A technique for analysing GOOSE packets when testing relays in an IEC 61850-8-1 environment

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Contents

1 Abstract

While the implementation of the IEC 61850 standard has significantly enhanced the performance of communications in electrical substations, it has also increased the complexity of the system. Subsequently, these added elaborations have introduced new challenges in relation to the skills and tools required for the design, test and maintenance of 61850-compatible substations. This paper describes a practical experience of testing a protection relay using a non-conventional test equipment; in addition, it proposes a third party software technique to reveal the contents of the packets transferred on the substation network. Using this approach, the standard objects can be linked and interpreted to what the end-users normally see in the IED and test equipment proprietary software programs.

2 Introduction

The IEC 61850 standard was published by the International Electrotechnical Commission (IEC) in 2003 to provide all required specifications for interoperability between intelligent electronic devices (IEDs) involved in monitoring, control, protection and automation in electrical substations. IEC 61850 has become the preferred communication method in the electrical power industry and it is very likely that in the near future, the entire industry will be involved in at least one aspect of 61850 technology. Ten years after its inception the standard is reaching maturity, however, there are still a number of challenges that need to be addressed. The use of new digital technology based on IEC 61850 means the use of hard-wires for interoperation between IEDs is not required. This in itself raises a big challenge as the test and commissioning engineers, who used to deal with the hard-wires, now have to learn to work with some virtual concepts in the software programs. As a result, the end-users need to have a very good understanding of the key elements of the IEC 61850 standard and what is happening in the background of the software tools.

In this paper, we first discuss the basics of IEC 61850 required for testing IEDs at the bay level; secondly, we study the contents of GOOSE messages transferred on the Station Bus with the help of the third party software. This will show the relationship between what is seen in proprietary software programs and the terms used in the standard. In addition, this paper proposes an approach to test the basic functionalities of an IED's communication process using a cross-platform freeware, without using any proprietary 61850 test equipment.

3 The Must-Know Basics of the IEC 61850 standard required for testing relays at bay level

3.1 Architecture of IEC 61850 substations

Every Substation Automation System (SAS) has a hierarchical structure, and IEC 61850-7-1[1] defines three typical levels for communication and application functions. *Station Level* includes Human Machine Interface (HMI), station computers and Gateway (GW). The functions related to this level communicate over a dedicated network called Station Bus. Some station level functions replace conventional hard-wires carrying binary information between IEDs. *Bay Level* includes Protection, control and measurement IEDs. The functions related to this level exchange information between IEDs within the Bay Level, to Process level (via Process Bus) and Station level (via Station Bus). *Process Level* includes primary equipment in the substation such as Current and Voltage transformers (CTs and VTs) and CBs. The functions related to this level replace analog signals from CTs and VTs with digital values. These functions communicate over a dedicated network called Process Bus[2]. Typical hierarchical levels in an IEC 61850 Substation are shown in Figure 1.

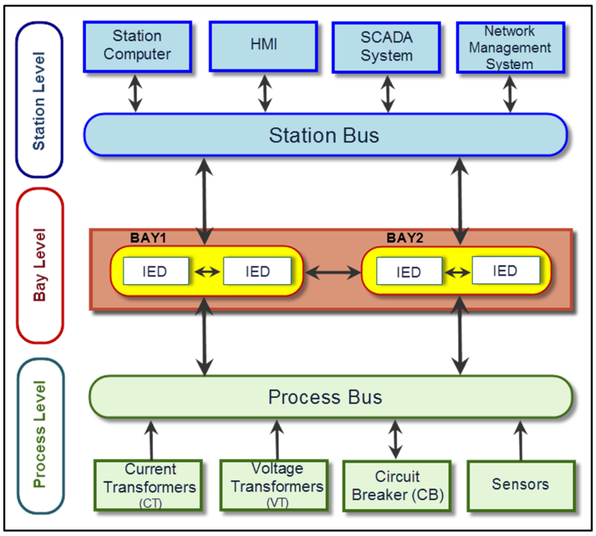

Figure 1 Typical IEC61850 Substation Architecture

3.2 IEC 61850 Modelling Approach

Parts 7-2[3], 7-3[4] and 7-4[5] of the IEC 61850 standard define logical architecture of an SAS and all possible functions that operate within the substation environment. Object modeling describes virtualization concepts and standardizes the names of the logical functions and their data in the standard. For example, the name of the 'Distance Protection' is PDIS and 'Time delay Under Voltage Protection' is PTUV. All functions running in 61850-compatible substations are called Logical Nodes (LN). IEC 61850 defines approximately 90 LNs in part 7-4 edition one[5] and more than 150 LNs in edition two[6] to cover all necessary functions within the substation. A data model is a set of data describing settings, status information and measured values of a function that might be routed to some Bay Level IEDs or Station level applications. This data is classified in smaller entities called Data Objects (DO), each of which contain a number of Data Attributes (DA). Figure 2 shows the hierarchical data modeling concept in IEC 61850.

