A Practical Guide of Troubleshooting IEC 61850 GOOSE Communication

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***Abstract*—IEC 61850 GOOSE (Generic Object-Oriented Substation Event) communication has been implemented in many substation automation applications, such as automatic transfer scheme, bus protection and power management system. With many advantages introduced by GOOSE, it also brings challenges to protection and control engineers. IEC 61850 standard comprises advanced communication and computer science technology with which protection and control engineers are not familiar. This paper examines GOOSE configuration, message structure, parameters, and actual communication capture in detail, analyses different fault situations in real world, evaluates communication diagnostic features, and provides a systematic troubleshooting path for troubleshooting GOOSE communication issues. This approach has been adopted in system integration for the past two years. System communication commissioning time was improved by 75%.**

***Index Terms*-- IEC 61850, GOOSE, troubleshoot, substation communication, practical guide.**

I. Introduction

IEC 61850 [1] is an international standard of communication networks and systems for power utility automation, prepared and published by IEC (International Electrotechnical Commission) TC57 (Technical Committee 57), to provide a solution for interoperability of IEDs (Intelligent Electronic Device) from different protection and control device vendors.

Data models defined in IEC 61850 can be mapped to a number of communication protocols, including GOOSE (Generic Object Oriented Substation Event) [2] [3] which is widely used for peer-to-peer communication in protection and control applications. When IEDs are updated with configurations with GOOSE application, network is connected and system are powered up, most of the time one or more issues will show up. The work presented in this paper is to provide commissioning engineer a systematic guide to troubleshoot GOOSE communication issue.

This paper is structured as follows. Section II reviews of Protection and Control application by IEC 61850 GOOSE. In section III, IEC 61850 data model and GOOSE configuration are analyzed in detail. In section IV, a new systematic troubleshooting procedure is introduced in detail with implementation results of more than ten substations. Summary and future work is discussed in section V.

II. 61850 GOOSE Application

Protection and control applications have been well developed [7] [8] and tested. Automatic Bus Transfer Scheme (ABTS) by GOOSE provides a quick way to automatically restore a bus that is affected by a loss of its own main source [5] Bus protection scheme by GOOSE provides high reliability, security, relay interoperability, easy of expansion, and cost savings [4]. A new approach for sympathetic tripping logic by GOOSE has reduced overall fault clearing time and improved system performance [9]. IEC 61850 GOOSE has also been used to implement Load Tap Changer (LTC) control to eliminate majority of copper wiring [10].

In the SLD (Signal Line Diagram) for a Main-Tie-Main automatic transfer application by GOOSE shown in Fig. 1, IEDs of Main A, Main B and Tie are connected to the Ethernet network through the Ethernet switch. Each IED is sending breaker status, selector switch status (Not showing in SLD), protecting operations, synchronization information, and internal logic to other two IEDs by GOOSE messages. The diagram shown below shows at that moment, source Main B is lost, breaker opens, and IED on Main B is sending this information to IEDs on Main A and Tie breaker by GOOSE. IED on Tie breaker will analyses this information, with other information received from Main A, process logic to close Tie break to power bus B from bus A, or not. So it is critical that GOOSE communication works among IEDs on this network to guarantee the ATS (Automatic Transfer Scheme) logic, or other protection and control logics. Other GOOSE applications have the similar network scheme.

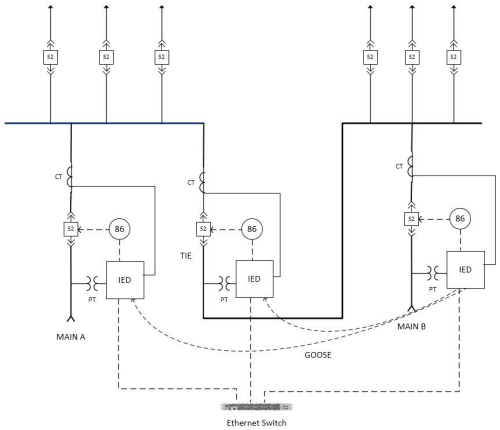

Figure 1 Main-Tie-Main Automatic Transfer by GOOSE

III. IEC 61850 GOOSE Configuration and Communication Message

IEC 61850 standard adopts modern technologies developed from computer science and communication industry, including OSI(Open Systems Interconnection) 7 layer model [11], Object Oriented Design [12], UML (Unified Modeling Language), publish – subscribe model [17], and XML(Extensible Markup Language) [14], to gain long term stability, interoperability of different vendors and shorten system engineering time.

