication line and devices are in good working order – any faults will be detected after the maximum period of GOOSE message transmission (from the operational point of view, almost instantly). In the case of traditional signal transmission, the fault is detected either during a routine check of the devices or in the event of incorrect operation of the relay protection and automation system.

Another feature of GOOSE message transmission is the use of the priority tagging functions of the IEEE 802.3u Ethernet standard, which are not used in other protocols, including the TCP/IP level. That is, GOOSE messages are prioritized over standard Ethernet traffic (Fig. 4).

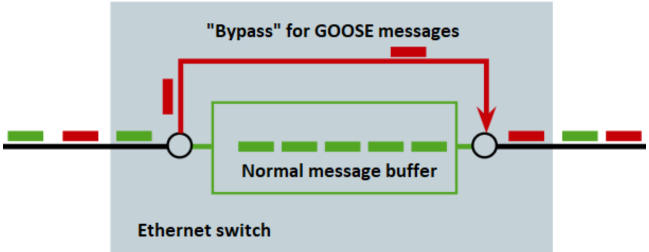

Fig. 4. Priority of GOOSE message transmission [2]

According to IEC 61850 [1], two options can be used to exchange GOOSE messages between power industry facilities.

The first option is tunneling, where a broadband Ethernet channel is organized between objects, through which GOOSE messages are transmitted using communication network equipment.

The second option is a gateway, which involves the use of devices for transmitting emergency signals and commands to exchange GOOSE messages between objects.

2. Conditions and methods of research

It is necessary to use software for these devices in order to configure GOOSE messages between IEDs from different manufacturers, in particular REF-615 and Sepam T62. For REF-615 the PCM600 software tool was used, for SEPAM T62 the CET800 software tool was used (CET850 is an IEC 61850 Edition 1 and 2 configurators for Sepam/Easergy P3 and P5/ION7x50/ION8650 IEDs) and the SFT2841 software tool was used to map GOOSE messages to specific LEDs on the configuration matrix [5].

As a first step, in the CET850 tool we have created a cid file called TP, once the file has been created and configured, the IP address of each device in the project must be different. To configure the signal exchange between REF-615 and SEPAM T62, this file is then saved and imported into the PCM600 programme.

The signal 'LD0.M120GGIO1. Ind1stVal' associated with the I101 SEPAM T62 physical digital input must be added before exporting the file. This is the input to which we will apply a signal by means of the SB1 push-button for input triggering [5].

On the PCM600, to add a third-party device to the project, select the IEC61850 generic IED. Then, into the added generic IED, import the TP.cid file that you created earlier [5].

After importing the 'CID' file in the previously created project 'TEST_REF615_SEPAM_T62', select the TP-Transformer IED, open the 'IEC61850 Setup' tool and see the GOOSE message sent by the TP-Transformer publisher (created from the imported TP.cid file).

We have configured the GOOSE message sent by the Sepam T62 IED. The REF-615 IED is subscribed to this message. It is also necessary to configure GOOSE messages sent in the opposite direction from REF-615 to Sepam T62 to fully verify the compatibility of the IEDs. Using the PCM600 programme, the GOOSE message sent by the REF-615 IED must now be configured [6]. To do this, open the 'IEC61850 configuration' tool in the previously created 'TEST_REF615_SEPAM_T62' project and create the 'PNHZRP180Q23.LD0.LLN0.DSGSE' dataset. Add the signal LD0.XGGIO110.Ind2.stVal to the data set. This signal is mapped to the corresponding physical binary input 2 of the X110 binary input card.

After that, we will save the configuration and load it into the REF-615 device. The GOOSE message configuration has been completed on the sender (publisher) side.

In order for the Sepam T62 device to receive a GOOSE message, it must be a subscriber to the GOOSE message. Sepam has 32 GOOSE inputs that can be used as binary inputs through the control of the Sepam logic functions.