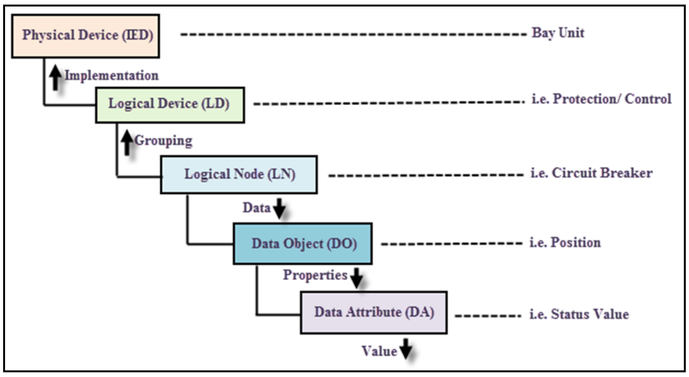

Figure 2 Hierarchical Data Model in IEC 61850

An important approach of the data modelling in IEC 61850 is the use of standardized names. The IEC 61850 model of a device is a virtualized model that begins with an abstract view of the device and its objects as defined in part 7 of the standard. This abstract model is then mapped to a specific protocol stack which is described in IEC 61850-8-1[9] based on MMS (Manufacturing Message Specification protocols of ISO9506), TCP/IP, and Ethernet. In the process of mapping the IEC 61850 objects to MMS, part 8-1 specifies a method of transforming the model information into a named MMS variable object that results in a unique reference for each element of data in the model7. The naming concept has been shown in three examples of hierarchical object naming in Figure 3.

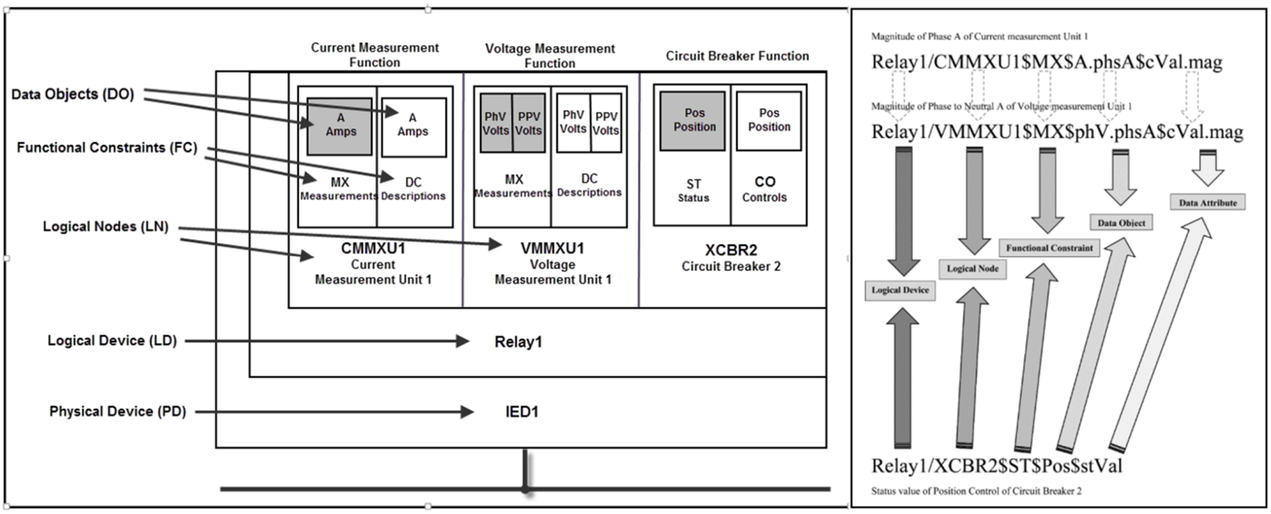

Figure 3 Structure of object names in IEC 61850-8-1

3.3 Communication between IEDs

Generic Substation Event (GSE) was implemented to replace the hardwiring between IEDs according to part 8 of the standard. There are two types of GSE; Generic Substation State Event (GSSE) and Generic Object Oriented Substation Event (GOOSE). GSSE was built into the standard to provide the backward compatibility with the UCA[11] (utility communications architecture) and only contains the state information in the dataset. GOOSE messages in turn, support not only the state information but various types of data in the standard8. GOOSE was defined by the IEC 61850 to implement 'horizontal' communication in the SAS and provide interoperation between IEDs (i.e. Interlocking and virtual Inputs/Outputs). GOOSE can be sent out by every IED to transfer information to the other IEDs. The information is packaged into a GOOSE dataset that typically contains binary status indications, but may also contain other data such as measured values. According to part 8-1 of the standard[9], the GOOSE messages are mapped directly into the Ethernet layer without linking to any other Open System Interconnect (OSI) middle layers. This is the reason that 'trip' signals are sent via GOOSE as it is a fast type message within the network. GOOSE transmissions are based on broadcasting data, using the 'Publishers-Subscribers' model. Publishers send GOOSE messages on multicast Mac addresses and subscribers listen to the network to pick what they need.

3.4 Data Sets and GOOSE Control Blocks

IEC 61850 defines Data Sets (DS) in part 7-23. DS is used for signal transmission for monitoring in vertical communication and also for GOOSE messages in horizontal direction. They also define values of DOs or DAs to be transmitted in case of a value change from one of their members. In order to manage GOOSE messages, part 7-2 of IEC 618503 also defines GOOSE Control Blocks (GoCB or GCB) that reside in logical node zero (LN0) of any logical device (LD). GCB distributes the input and output data values between IEDs in horizontal direction on the Bay level. Whenever two or more IEDs are to exchange functions' data, the GOOSE message will be used. In order to send a GOOSE message, a GCB needs to be created from the DSs which have the information of DOs and DAs.