A. Data Model

Different from traditional communication protocols, IEC 61850 defines a semantic hierarchical object data model and communication services based on this data model. In this data model, each IED is a container of logic devices. Each logic device is a group of logic node with specified functions defined by IEC 61850 7-4 [15]. Logic node has multiple data object to store parameters, data value and control outputs. Each data object is an instance of data class defined by IEC 61850-7-3 [16]. All data point is defined with the format like this:

LogicDevice.LogicNode.DataObject.DataAttribute

One example of circuit breaker status, no longer as a simple binary input, would be with this format: "**Ctrl.CBCSWI1.Pos.stVal**", which means IED has a logic device named **Ctrl**, which includes all control functions. Logic device **Ctrl** contains a **CBCSWI1** logic node, which is an instance of **CSWI** [15], a breaker switch controller logic node. Logic node **CBCSWI1** has a double point control data object [16] **Pos**. Attribute **stVal** of this data object **Pos** stores the circuit break position value.

B. Configuration

Configuration of GOOSE application includes three steps:

1) Prepare a GOOSE data set.
2) Setup GOOSE Control Block parameter to specify how to send this data set.
3) Specify which IEDs are going to receive these GOOSE data set by subscribing.

A GOOSE data set is just a list of detailed data attributes of data points based on IEC 61850 data mode as shown in the list below. (Fig. 2). User can create a GOOSE data set, add data attributes to the list or remove from the list.

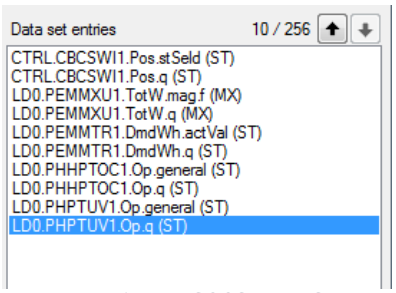

Figure 2 GOOSE Data Set

GOOSE Control Block (GCB) specifies the properties and behavior of the GOOSE message (Fig. 3).

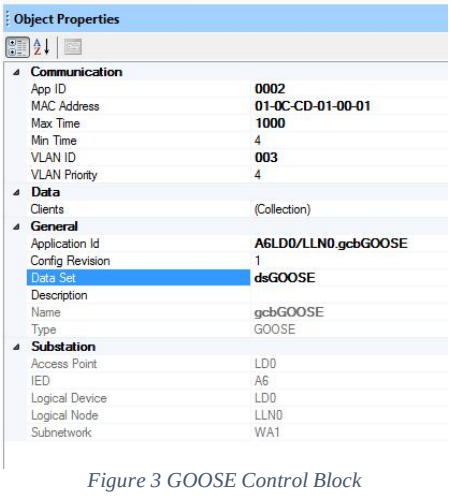

Figure 3 GOOSE Control Block

GOOSE control block specifies which **data set** it controls. Destination **MAC address** and **App ID** are configured to be a unique message identifier. While multiple GOOSE messages are sending to all devices on the network by broadcasting, GOOSE receiver uses this information to check if received GOOSE message is the one being expected.

Max time is defined to control GOOSE heart beat message frequency in millisecond. As in this configuration, IED is sending GOOSE message every 1000 millisecond when there is no new event. The GOOSE receiving IED waits twice long of this time, 2000 millisecond. If it does not receive GOOSE message in 2 seconds, the receiving IED will conclude communication with GOOSE sending IED is broken.

VLAN ID is used to include GOOSE broadcasting message only in a contained network instead of flooding to other unnecessary devices. **Configure revision** is not a configurable parameter, which changes everything GOOSE data set is updated. These parameters are very useful information for troubleshooting GOOSE communication.

IEC 61850 GOOSE communication is based on publish-subscribe mechanism. IEDs broadcasts GOOSE messages to

all devices connected on the network. Receiving IED needs to know which GOOSE messages received to process.