In the PCM600 programme it is not possible to assign data attributes (signals) to the GOOSE input of Sepam. For this reason, the project must be exported as a SCDfile. Then open it in CET850. It is there that we will set up the subscription and assign the signals to the corresponding inputs. The required data attribute 'LD0.XGGIO110.Ind2.stVal' is assigned to input G406 in the GOOSE input allocation table (Fig. 5).

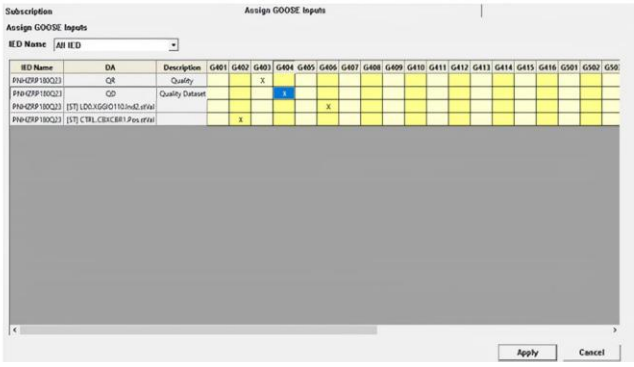

Fig. 5. Sepam GOOSE input assignment table [2]

It will also be necessary to use programmable LED 10 on the REF-615 IED to visualise the success of receiving GOOSE message from Sepam T62. For this purpose, in the PCM600 programme, assign the signal received from Sepam T62 to this LED with the data attribute 'LD0.M120GGIO1.Ind1.stVal'.

In the signal matrix and in the logic configuration tool, assign the signal 'LD0.M120GGIO1.Ind1.stVal' to the block 'GOOSE_BI120', create the variable 'TP_CLOSED' and connect it to the LED 10.

Upon finalizing the GOOSE message configuration, the changes must be saved and uploaded to the devices. All configuration operations are complete and testing can begin.

3. Experimental methodology for transmitting GOOSE signals

To test the GOOSE protocol compatibility, connect two IEDs to each other, via Ethernet interface, using the ACE850 TP communication module (Fig. 6).

Let's use the system (Fig. 7) assembled for the test, where we use the Retom-11 tester, the SB1 and SB2 pushbuttons, the REF-615 IED and the Sepam T62 (Fig. 8), with Retom-11 powering the circuit of the system. The external command of the SB1 and SB2 push-buttons simulates the trip command, for example, and signals are transmitted between two REF-615 and Sepam T62 units. Sepam T62relay receives binary signal from SB1 push-button and transmits it to REF615. Conversely, the REF-615 receives a binary signal from the SB2 button on its binary input and sends it as a GOOSE message to the Sepam T62. Using this system, we will also study the cyclic transmission mechanism and check the GOOSE communication monitoring function.

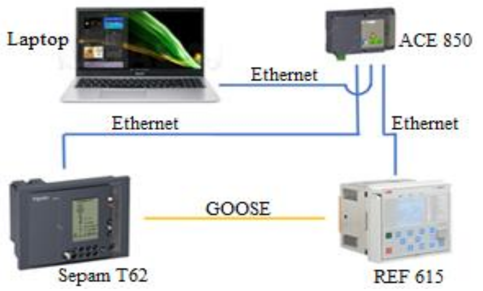

Fig. 6. Conditional connection between devices [3]

Fig. 7. Test setup [3]

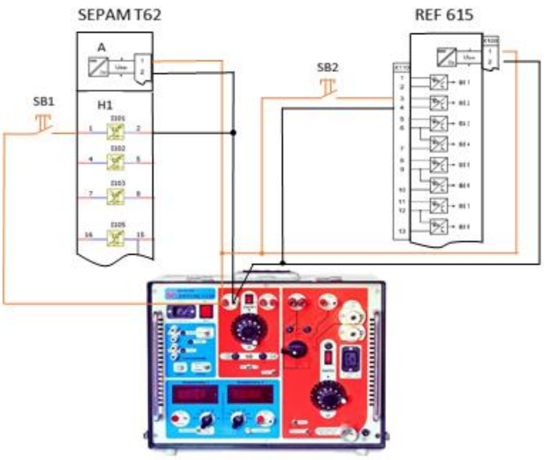

Fig. 8. Connection diagram of the test setup [5]