4 Case Study - Analysing GOOSE packets during the testing of a distance Relay

Protection relay testing has been conducted at the Insulect testing lab. We have studied the GOOSE messages transferred on the Station Bus while testing the distance protection and analysed the contents of the DS to check the status of the virtual trips encapsulated in the GCBs. In this case study, a native IEC 61850 relay (Protecta EuroProt+) was tested using a non-conventional secondary injection test set with an IEC61850-8-1 interface (ISA DRTS 66). The relay connections for the test bed are shown in Figure4.

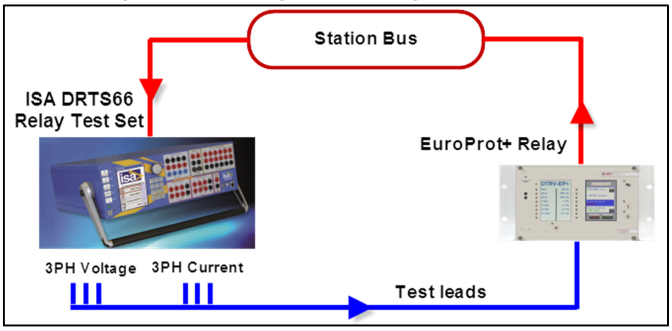

Figure 4 Relay connections to Station Bus and the test equipment

Analogue currents and voltages are injected via the test leads to the physical inputs of the relay. Test equipment stops injection by the commands received from the virtual trips through its IEC61850 interface. Before performing the test, each software tool needs to be configured in a way to meet the test requirements. As shown in Figure 5, the following software tools are used for the configuration and packet capturing:

1. EuroCap software as IED Configuration tool
2. TDMS software as testing equipment program
3. Wireshark software as Network analyser tool

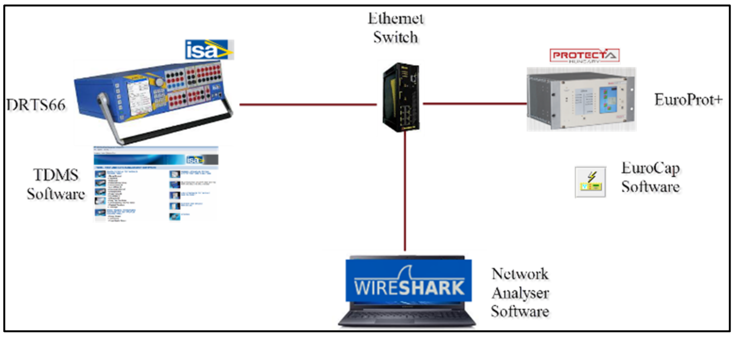

Figure 5 Software tools used for the test bed

4.1 Wireshark network Analyser

'Wireshark' is a free and open-source network analyser that is used for troubleshooting, analysis, software development and education. It is a cross-platform software that runs on Linux/Unix and Microsoft operating systems10. We have used Wireshark as a third party software to capture the GOOSE packets travelling on the Station Bus and show how the raw data in the GOOSE messages can be translated into the terms seen in the proprietary relay and testing programs and IEC 61850 terminology.

4.2 Introducing Logical Node GGIO

IEC 61850 provides consistent designations for input and output of information. The standardized LN 'GGIO' (Generic Process Input Output) is used to designate input and output signals according to IEC 61850-7-4[5]. Figure 6 shows eight inputs GOOSE Publisher GGIO LN of the EuroProt+ relay we used to send the trip signal to the test equipment instead of the conventional physical trip contact of the relay.

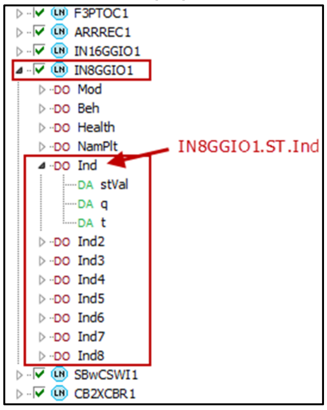

Figure 6 Data Objects of GGIO Logical Node in EuroProt+ Relay

There is a suffix for each Data Object representing the number of the virtual inputs of the GGIO GOOSE Publisher Function Block (FB) in relay 'logic design' program. As shown in Figure7, the FB linked to the GGIO logical node is found in the relay 'Logic Editor' as Go8.

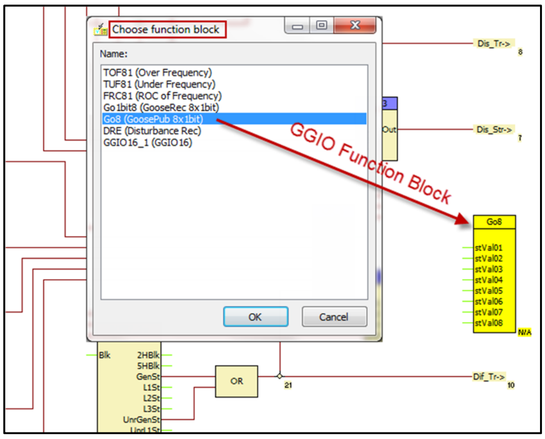

Figure 7 Eight input GGIO GOOSE Publisher FB in 'Logic Editor' program

Data object 'IN8GGIO1.ST.Ind' shown in Figure 6is mapped in to the corresponding FB (Go8) in Figure 7. The value TRUE or FALSE for stVal DA will be returned in the GOOSE message for the IED that issued the 'GetDataValues' request.