In IEC 61850 configuration tool, check boxes are normally used to enable subscription from IEDs in the column to GOOSE control blocks in the row. When GOOSE subscription is checked, information of GOOSE data set and GOOSE control block are copied to GOOSE receiving IED from sending IED. When a GOOSE message is received, it will be compared with GOOSE control block information in the receiving IED. If they match, then the GOOSE communication will be processed. GOOSE receiving IED will reject the GOOSE message if it finds GOOSE control block information of received message does not match the configuration, especially destination MAC address, App ID and configuration revision. Receiving IED will generate error event if MAC address and App ID match but data set entries or control block information do not match.

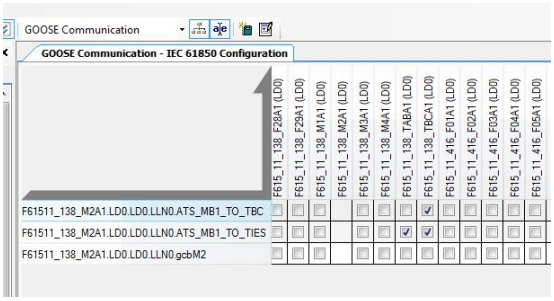

Figure 4 GOOSE Subscribe

IV. Troubleshooting of GOOSE Communication

Following OSI 7 layer model and data flowing direction, a bottom-up approach is introduced here to troubleshoot GOOSE communication, with steps including network scheme, hardware connection, GOOSE publishing, GOOSE receiving, and redundancy.

A. Network Scheme

Network scheme diagram like Fig. 1 should be available before any troubleshooting activity starts. All network connected devices on the network need to be identified and checked according to up to date network scheme diagram. It's not uncommon that actual wiring does not match the design drawing.

B. Hardware Connection

The lowest layer in OSI model defines electrical and physical specifications of the data connection, which will be the starting point of investigation. First make sure there is a good network connection with no hardware failures. Broken fiber optic cable, loose terminal connection, and faulty pinout of RJ45 plug and wrong wiring are at the top of list for failure network connection.

Some basic methods to check the network connection are LED status, Ethernet switch port status, and ping.

1) LED Stats: LEDs on IED device and Ethernet switches display communication status. Color code and flashing pattern are normally defined by vendors to help network diagnostic. Normally a solid green LED or flashing green suggests healthy connection with data receiving and transmitting.

2) Network Port Status: Besides LEDs stataus, IEDs and Ethernet switches provide network status information through some interface, could be local HMI(Human Machine Interface) or web browser. Check network status information will confirm healthy network connection has be established. Fig. 5 shows an example of network status of IED, which shows Ethernet port 1, port 2 and 3 all have bad connecting.

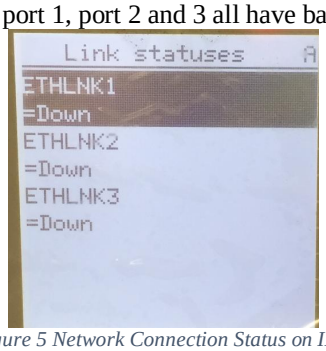

Figure 5 Network Connection Status on IED

Most of the time IEDs are connected to Ethernet switches instead of connecting with each other. Here is the network status on Ethernet switch showing connection status of each port (Fig. 6). From the network scheme diagram, we will be able to tell which IED has good connection to the Ethernet switch or not.

Figure 6 Network Connection Status on Ethernet Switch

3) Ping: Although we are check layer 1 hardware connection, we still can use some upper layer application tools, like Ping. Ping is a widely used and implemented netowrk administration software application to test the reachability on Internet Portocol (IP) network. Ping sends Internet Control Message Protocol(ICMP) Echo Rrequest packet to the target device and wating for an ICMP Echo Reply. When IEDs are connected to the network, normally they are assigned unique IP address for each IED. Ping can be used to test the network connection of IEDs.

Connect a computer to the network, and try to ping all IEDs. If we can ping all IEDs with no error, then all IEDs should have good network connection. If connection of IED is not good, Ping will report a "Request timed out" error message.

