

Study of Application of IEEE 1588 in Substation Time Synchronisation

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1 INTRODUCTION

Substations are important component in power network, influencing the transmission efficiency and the quality of distributed electricity. They can not only monitor and control power flows but also provide interconnection between generating facilities, transmission and distribution networks and end consumers. In the past 20 years, the substation automation system (SAS) has had rapid development. Communication technology becomes the key technology of SAS. Due to the delay in publishing the corresponding communication protocol, there is difference in the device communication mode and transmission protocol among different vendors. The Intelligent Electronic Devices (IEDs) from different manufacturer cannot interconnect with each other. To realize the interoperability of those IEDs, IEC 61850 standard is published by TC57. It is the international standard applicable to Substation Automation System [2]. It provides a standardized frame work for substation integration that specifies the communication requirements, the functional characteristics, and the structure of data in devices, the naming conventions for the data, how applications interact and control the devices, and how conformity to the standard should be tested [1]. But depending on the manufacturer's different understanding of the protocol, the problem of interoperability between devices could occur. Tests are required to carry out to check the performance of IEDs.

The paper will discuss how the test will set up affect the operation of substation communication system and the function the IEC 61850 standards can offer to traditional protection scheme.

2 SUBSTATION AUTOMATION USING IEC 61850

2.1 Objectives of IEC 61850performance evaluation project

IEC 61850 is the future solution of substation automation and protection system. It utilizes the Ethernet-based local area network communication to get rid of the complex connection of copper wire from primary plant to secondary protection and control system. It uses sample value stream to transmit voltage and current signal and GOOSE message to deliver the device status. At the same time it uses MMS, SNTP to manage the devices. But at the current stage, implementing the protocol is not reliable. The signals have latency when travelling through the network and the manufacture of the devices which can support the IEC 61850 standard has problem of interoperability. We need to figure out a standard principle to evaluate the equipment and work out the optimal structure of the network that minimise the signal latency and most important reliable and secure. This structure also must be able to upgrade and capable of integrate new firmware to perform routine tests in the future.

2.2 Architecture of Communication Systems of IEC61850

The IEC61850 standard introduces a view of a substation automation system comprising three hierarchical levels; they are station level, bay level and process level. Two levels of communication

network connecting these hierarchical levels are described - the station bus and the process bus. The three levels conceptual architecture of IEC 61850 substations is shown in Figure 1.