Apply a discrete signal (stVal attribute value – 'true') to the I101 Sepam input using SB1 button. At the same moment the 10th LED on REF-615 lights up, which confirms the success of receiving GOOSE-message (Fig. 9).

The following examines the transmission of the GOOSE signal from the REF-615 to the Sepam T62. Using the SB2 button, a discrete signal is transmitted (stVal attribute value is 'true') to binary input 2 of the X110 board. To check the success of the signal delivery, connect to the Sepam T62 using the SFT-2841 software, open the "Input/Output Lamp Status" monitoring utility and you will see that the GOOSE input G406 turns yellow, confirming the success of the GOOSE signal reception (Fig. 10).

The use of at least two software tools is necessary for the configuration of GOOSE message exchange between devices from different manufacturers, which in turn complicates the process of GOOSE message configuration. In terms of discrete signal exchange via GOOSE messages, the test showed full compatibility between REF-615 and SEPAM T62.

To ensure reliable GOOSE communications, a userconfigurable cyclic transmission mechanism is provided. This mechanism also allows the Information Network to continue diagnosing and responding to each other. A device configured to receive a message will await the arrival of the message at a given periodicity [7].

If one of the attributes of the transmitted record changes, a new packet containing the updated data is generated and immediately sent. This is followed by several retransmissions of this packet at a minimum time interval. However, if the data does not change, the interval between subsequent messages is increased again to the maximum value.

We now have an experimental test of this mechanism. We are going to use Wireshark to analyse the network traffic using the GOOSE protocol. Previously, the functional compatibility of the REF 615 and SEPAM T62 terminals under the conditions of the GOOSE protocol was tested experimentally.

The following section considers the transmission of GOOSE messages using the REF 615. In the PCM600 programme, to set the periodic time for sending GOOSE messages, the maximum time (TAL) is set to 10 seconds and the minimum time is set to 2 ms. This means that if the data attribute does not change, then GOOSE messages will be sent periodically at approximately 10 seconds. In figure 11, line 170 is highlighted: binary input REF 615, to which this GOOSE message is 'associated', has not been triggered (stVal value is 'False' or 'logical 0'), GOOSE message time is 50.280503.

It can be observed that (Fig. 12), starting from line 36, ending with line 170, REF 615 (source ABBMediu_57:a7:eb) periodically, with an interval of about 10 seconds sends GOOSE – message. This is in a state where attribute values remain unchanged the attribute values of the transmitted data.

Now consider figure 12, line 197: the discrete input REF615 'associated' with GOOSE – message has been triggered (value stVal – 'True'), GOOSE change time – 59.947671.

As illustrated in figure 12, after changing the attribute (line 197), sending the message is repeated with a minimum time delay of less than 3 ms, which ensures fast transmission of the message with actual data (lines 197–200). After that, the message retransmission time increases – 100 ms, 3 sec (lines 200, 205, respectively).

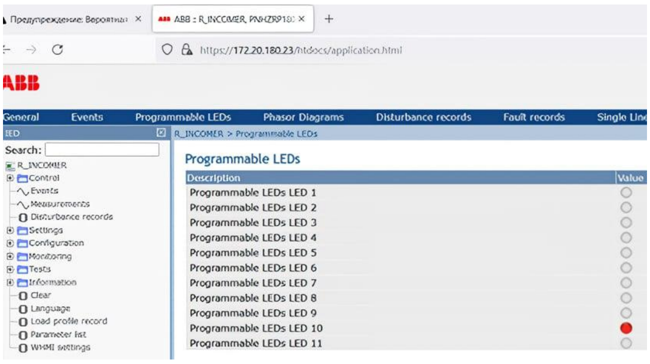

Fig. 9. Connection to REF-615 via web interface [5]