C. GOOSE Publishing

When a good network communication system with no hardware failure is confirmed, next step is to check if GOOSE messages are sending out. To achieve high speed communication with real time message, GOOSE adopts publish-subscribe model and is implemented at OSI layer 2, data link layer. When IED publishes GOOSE message, it broadcasts to all devices connected to the Ethernet network. All devices connected to the network will receive the GOOSE message

While IED is broadcasting GOOSE message to the whole network, one way to check the GOOSE message being successfully sent is to use network sniffer to capture and check the GOOSE message. **Wireshark** is a free and open source network analyzer, which can be used to do that. Detailed analysis of GOOSE message in Wireshark was provided in [6]

Connecting a computer to the network, we can run Wireshark on the computer and start capturing communication packets.

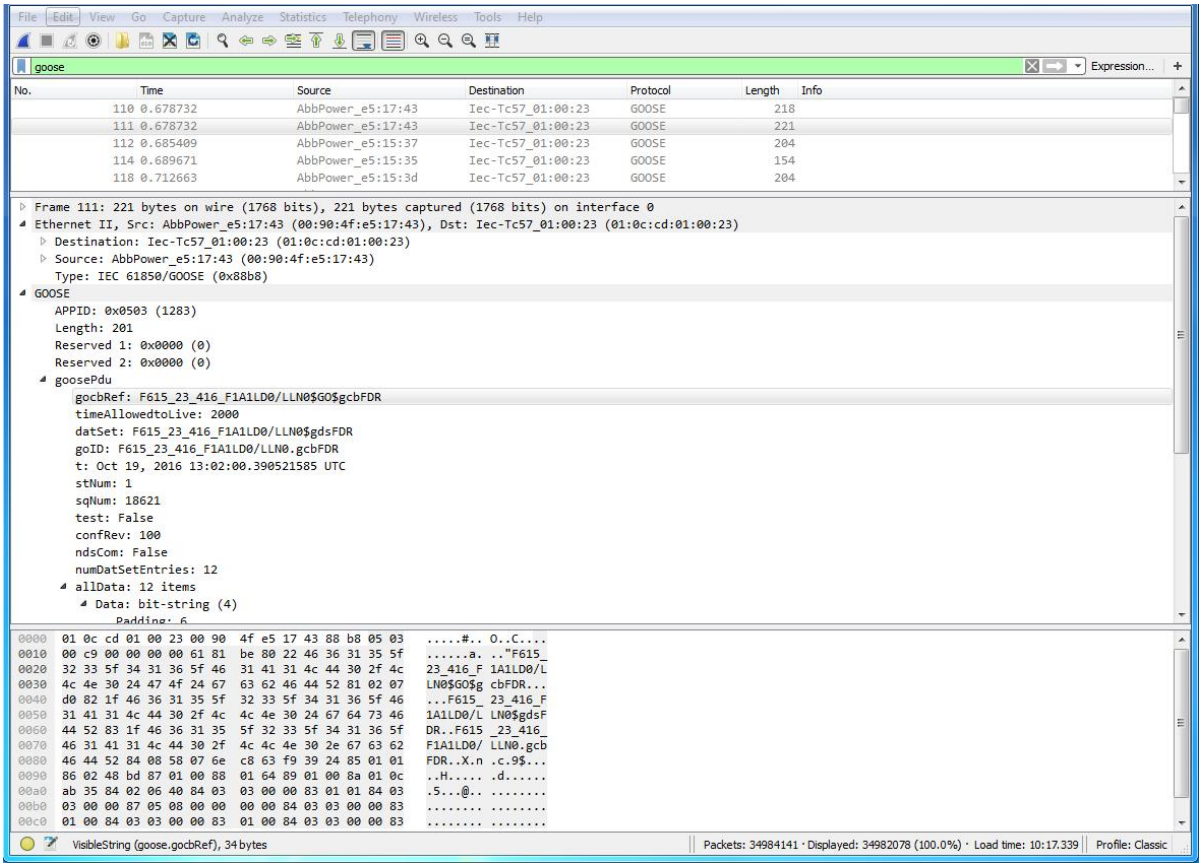

Figure 7 GOOSE Communication Capture

If GOOSE messages are captured from the network analyzer as in Fig. 7, we will know the IED is publishing GOOSE message to the network. We can learn a lot from captured GOOSE message.