4.3 Virtual Pushbutton

'Virtual pushbutton' is an approach introduced in this paper to test the IED virtual output functionality in the IEC 61850 environment. It confirms that the IED is communicating correctly on the Station Bus without engaging the test equipment and by using a PC running Wireshark software. As there might be no hardwires existing for trip contacts at the Bay level, using virtual pushbuttons can simplify troubleshooting when the sender or receiver IEDs don't work as expected. This method is developed with EuroProt+ relay, however, it can be expanded to any other relay that supports Matrix functionality in its web interface. This virtual pushbutton together with the Wireshark software will be a test tool for checking the communication functionality of the IED.

EuroProt+ relay has a Matrix tool in its web interface which allows to link any FB outputs to the internal virtual inputs. These internal virtual inputs, in turn, can be assigned to the physical outputs such as front panel LEDs, binary outputs or the virtual outputs in the relay's logic.

4.3.1 Using GGIO FB as a switch

The idea is to configure the IED in a way that the end-user can access the GGIO input variables via the web interface. So any protection function output (i.e. distance 3ph trip) can be sent to the Station Bus as a GOOSE message by using a check box in the webpage. This will confirm the correct communication of the IED on the Station Bus in a very easy and fast approach.

In the first step, a new matrix column is created to represent one input of the GGIO GOOSE publisher FB. Figure 8 illustrates the process of creating this matrix column in the numbering order. After updating the relay with the new configuration, the name of the column 'GoosePub' appears in the relay web page.

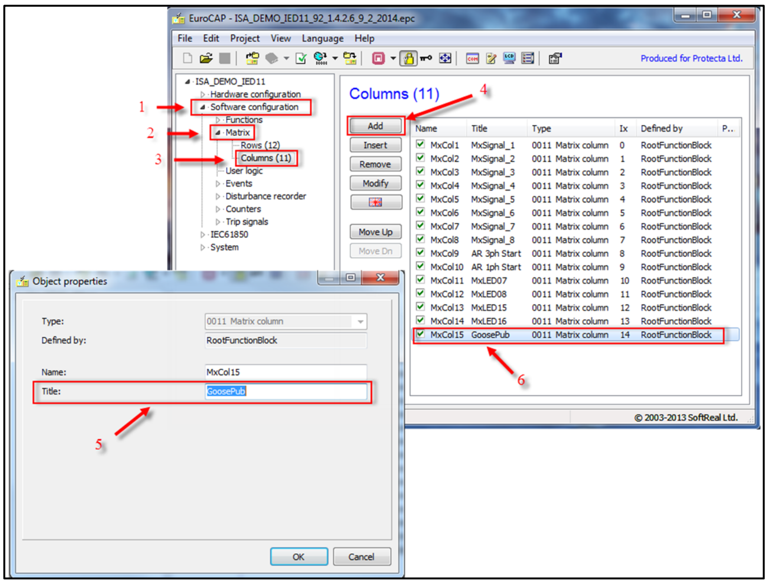

Figure 8 Creating a Matrix column to represent the first input of GGIO FB

The output status of all protection functions are available in the web interface as Matrix rows. We need to provide an 'Always true' constant in the matrix so the virtual push button can be turned ON and OFF at any time in the webpage. In order to create this matrix row, a 'Volatile User Status' value is defined in the 'Logic Editor' program which will be then used to create a matrix row. Figure 9 shows the process of creating an 'Always True' status in the 'Logic Editor' program.

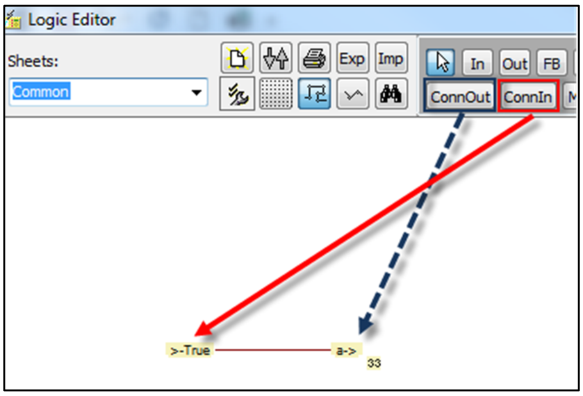

Figure 9 Creating 'Always True' status in 'Logic Editor' program

The connection 'a' is now listed in the software configurator as an output object. Figure 10 shows the process of using this output connection to make the matrix row named 'always true'.