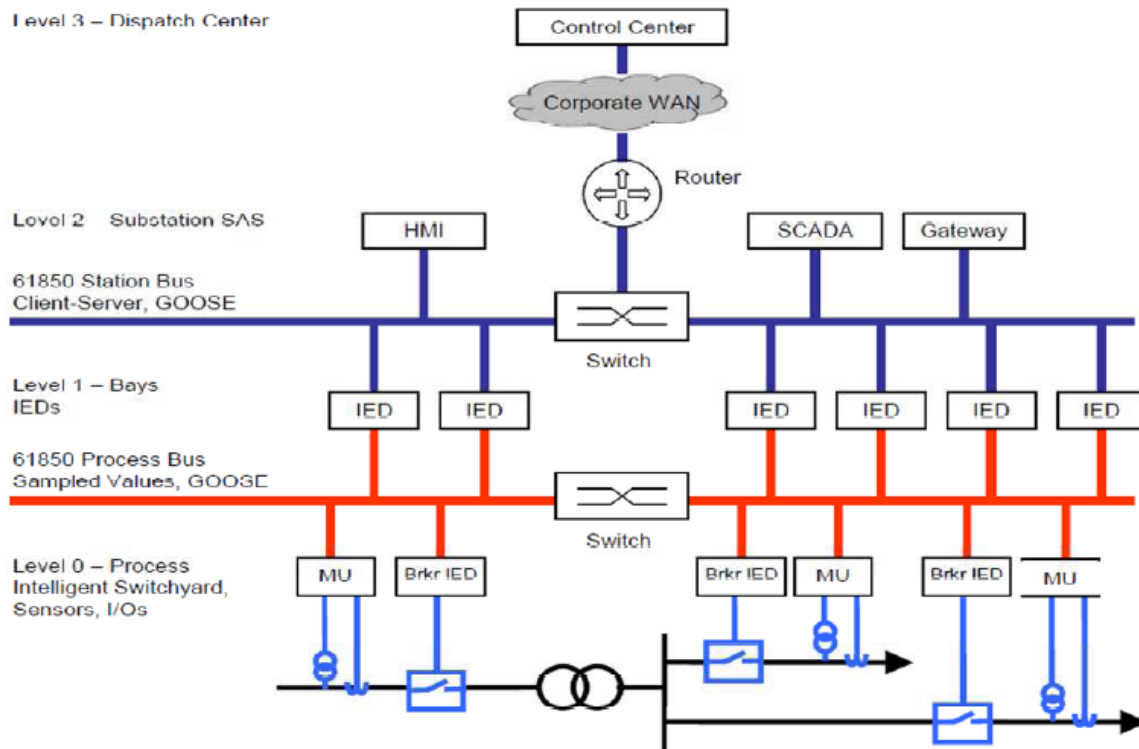


Fig. 1: Architecture of IEC61850 Substation Automation System[3]

The functions in SAS can be assigned to one of three levels. According to IEC 61850 standards, The Process level includes switchyard equipments such as instrument transformers, circuit breakers, sensors and actuators, etc. These devices connect to the high voltage plant and associated equipment. The bay level includes protection and control IEDs of different bays. It is responsible for the protection, control and metering of the bay, which contains one feeder of transformer. The functions requiring data from more than one bay are implemented at the station level. The station level devices operate across the entire substation and would include a local operating console, remote control gateways for a control centre [4].

The “process bus” between the process level and bay level supports services defined in IEC 61850-9-2 for sampled values. According to IEC 61850, the process bus provides information such as the status of breakers and switches and trip commands through an input/output unit using the services defined in the standard. This facilitates the time critical communication between protection and control IED [5]. The process bus also reduces the life-time cost of the secondary systems and improves flexibility and functionality. The station bus between the station level and bay level facilitates communication between station level and bay level. It also allows communication among different bays.

2.3 Introduction of Test Bed

The starting point of the research is to build up a physical testbed based on the IEC 62439-3 PRP protocol as shown in Figure 2. In the redundant double star topology, there are 4 levels for the switches from bottom to top. They are bay switches, diameter switches, voltage level switches and root switches. Voltage level means particular switches are used for a specific voltage level. For example, 400 kV switches are deployed for the 400 kV network in a substation. The 400 kV switches connected to several Diameters and each connected to some Bay level switches. The number of Diameter and Bay level switches based on the substation size and the design method. The voltage level switches are then connected to the root switches. Two IEEE 1588 grandmasters (One is in active

state and the other is in stand-by mode) transmitting the reference time signal is directly connected to the root switches.