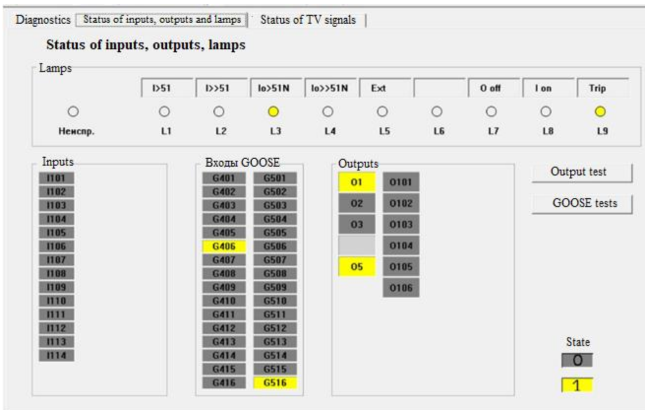

Fig. 10. Programming interface SFT2841, diagnostic tool 'status of inputs, outputs, lamps' [5]

Next, if we change the value of the attribute using the binary input, the repeated transmission starts after 3 ms (lines 216–219), 100 ms, 9 s, 10 s (Fig. 13). The transmission period increases to a value equal to the time of the maximum period.

As can be seen in figure 14, after the transmission of six packets of GOOSE messages, the retransmission time has increased to the maximum.

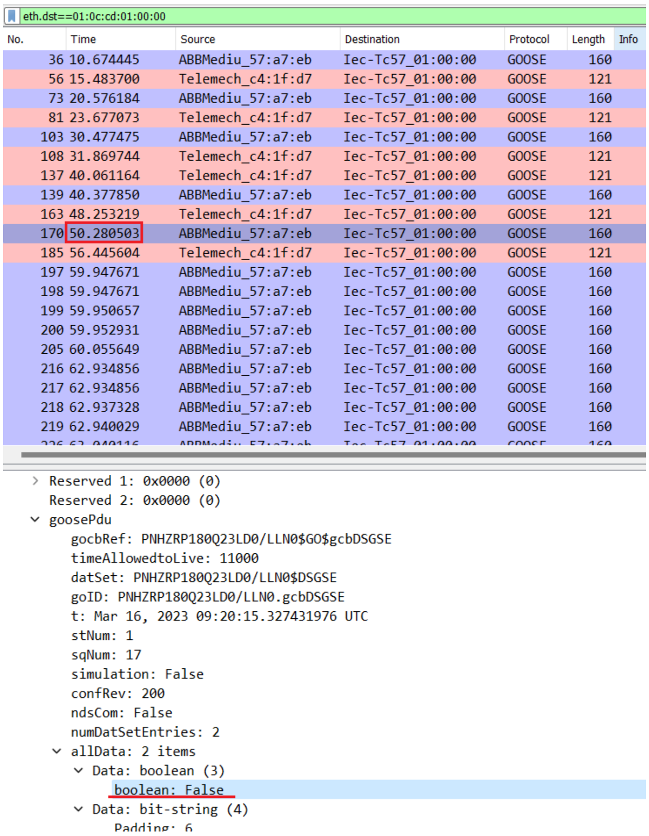

Fig. 11. GOOSE transmission without triggering the binary input REF615 [5]