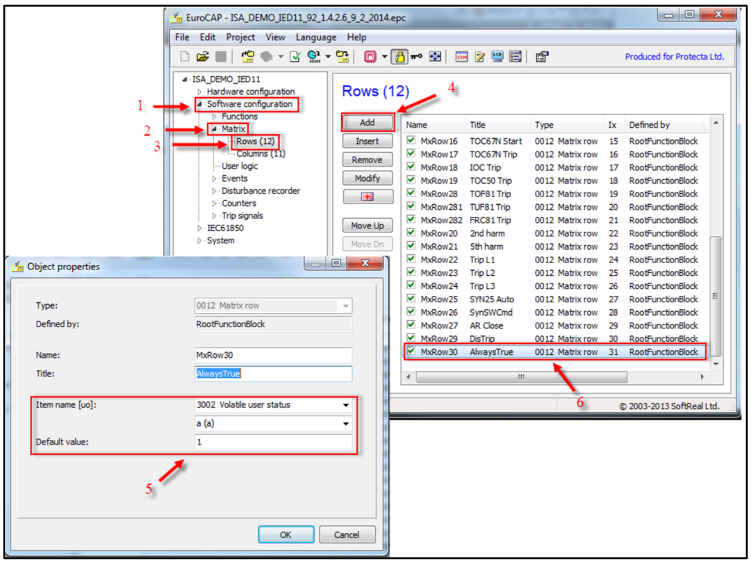

Figure 10 Creating Matrix row to represent 'Always true' in web interface

The Boolean state of the first input of GGIO FB should be encapsulated and published as a GOOSE message so anew DS is created using DOs of GGIO logical node. DA 'stVal' of DO 'Ind1' from GGIO LN is used to form a new DS. Figure 11 illustrates the process of creating a DS named 'Testing_GGIO_DataSet'.

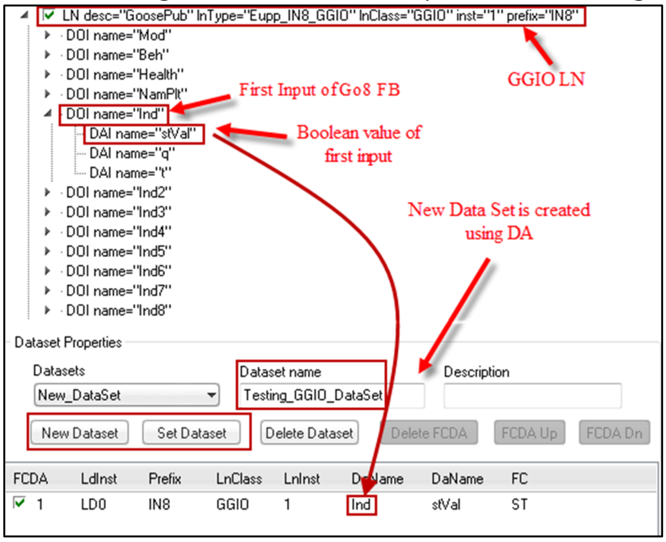

Figure 11 Boolean state of the first input of GGIO FB is used to form a DS

The new DS is then used to create a GCB to transfer the Boolean values of the virtual push button. Figure12 shows the process of using 'Testing_GGIO_Dataset' to make a GCB named 'Testing_GGIO_GSECB'.

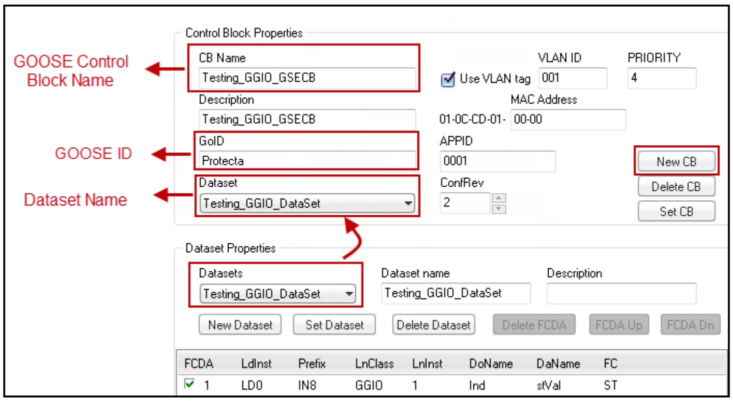

Figure 12 Creating a GCB for virtual push button

As shown in Figure 13, the matrix column variable is linked to the first input of the GGIO FB in the logic design tool.

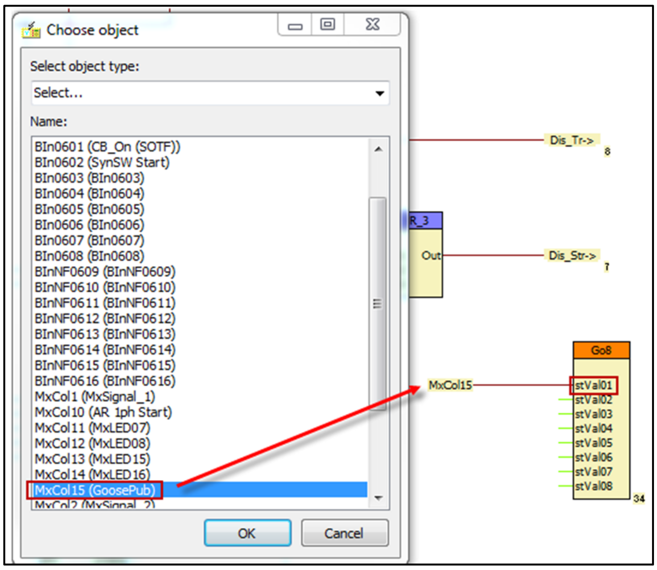

Figure 13 Linking matrix column variable to GGIO FB

4.3.2 Using virtual push button to check correct communication of the IED

The IED is broadcasting GOOSE messages on the Station Bus repeatedly and any GOOSE subscriber IED can capture the packets. Figure 14 shows the packet capture result in Wireshark when GOOSE filter is activated. The contents of each GOOSE message can be studied in Wireshark to check the entities of the GCB and DS such as the Boolean status of the virtual push button. The Boolean state is false before using the push button.