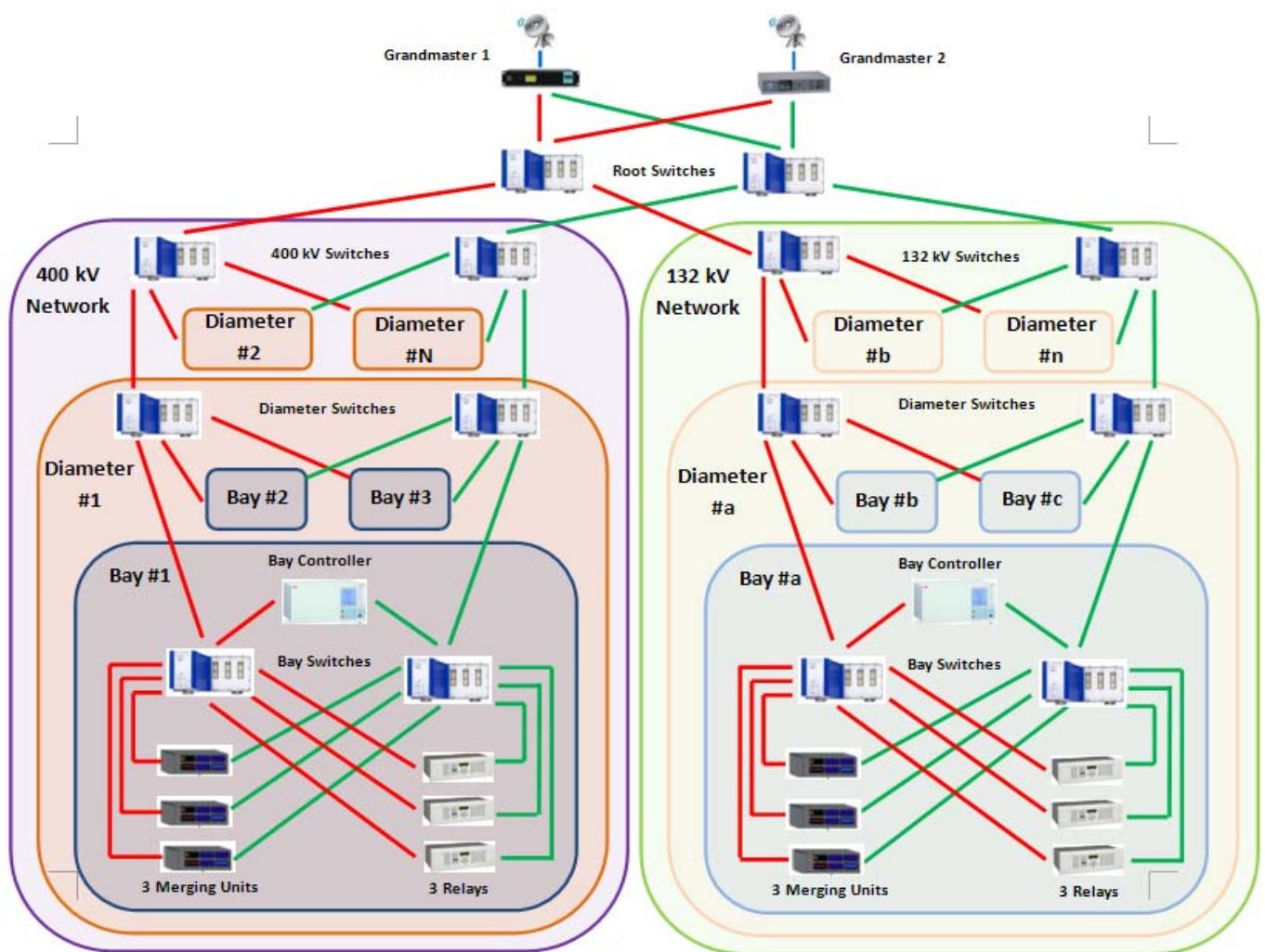


Fig. 2: IEC 61850 test bed structure with PRP network

2.4 Testing Point of IEC 61850 protocol

IEC 61850-9-2 facilitates an implementation of merging units, process bus and protection IEDs. The commonly considered problems include:

- Ethernet message performance
- Network traffic load issue
- Interoperability between IEDs from different manufacturers
- Zero Reconfiguration time of PRP network

IEC61850 has specified performance requirement for SV and GOOSE, the SV message should be delivered within 3.0 ms in transmission substations, including the communications processing time at each end and the media transfer time. GOOSE message that trip plant has 3ms transfer time and other GOOSE “fast message” has 20ms transfer time. Test set are used to generate the SV message and GOOSE message we need and use network card to capture the message packet to measure the time delay between them.

The network issue needs to be considered. Most traffic in IEC61850 automation systems is based on Ethernet. In the substation we can find:

- a. Protection traffic based on GOOSE messages, which are multicast Ethernet frames
- b. Control and monitoring traffic, reports and commands, which are based on MMS over TCP/IP
- c. Synchronization information, based on SNTP/UDP/IP and IEEE1588
- d. Management information, being the most common used protocols, FTP for exchanging SCD/CID files and HTTP for accessing IED's configuration parameters via their built-in web servers [2].

Different IEDs with client/server communication and real-time data (SV and GOOSE) coexist in one network. The client-server has minor impact on network load due to its unicast-communication and no real-time requirements. In case of a disturbance the number of reports transmitted will increase, combined with file transfer (disturbance records) the load on the network will be remarkable [6].

GOOSE use multi-cast mechanism and publishes a signal repeatedly. In case of signal change, the repetition interval is getting smaller. Even in case of a GOOSE avalanche the requirement of network bandwidth is limited. A good configured switched Ethernet with priority will have no problems [6].

SV increase the network load dramatically. One data stream needs 6.3 Mbit/s. The maximum capacity for 100 Mbit/s network would be 15 streams. SVs are big network load and require good design network [6].

The network traffic is present in the substation network and the traffic interferes. If there is much traffic in the network, it may cause load for IED's processor, possibly leading to a situation that the IED becomes unable to respond to other requests. When crossing the network, the packets involved in the application will be forwarded by switches, where they may interfere with the other data packets. By using the priority tagging, data packets can be assigned to different priority. According to IEC 61850 standards, the priority of Sample Values is fixed at 4. To see the interaction between the different protocols, numbers of Sample Value streams will be generated by test set which is equivalent to the amount of 0, 6, 12 and 20 Merging Units and change the priority of GOOSE to see their interaction. The same method can be applied to MMS, SNTP, HTTP and PING message. Depending on the test design, we can work out the influence of Sample Value traffic on other messages such as PING and GOOSE, as well as the influence of GOOSE, HTTP etc.