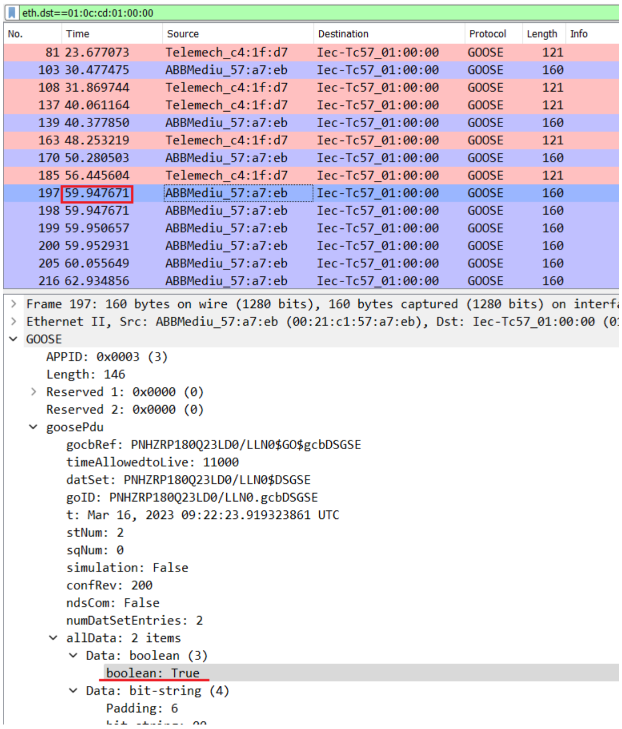

Fig. 12. GOOSE message transmission after triggering the binary input REF615 [5]

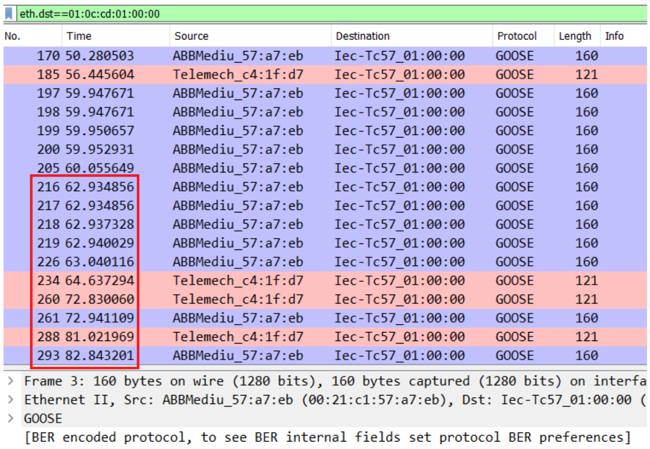

Fig. 13. Spontaneous transmission of GOOSE messages after changing the signal value of binary input REF 615 to '0' [5]

SEPAM T62 IED does not show such an increase. In figure 14, after changing the value of the attribute, SEPAM T62 (source Telemech_c4:1f:d7) generates GOOSE messages with updated data at intervals of 4–5 ms (lines 176, 178), 7 ms, 16 ms, 32 ms, 64 ms, 128 ms, 256 ms, 512 ms, 1 s, etc., until the time between messages increases to the maximum time of the transmission period. Up to this point SEPAM will send 13 messages.