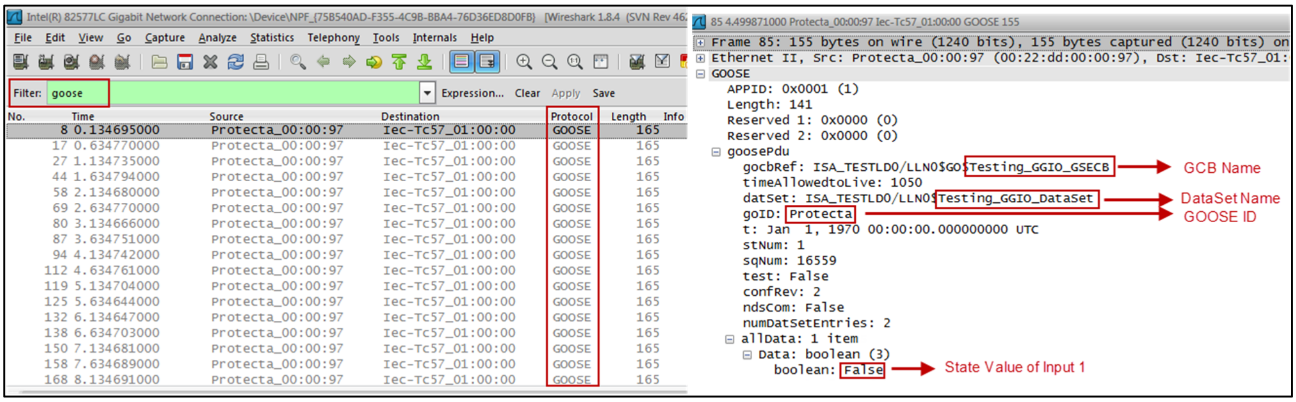

Figure 14 GOOSE packets captured in Wireshark

As shown in Figure 15, the "GoosPub" variable in the matrix can be marshalled to the 'always true' constant using the virtual pushbutton in the web interface.

Figure 15 Using virtual push button in Matrix tool

Activating the 'GoosePub' variable in matrix tool will change the Boolean state of the first input of GGIO FB from 'False' to 'True'. Figure16 illustrates how the Boolean state is changed when the push button is ON.

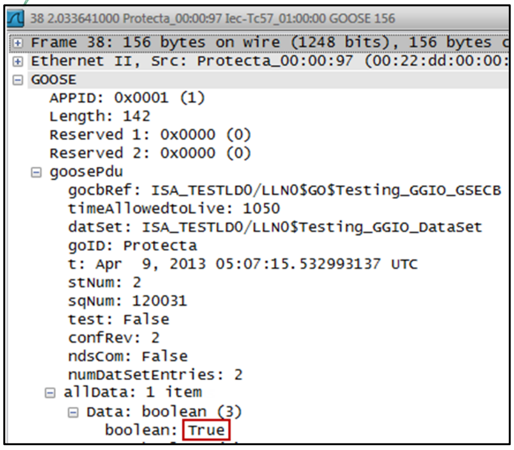

Figure 16 Boolean state is changed in the GOOSE message

4.4 Testing Distance protection function using virtual trips

4.4.1 IED configuration

Distance function of the EuroProt+ relay is tested using a non-conventional test set (ISA DRTS 66) while the trip signals are sent via GOOSE message. The experience with virtual push button can be used to test any protection functions when using the FB outputs instead of the 'Always true' constant. In order to route the trip signals to the Station Bus, three phase trip output from Distance FB is assigned to an input of GGIO FB. As shown in Figure 17, instead of using trip logic FB (which sends the signals to physical output contacts), Distance trip output initiates the GOOSE publisher GGIO FB.

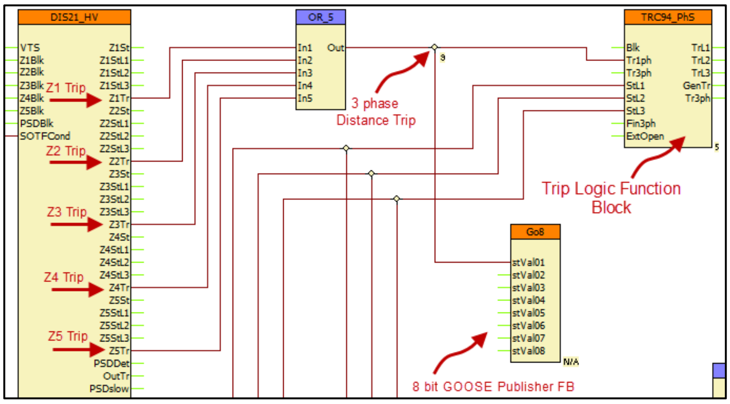

Figure 17 Trip output of Distance FB is linked to Go8 FB

The same as virtual push button, a DS and GCB are created to encapsulate the state value of the input of GGIO LN. Figure 18 shows the process of creating a GCB from a DS named 'Virtual_Trip_Dataset'.