The central goal of IEC 61850 is to provide comprehensive interoperability in SAS between control, protection and station level devices of different suppliers. The purpose of Interoperability investigates the challenges that emerge from requirement and derive guidelines and recommendations for future engineering processes. Merging Units from different manufacturers may vary in performance characteristics such as delay, dynamic range and conversion error. Presently there is no particular MU specification. We will use Merging Units from different manufacturers connected to Alstom relay or another brand relay and let Merging Units transmit the converted digital signal to the IEC 61850 compliant relay to see whether the relay can read the signal from MU.

The compatibility will be tested between IEDs and IEDs or the IEDs and MUs in terms of performing required protection function. The test bed is based on the RSTP and PRP protocols. Tests are designed to see whether the time critical messages (Sample Values and GOOSE) generated in the MUs or IEDs in one bay can be transmitted to and recognized by the IEDs in another bay correctly.

There would be some disturbance happen in the network that causes the message packet missing, corruption or link interruption. As a result, the performance of IEDs will be influenced and different network problem will cause different behaviour of IEDs. Different network situations will be created by network impairment to see how the IEDs will respond to different kinds of disturbance.

The test bed is built based on the RSTP and PRP protocols. PRP uses two independent networks of any topology. The most important feature of PRP structure is the zero time recovery after a network fault, which eliminates a downtime and guarantees the highest communication availability. The test will be conducted in the conditions where the network is unhealthy (somewhere the link is interrupted, data packet is lost or corrupted), the test will be designed to see whether PRP can provide the "seamless redundancy" and still receive the correct messages. Tests are designed to see whether the

time critical messages (SV and GOOSE) generated in the MUs or IEDs in one bay can be transmitted to and recognized by the IEDs in another bay correctly.

2.5 Testing Ideas of IEC 61850 protocol

To test the interoperability of MU and the performance of IEC 61850 compatible IEDs, the test system has been set up.