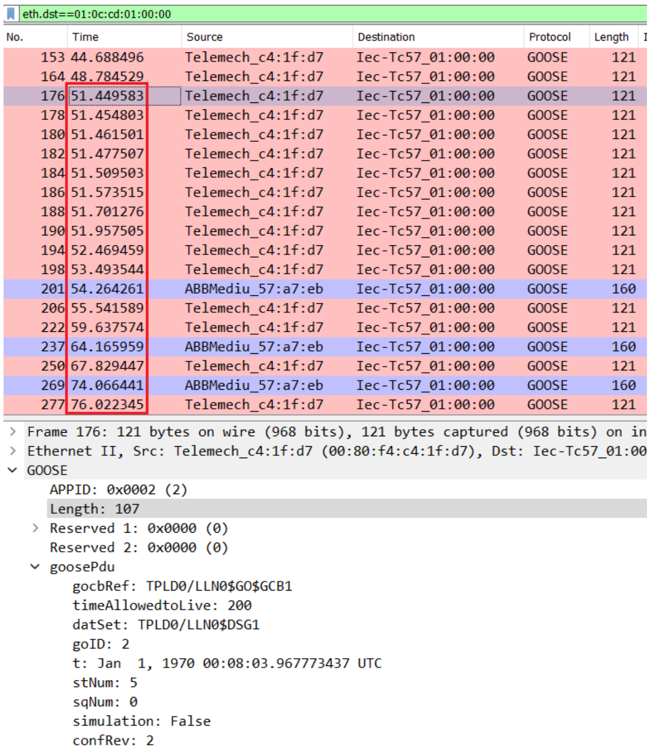

Fig. 14. Spontaneous transmission of a GOOSE message following a change in the value of the binary input of the SEPAM T62 terminal [5]

The IED continuously transmits messages with the maximum time set (which is set to 10 seconds), thus providing a continuous monitoring of the operability of the communication line and of the device.

After changing the GOOSE attribute value, the REF-615 IED registered a cyclic transmission rate of less than 3 ms, complying with the strictest requirements of the standard. A rate of 4–5 ms is achieved by the Sepam T62 IED. Additionally, after six packets of GOOSE messages had been sent, the REF-615 retransmission time increased to the maximum (TAL). The Sepam T62 has 13 messages, which leads to a more intensive load on the information network.

4. Results

It is necessary to configure the appropriate GOOSE quality control functions and perform the test to verify the GOOSE transmission link between REF-615 and Sepam T62.

Firstly, to monitor the reception of GOOSE from the SEPAM T62 IED, the configuration in the PCM600 for the REF-615 IED must be configured. In the application logic, we are going to insert the GOOSE monitoring counter function block 'GSELPRT1'. Let's create a variable 'GOOSE_ALARM' to be connected to the 'ALARM' output of the 'GSELPRT1' block, then connect it to the 'LED5' LED for visual control of the GOOSE alarm (Fig. 15).

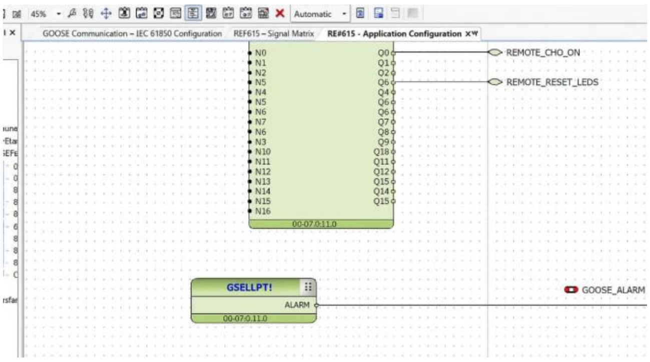

Fig. 15. Connection of the block 'GSELPRT1' to the LED 'LED5' [6]

After saving all the changes and upload to the device REF-615. Next, configure the GOOSE reception control for SEPAM T62 IED. In CET850 in the GOOSE input assignment table assign the quality attributes QR and QD and define them to G403 and G404 respectively (Fig. 16). Save and upload to Sepam T62.

Fig 16. Assignments of the GOOSE inputs of Sepam [6]

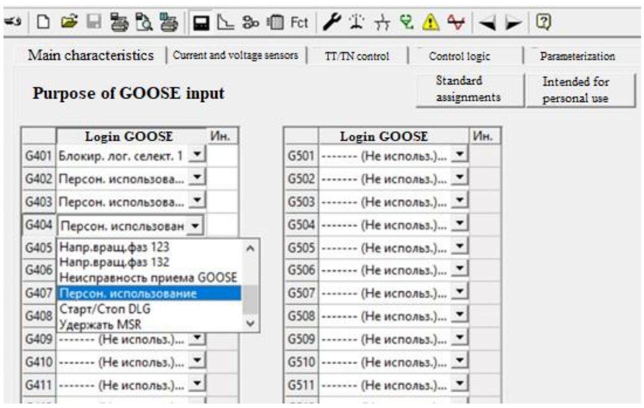

Fig. 17. Activation of inputs G403 and G404 [6]

In order to monitor GOOSE reception, it is necessary to activate the corresponding GOOSE inputs in the SFT2841 by setting their state from 'not used' to 'personal use' (Fig. 17).