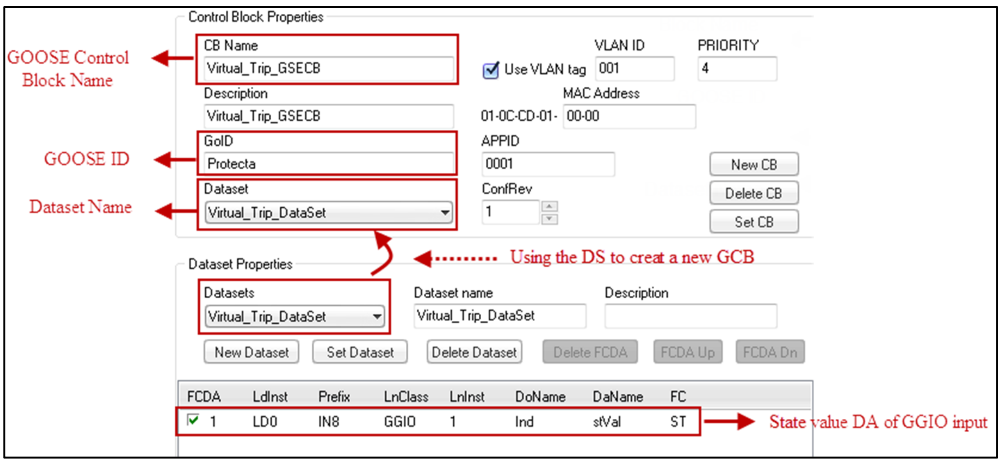

Figure 18 The DS 'Virtual trip' is used to form a GCB

4.4.2 Test set configuration

For testing a conventional protection relay, physical output contacts of the relay are connected to the test equipment's binary inputs (BI). In an IEC 61850-8-1 environment, trip commands from the relay go to the test set via GOOSE messages to stop analog injection. Therefore, the test equipment should be equipped with a kind of hardware and software interface to handle GOOSE messages. Figure 19 illustrates the physical BIs and IEC 61850-8-1 interface of the DRTS66 test set.

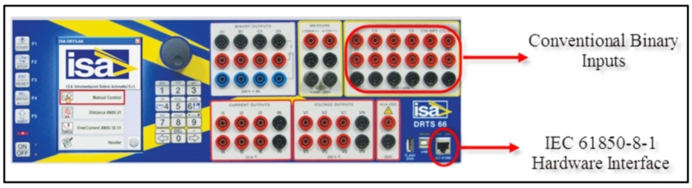

Figure 19 IEC 61850-8-1 interface and conventional BIs of a DRTS66 test set

Testing software explores the Station Bus and captures all broadcasted GOOSE messages. Then a Boolean variable from a DS is defined as virtual contact to stop analog injection. As shown in Figure 20, the Boolean variable of the DS 'Virtual_Trip_Dataset' (defined in previous section) is selected to act as a virtual contact.

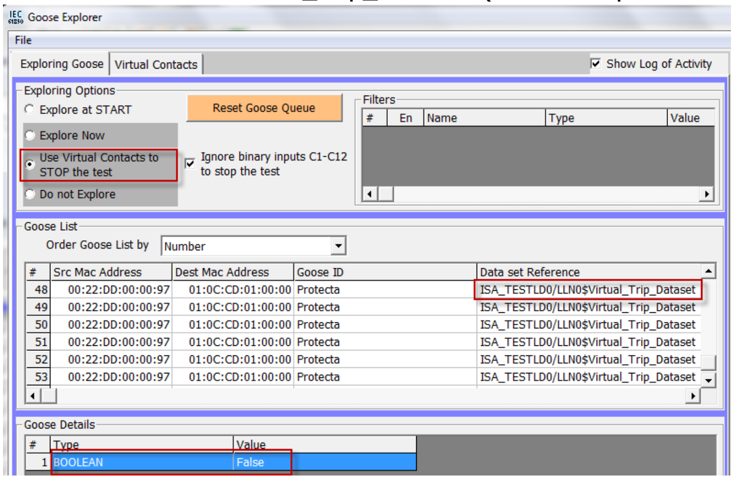

Figure 20 Using the Boolean parameter to act as virtual trip

4.4.3 Verify R/X characteristic of distance scheme

This test accurately verifies the distance zone curves in R/X characteristic. As shown in Figure 21, the testing program defines the test points around the nominal curves and the test results are 'passed' if they are within the selected maximum percentage error setting in the software. Figure 21 also shows the test results when all trip times are calculated according to virtual trip operation.