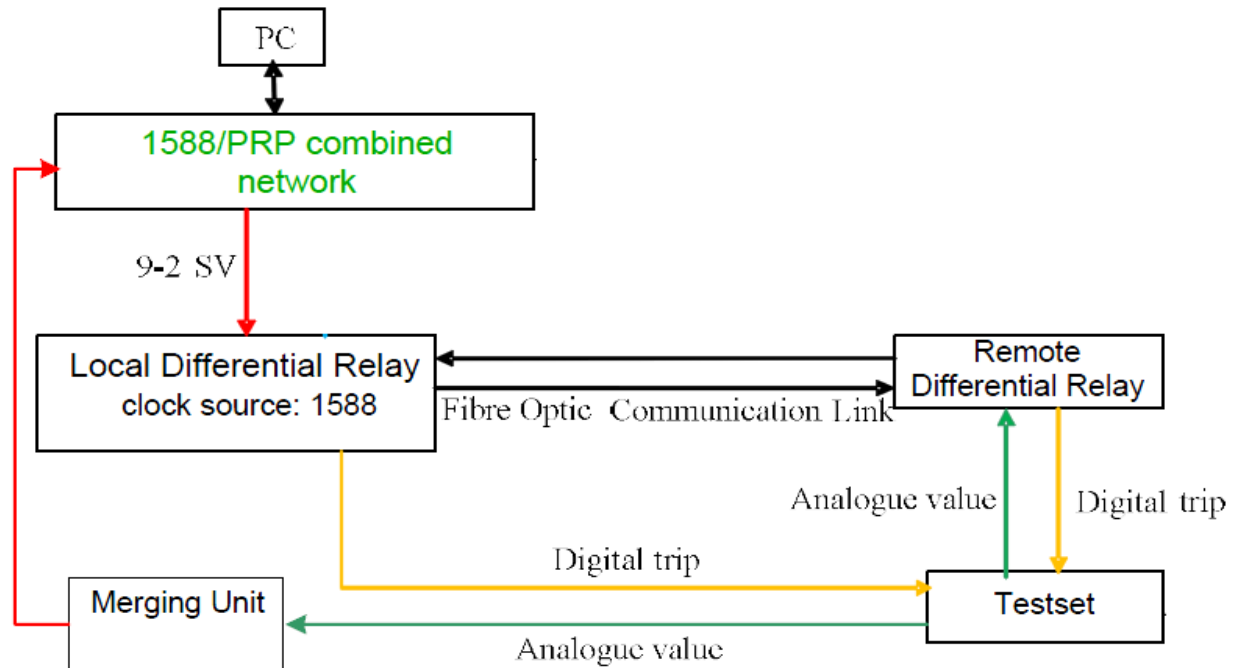


Fig. 3: Test setup diagram

Merging Unit (MU) is an important intelligent electronic device in digital substation which samples the output of current and voltage transformers. It consists of an interface between electronic current and voltage transformers and such secondary equipment as protective or measuring devices. The MU digitizes the CT/VT data and sends this data to the IED through the fibre link. This cable is not subject to the electromagnetic interference that would be experienced by copper cables [6].

A merging unit prepares the “time-coherent” sampling of three-phase currents and voltages. The function of an MU is to merge different types of measurements in one device and send the standardized digitized output to the required protection and control devices. MU from different manufacturers may vary in performance characteristics such as delay, dynamic range and conversion error. Presently there is no particular MU specification [7].

IED is connected to a MU using a fibre-optic cable and an Ethernet Switch. The IEDs interface with the process bus via the Ethernet network. They use information from Ethernet Switch for fault detection, faulted phase selection and protection elements operation etc., and can take an action based on their functionality. This is typically to operate their relay outputs in order to trip a breaker or to initiate some other protection or control function.

The test set generates two analogue signals, one to the remote differential relay which is the conventional relay. The other goes to the Merging Unit, the output signal from the Merging Unit which is Sample Value streams are connected to the IEC 61850 compatible relay. Merging Unit from different manufactures can be connected to the system to see whether the relay can read the Sample Value streams within the time required and perform the correct protection operation.

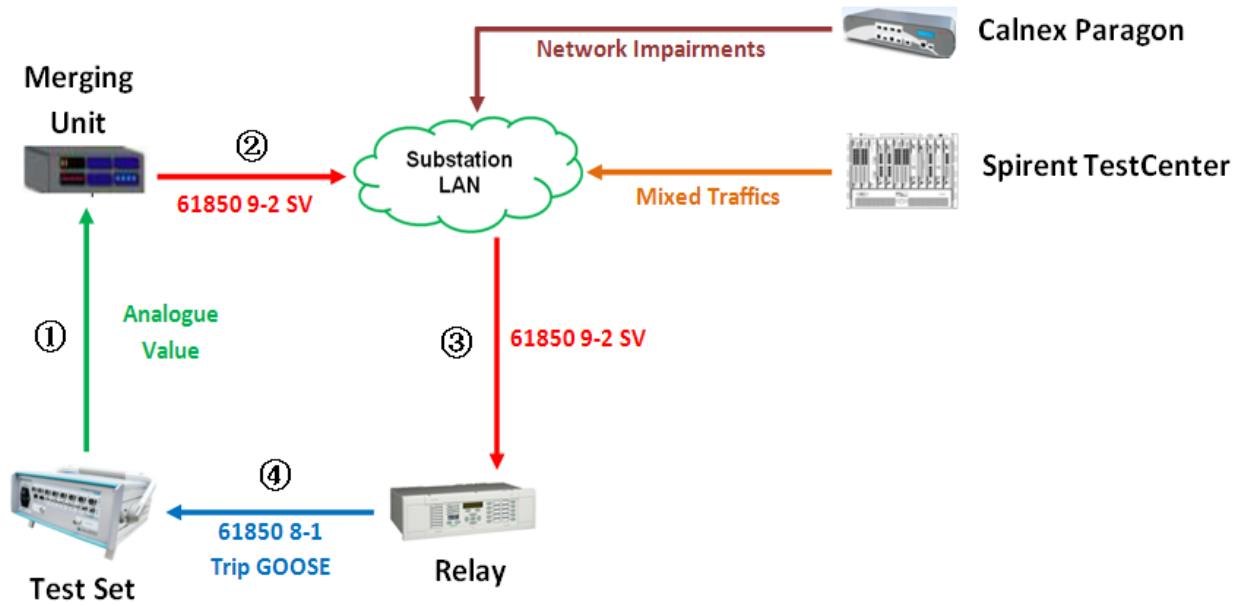


Fig. 4: Test set-up with the test bed based on Ethernet switch

The test bed replaces the single Ethernet switch in Figure 4. It utilises the PRP redundancy protocol. The PONOVO NF801 will be regarded as test set to generate IEC 61850 compatible signals (Sample Values and GOOSE). The test set has 8 optical ports to receive and send IEC61850-9-2 format Sample Value and GOOSE message.