MAC address of each port of each IED is unique. Source MAC address of the GOOSE message tells us which port of which IED is sending the GOOSE message.

Different data set of different IEDs can have same destination **MAC address** or same **AppID**, but combined destination **MAC address** and **AppID** of each GOOSE control block should be unique. In the captured GOOSE message, destination **MAC address** and **AppID** should be checked if they are correct and unique for each GOOSE control block. If there are two GOOSE control blocks are configured with the same destination **MAC address** and **AppID**, receiving IED will be confused and generate error event.

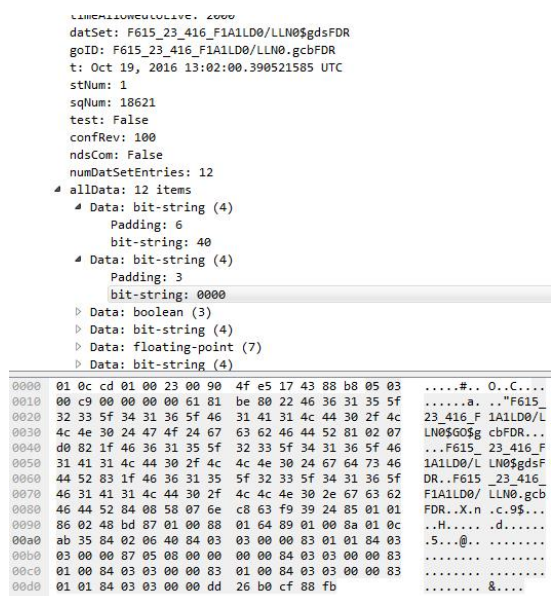

Figure 8 Parameters and Data Points in GOOSE message

One important parameter in the GOOSE message is configuration revision **ConRev**, configuration revision, with value 100 in Fig. 8, represents how many times GOOSE data has be modified (increase by 100 for each edition). This configuration revision number should match between GOOSE sending IED and receiving IED. Receiving IED uses this number to validate the GOOSE message received. If Receiving IED found this number does not match the one it saved, it will treat is as an invalid message and throw it away. This situation happens when GOOSE data point changed on sending IED but configuration on receiving IED is not updated.

In the captured GOOSE message, correct GOOSE data values can be checked if they match actual status. One way to check is changing status on the GOOSE sending IED and watch the value changing on the GOOSE message.

One important data attribute **Quality** is normally included in GOOSE data set to represent quality condition of the data value. Quality bit is encoded in IEC 61850 with different error conditions, which can be used for further diagnostics.

Table 16 – Encoding of IEC 61850-7-3 quality

Bit(s)	IEC 61850-7-3		Bit-String	
	Attribute name	Attribute value	Value	Default
0-1	Validity	Good	0 0	0 0
		Invalid	0 1	
		Reserved	1 0	
		Questionable	1 1	
2	Overflow		TRUE	FALSE
3	OutofRange		TRUE	FALSE
4	BadReference		TRUE	FALSE
5	Oscillatory		TRUE	FALSE
6	Failure		TRUE	FALSE
7	OldData		TRUE	FALSE
8	Inconsistent		TRUE	FALSE
9	Inaccurate		TRUE	FALSE
10	Source	Process	0	0
		Substituted	1	
11	Test		TRUE	FALSE
12	OperatorBlocked		TRUE	FALSE

Figure 9 Encoding of IEC 61850 data point quality

When there is no new GOOSE event, IED still sends supervision heartbeat messages (Fig. 10) with time interval defined by parameter **MaxTime**. As seen in the captured GOOSE communication below, IED is send the message every 1 second, which matches the setting in the configuration. In actual GOOSE message, this value is encoded to field **time allowed to live** with value 2000, 2 seconds, which is double the time of the setting of **MaxTime**. If receiving IED does not receive GOOSE message for double the time of **MaxTime** setting, 2 seconds here, it will determine GOOSE sending IED is offline.