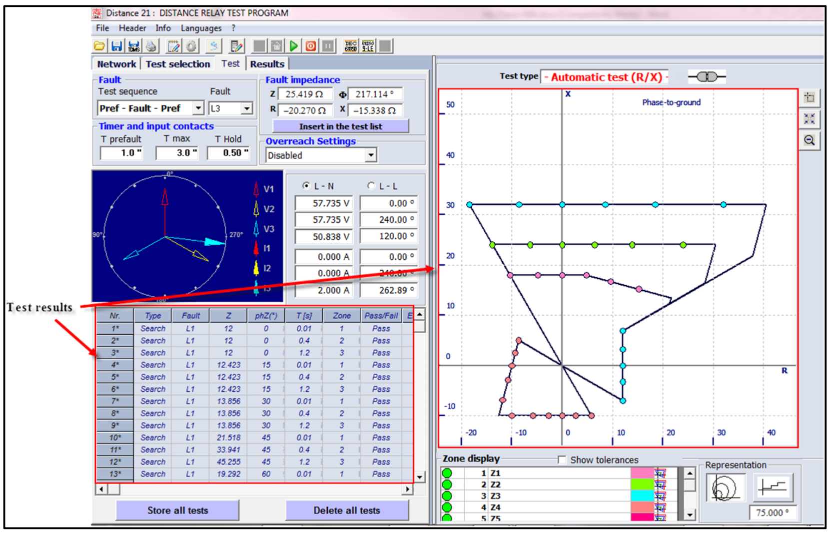

Figure 21 Test results of distance characteristic test using virtual trip

4.4.4 Wireshark analysis

All GOOSE messages were captured by Wireshark while the relay was sending virtual trips to the test equipment. Once the distance FB issues the trip, the first input of GGIO FB is activated and changes the state of the Boolean value in the DS. Figure 22 shows the Boolean state of the GGIO input in Wireshark when the relay issues the virtual trip for distance protection.

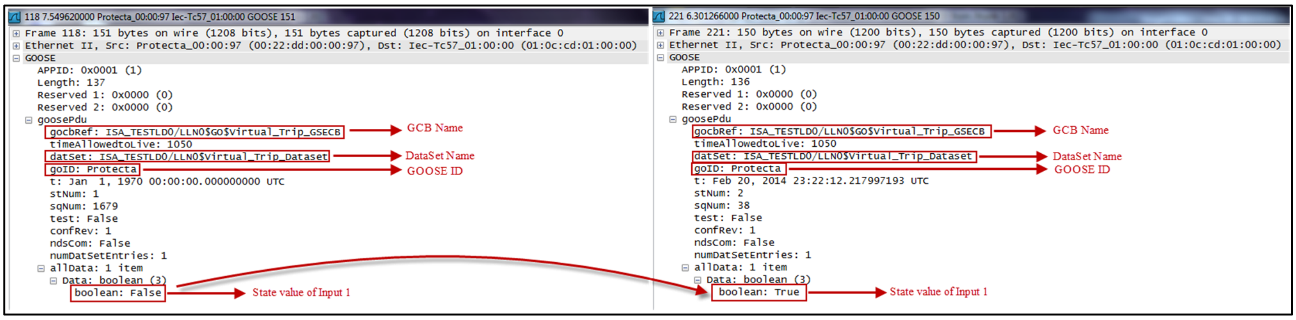

Figure 22 Change of Boolean Value in the DS when relay sends the virtual trip to the test set

5 Conclusion

Migration from the current model to digital substations involves complex issues and the IEC 61850 standard addresses most of them. Advanced computer and networking technologies are used to enhance reliability and performance while minimizing the cost of design, installation and commissioning. However, to enable this migration, new tools and additional knowledge and skills are required. In this paper we have demonstrated the possibility of using third party software to reveal the background of testing relay in IEC 61850. This also enables the end-users to understand the fundamental concepts of IEC 61850 related to the Bay level, and familiarise them to the terms used in the IED software programs.

References

1. International Standard, 2003, IEC61850, *IEC 61850-7-1 Communication networks and systems in substations, Principles and models*, in *IEC TC57 Standard*.
2. Power Quality Conference, 2007, *IEC 61850 and Power-quality Monitoring and Recording*, Apostolov, A.
3. International Standard, 2003, IEC61850, *IEC 61850-7-2 Communication networks and systems in substations, part 7-2: basic communication structure for substation and feeder equipment*, in *IEC TC57 Standard*.
4. International Standard, 2003, IEC61850, *IEC 61850-7-3 Communication networks and systems in substations: part 7-3 basic communication structure for substation and feeder equipment: common data classes*, in *IEC TC57 Standard*.
5. International Standard, 2007, IEC61850, *IEC 61850-7-4 Ed.1 Communication Networks and Systems in Substations- Part 7-4: Basic Communication Structure- Compatible Logical Node Classes and Data Classes*, in *IEC TC57 Standard*.
6. International Standard, 2010, IEC61850, *IEC 61850-7-4 Ed.2 Communication Networks and Systems in Substations- Part 7-4: Basic Communication Structure- Compatible Logical Node Classes and Data Classes*, in *IEC TC57 Standard*.
7. Proceedings of the VIII simposioiberoamericanosobreproteccion de sistemaselectricos de potencia, Monterey, Mexico, Citeseer, 2004, *IEC 61850 communication networks and systems in substations: an overview for users,* Baigent, D.,Adamiak, M., Mackiewicz, R..
8. 2008, *The impact of IEC 61850 on protection,* Brunner, C..
9. International Standard, 2011, IEC61850, *IEC 61850-8-1-Ed.2 Communication networks and systems in substations–Part 8-1-Ed.2: Specific Communication Service Mapping (SCSM)–Mappings to MMS (ISO 9506-1 and ISO 9506-2)*, in *IEC TC57 Standard*.
10. Wikipedia. *Wireshark*. Available from: http://en.wikipedia.org/wiki/Wireshark.
11. UCA Website. *UCA*. Available from: http://www.ucaiug.org/

List of Figures

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