The test set will simulate the fault situation and send the corresponding current and voltage signal to the Merging Units. The Sample Value streams will travel through the test bed network and eventually the relay will receive the Sample Value and generate GOOSE signal. The GOOSE signal is connected to the test set and the test set and record the time when the GOOSE signal arrives. Whether the fault trip time can satisfy the standard requirement can be test by comparing the difference between the time when the fault occurs and the time when test set receives the GOOSE signal.

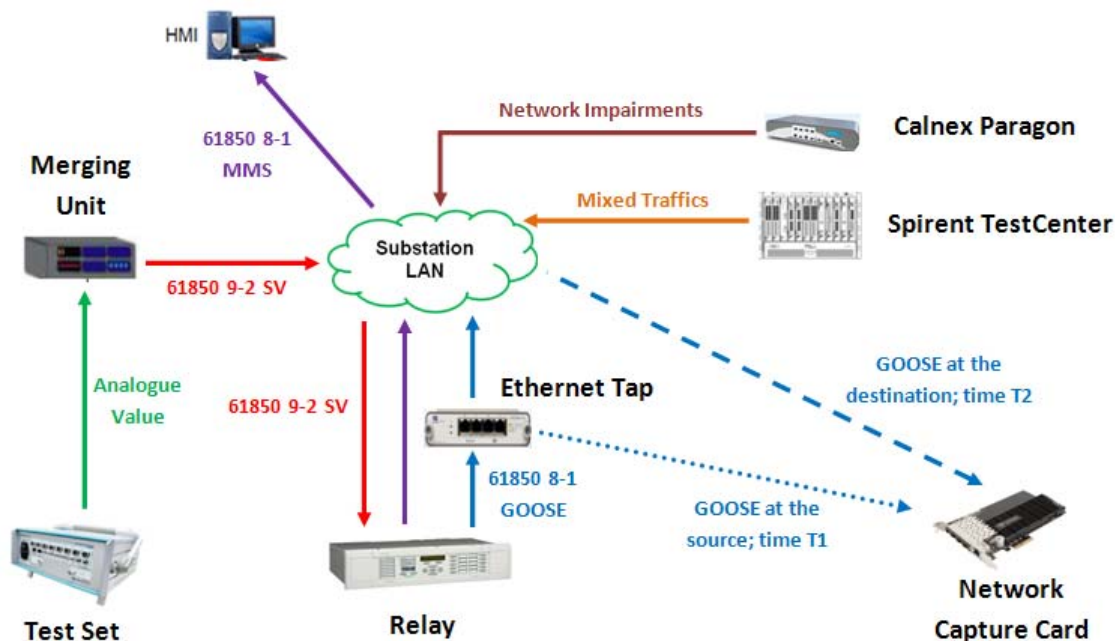


Fig. 5: Test system to measure the delay of message in the Ethernet switch

As mentioned above, IEC61850 has specified performance requirement for Sample Value and GOOSE, the Sample Value message should be delivered within 3.0 ms in transmission substations, including the communications processing time at each end and the media transfer time. GOOSE message that trips plant has 3ms transfer time requirement and other GOOSE “fast message” requires less than 20 ms transfer time. The performance of Sample Value streams and GOOSE message should be tested by generating the Sample Value streams and GOOSE message needed and network card is used to capture the message packet to measure the time. The Ethernet cap can be connected between the test set and the Ethernet switch. The cap can copy the exact input message packet and outputs two identical message packets. One of the packages transmits back to the test set and the time when the message received will be recorded by the test set. The other message travels through the Ethernet switch and then back to the test set to record the received time. The time difference between the arrival time of the two packets is the time delay in the Ethernet packet. Then the Sample Value streams delay in single Ethernet Switch can be measured.

3 CONCLUSION

There are a number of important considerations which must be taken into account when developing any new technology structure within a power substation. These include not only technical factors such as performance, security and reliability but also significant business considerations like safety and overall cost. The IEC 61850 international standard “Communication Networks and Systems for Power Utility Automation” ushers in a new era in substation design. It offers new possibilities for maximizing the economic and effective utilization of the transmission assets and network. IEC 61850 provides a solid basis for future Smart Grid solutions and provide reliable and cost-effective protection and control. The optimal application of a process bus based protection scheme can be achieved by close collaboration between protection specialists in academia and industry.

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