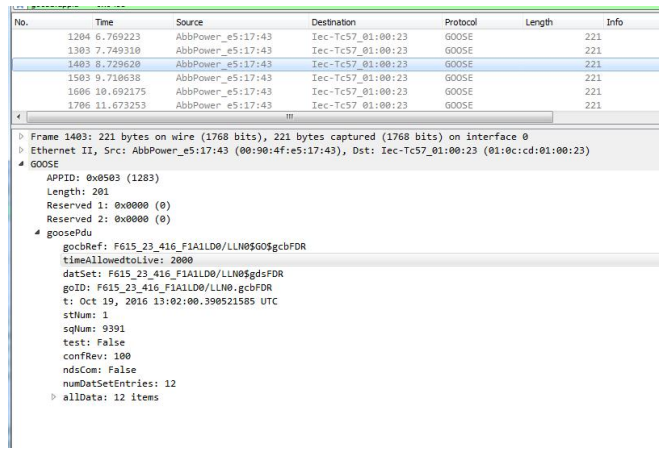

Figure 10 GOOSE Heart Beat Message

To achieve high reliable, high-speed peer-to-peer communication, instead of sending message to each subscriber separately, IED broadcasts GOOSE message to all the devices on the network. The side effect of this mechanism is devices on the network receive these GOOSE message even they are not interested in. So in network design, we want to contain the GOOSE message inside the substation, or with only the IEDs assigned to receive it. We do not want the broadcasting GOOSE message being sent to any devices not supposed to receive it, like RTUs, SCADA or corporate network. To achieve that, Virtual LAN is used by IEC 61850 to build a single GOOSE network domain (Fig. 11). A Virtual LAN is a designated network includes only IEDs involved in a specific GOOSE application. GOOSE message will be contained in this virtual network. Any IED outside this VLAN will not receive any GOOSE messages. VLAN network is usually setup on managed Ethernet switches. VLAN is defined with a unique VLAN ID and ports are configured to be include or exclude to the VLAN. VLAN ID setting on the GOOSE control block will match the VLAN ID on the Ethernet switch to be included in the VLAN network. GOOSE sending IEDs and receiving IED need to connect to the ports within the VLAN. Computer with Network analyzer running needs to connect to the port within the VLAN also, otherwise it will not receive and capture any GOOSE communication.

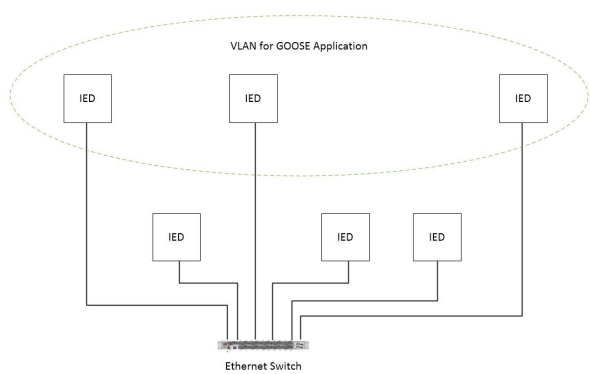

Figure 11 VLAN

D. GOOSE Receiving

When GOOSE publishing is confirmed, it is up to the GOOSE receiving IED to process the message. There are several ways to exam GOOSE communication on the receiving side.

1) GOOSE Communication Status: GOOSE diagnostic counters on the IED can be checked to investigate the communication status (Fig. 12). Increasing of receiver time-out counter means there is a connection error, or IED is not sending GOOSE message. If counters for Received and transmitted message accumulates consistently, then we can tell there is no hardware connection error, and IED is receiving GOOSE communication. Counter of errors will tell what kind of communication error with the GOOSE communication.