To test the control function, let's simulate an interruption of communication by disconnecting the Ethernet cable connected between the devices.

To observe the result of the experiment on the side of REF-615, in PCM600 it is necessary to switch on the mode 'work online', as you can see, in figure 18 the line 'GOOSE_ALARM' lit up red, which indicates that the control function is working, the output 'ALARM' of the block 'GSELPRT1' was triggered and the LED 'LED5' lit up.

Observation of the experiment on the side of the Sepam T62 IED. Using the program SFT2841 it is necessary to connect to the device, open the monitoring tool 'States of inputs, outputs, lamps', we see that GOOSE inputs G403 and G404 lit up yellow, which confirms the work of GOOSE communications monitoring function (Fig. 19).

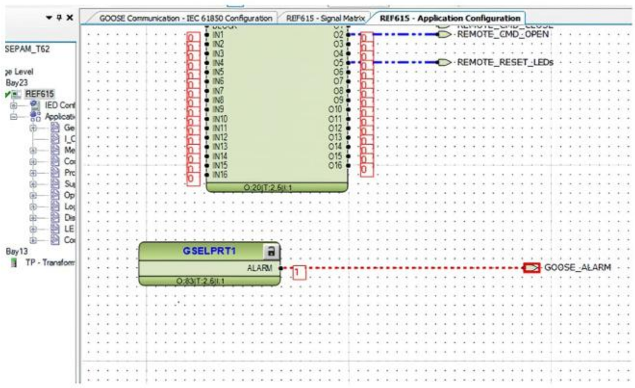

Fig. 18. Operation of PCM600 in the 'Online Monitoring' mode [6]

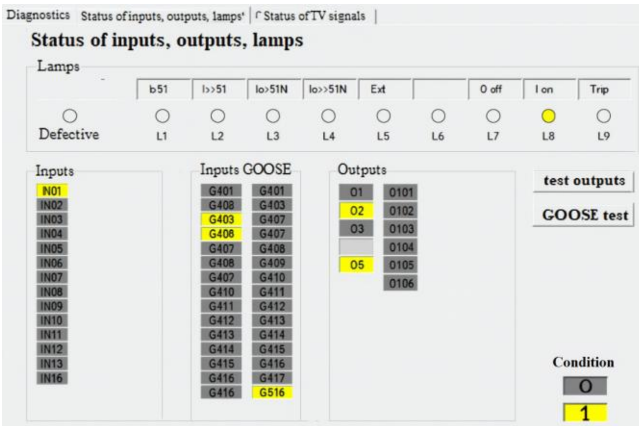

Fig. 19. SFT2841 programme interface, diagnostic tool 'status of inputs, outputs, lamps' [6]

5. Conclusion

The purpose of the paper is to justify the digitisation of substations, that is, the conversion of substations to process and station bus communication protocols according to IEC 61850 and IEEE 1588 v2 (PTP) precision time protocols.

GOOSE is a subset of the IEC 61850 standard used in substation control systems to transfer event data between devices in realtime. GOOSE is ideal for applications requiring fast data transfer, such as protection and automation in the power industry, as it provides a high reliability, low latency event transfer mechanism [8].

It is not possible to avoid using a particular vendor's programme after exploring the capabilities of the above software tools.

According to its purpose, the GOOSE message is designed to replace the transmission of discrete signals over the network of the operating current.

The experiment carried out showed that both the REF-615 and the Sepam T62 IEDs were able to effectively control the GOOSE communication function from both sides.

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