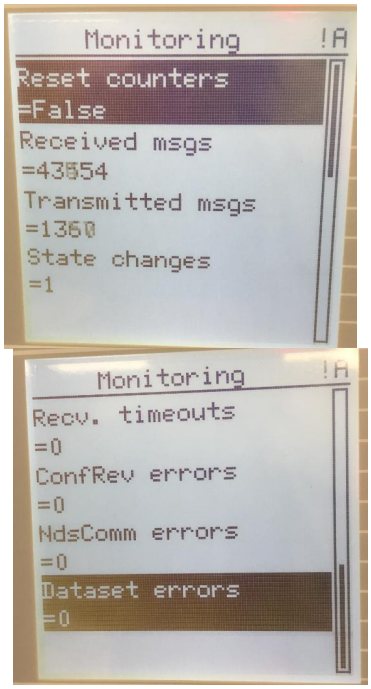

Figure 12 GOOSE Communication Status

Received **ConfRef** mismatches happens when GOOSE receiving IED has different configuration revision number from GOOSE sending IED. When data set has been changed on GOOSE sending IED but not on the GOOSE receiving IED.

2) On-line mode: Most modern microprocessor based IEDs have debugging capability. Application configuration tools can be switched to on-line mode to show real time status of internal logic as in Fig.13. Changing data point status on GOOSE sending IED and watching the status change in application configuration tool in on-line mode will tell if IED receives valid GOOSE data, validation and quality values. On-line mode can also show any problems with GOOSE communication or application logic.

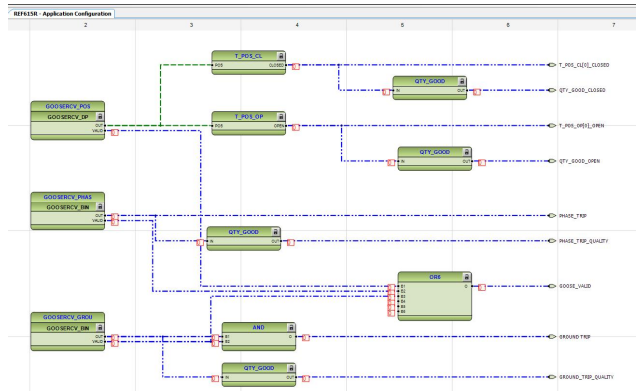

Figure 13 Application Configuration Tool in On-line Mode

E. Redundancy

When many protection and control applications based on GOOSE are implemented, the high availability of network becomes even more important. To increase network availability, high available redundant network (IEC 62439) are highly recommended for GOOSE applications. Seamless redundant communication protocol PRP (Parallel Redundancy Protocol) and HSR (High-availability Seamless Redundancy) are recommended by IEC 61850.

When applications run on PRP or HSR, GOOSE messages are sent and received on two network path independently. System availability is increased by eliminate single point failure. New communication issues arise if redundant system is not configured properly.

In the PRP system shown as Fig. 14, IEDs has two ports to connect two independent networks and GOOSE messages are sent to both network at the same time. IEDs are receiving GOOSE message from two ports simultaneously.

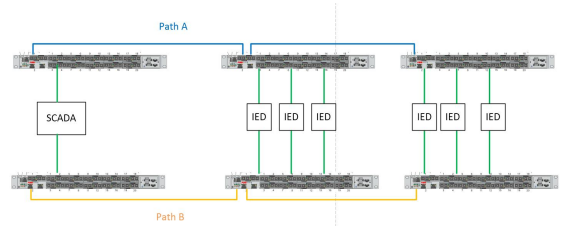

Figure 14 PRP Network

To make PRP redundancy work, the two ports of IED need to be configured as two separate Ethernet interface. These two ports should be separate and no communication packet should be allowed to parse from one port to another. If these two ports are not separated, redundant network paths will be short-circuited and network will crash. Every IED on the redundant network needs to be configured for redundant network to make sure there is no short-circuit between these two redundant paths.

When GOOSE applications run on redundant network, redundancy should be disabled by shutting down Ethernet switches of second path or disconnect all connections to second path before troubleshooting starts. When GOOSE

communication with each network be tested separately and confirmed with no error, redundant network can be enabled and GOOSE communication for whole system can be tested. Any device not supporting PRP or any short-circuit in the network will break communication at this point.

F. Conclusion

This bottom-up troubleshooting approach begins with network knowledge, starts hardware connection check, followed by checking network diagnostic, and investigating GOOSE message from publishing to subscribing by following data flow direction. The main steps are:

1) Network: Read system network scheme and compare actual wiring againt the design.

2) Dedundancy: Disable redundant network if redundant network is implemented.

3) Connection: Check hardware wiring, connection status to make sure there is a good netowrk connection between GOOSE sending IED to receiving side.

4) Publishing: Check GOOSE message is published as configured on both sending and receiving side.

5) Receiving: Check GOOSE communicaiton status and GOOSE data value received.

6) Redundancy: Enable redundant network if redundant network is implemented and repeat step 3) to 5) to make sure GOOSE communication is not broken in redundant network.

Fig.15 shows the workflow of these troubleshooting steps.

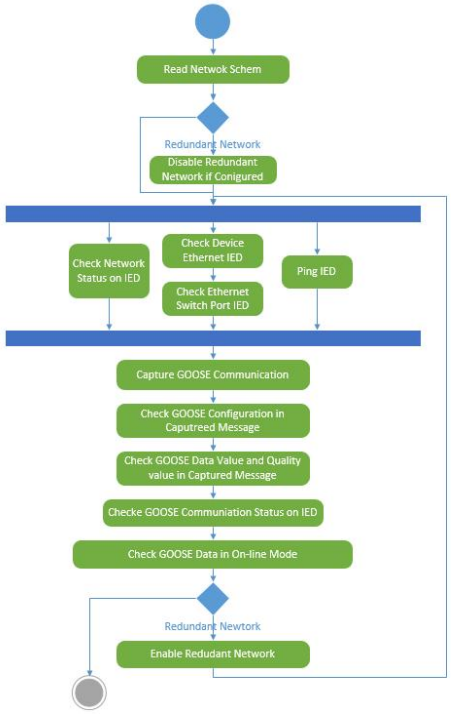

Figure 15 GOOSE Troubleshooting Workflow

G. Result

This troubleshooting approach is accumulated and adopted from system integration practice of several large projects in the past two years. Most troubleshooting activities happened during substation commission time. Ad-Hoc troubleshoot method was applied for early projects and more systematically techniques were developed and evolved to today's result. We use the average system communication commission time per IED to measure the efficiency of this approach.

Substation communication commission time is listed in chronological order in Table 1. The leftist column is the time recorded for the first substation commissioning 2 years ago, and the rightest is for the latest substation. Fig.16 is the graph derived from Table 1, in which we can see average commission time was shortened by 75% from 2.61 hour-per-IED to 0.66 hour-per-IED in two years.

Table 1 System Communication Commission Time

Substation	SS-A	SS-B	SS-C	SS-D	SS-E	SS-F	SS-G	SS-H	SS-I	SS-J	SS-K
Number of IED	46	95	21	22	25	17	17	61	60	48	62
Commission Hours	120	184	40	24	40	24	24	73	46	35	41
Average Commission Hours	2.61	1.94	1.90	1.09	1.60	1.41	1.41	1.20	0.77	0.73	0.66

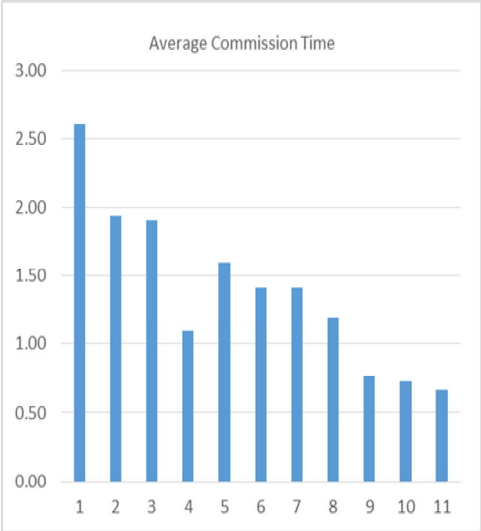

Figure 16 Average Commission Time

V. SUMMARY

In this paper, we analyzed IEC 61580 data model, GOOSE configuration, service and message, investigated actual communication issues at different layer and proposed a bottom-up troubleshooting steps. This method has been implemented and showed good result in actual substation system integration tasks.

For future development, we would like to investigate GOOSE communication issues in more detail, and develop better GOOSE diagnostic tool with better features to increase substation system integration commissioning work quality.

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VII. BIOGRAPHIES

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