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IEC 61850-9-2 PROCESS BUS COMMUNICATION AND ITS IMPACT ON SUBSTATION PERFORMANCE

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ABSTRACT

IEC 61850-9-2 standard proposes switched Ethernet based process bus communication network between process level switchyard equipments (CTs/PTs, Circuit Breakers (CBs), power transformers etc.) and bay level protection & control devices (multifunctional IEDs, bay controllers etc.). Process bus communication network is critical for the transmission of mission critical messages i.e., GOOSE and SVs in 'all-digital' substation automation applications. The paper investigates the salient features, benefits, scope and impact of process bus communication which helps not only to develop cost effective and efficient substation automation systems but also provides various opportunities for designing and implementing distributed protection applications. The work also investigates the impact of 'Quality of service' features of switched Ethernet technology on process bus communication to match it with the performance of the traditional hardwired signals.

Keywords: Communication and information technology, IEC 61850 communication protocol, IEC 61850-9-2 process bus, Substation automation system, switched Ethernet.

I. INTRODUCTION

Standard design procedures are adopted for designing traditional substation automation systems where point-to-point copper cables connections are utilized for all interfaces between the process level high voltage switchgear and bay level equipment. Thereby, these substations require more time, efforts and huge investments in copper cables with different lengths, and sizes that need to be designed, installed, commissioned, tested, maintained and configured manually. Further, the protective system has limited access to the process level signals. Therefore, each protective relay requires their own instrument transformers as CTs/PTs outputs cannot be shared with several devices.

In IEC 61850 Substation Automation Systems (SAS), process bus is an Ethernet network based serial communication link that replaces complex network of multiple heavy copper cables at the process end with simple and lighter fiber optic cables for connecting switchyard equipments with multifunctional SAS Intelligent Electronic Devices (IEDs) at bay level.

The standard IEC 61850-9 defines the Specific Communication Service Mapping (SCSM) for the transmission of Sampled Values (SVs) in two parts. IEC 61850-9-1 [1] standard specifies a serial unidirectional multi-drop point-to-point link carrying a fixed data set in accordance with IEC 60044-8 [2], whereas IEC 61850-9-2 [3] proposes bidirectional multicast communication of configurable (user defined) dataset using Ethernet LANs (defined in the ISO/IEC 8802-3 or IEEE 802.3 [4].The standard *'9-2 LE'* specifies the SV packet format, sampling rate, time synchronization needs, and the interfaces for the transmission of SVs of currents and voltages for substation applications [5]. In brief, the process level information is collected and converted to standardize digital signals, and formatted for subsequent transmission via the process bus LAN; includes redundant Ethernet switches with advanced network management features, to bay level protection devices [6-9].

Protective functions are performed at the bay level, which involves the SVs messages exchange from Merging Units (MUs) to P&C IEDs and Generic Object Oriented Substation Event (GOOSE) messages exchange among substation IEDs. However, GOOSE and SVs messages, over the process bus network, are mission sensitive that must be highly reliable and possess real time performance characteristic, as per IEC 61850-5 standard, even under network congestion scenarios [10]. Thus process bus communication network is critical for the transmission of GOOSE and SVs in realizing '*all-digital*' substation automation applications. Therefore, it is important to investigate the impact of '*Quality of service'* (QoS) features of switched Ethernet technology on process bus communication to match it with the performance of the traditional hardwired signals.

This paper discusses the scope, major features, benefits, and an impact of IEC 61850-9-2 process bus communication which helps not only to develop cost effective and efficient SAS but also provides various opportunities for designing, operating and implementing distributed protection applications.

The rest of the paper is organised as follows: IEC 61850-9-2 process bus communication; its major features and challenges are discussed in Section II. The impact of QoS features to enhance process bus communication is described in section III of the paper. Section IV discusses the major impact of process bus on IEC 61850 substation performance. Finally, concluding remarks are provided in section V of the paper.

II. IEC 61850-9-2 PROCESS BUS COMMUNICATION

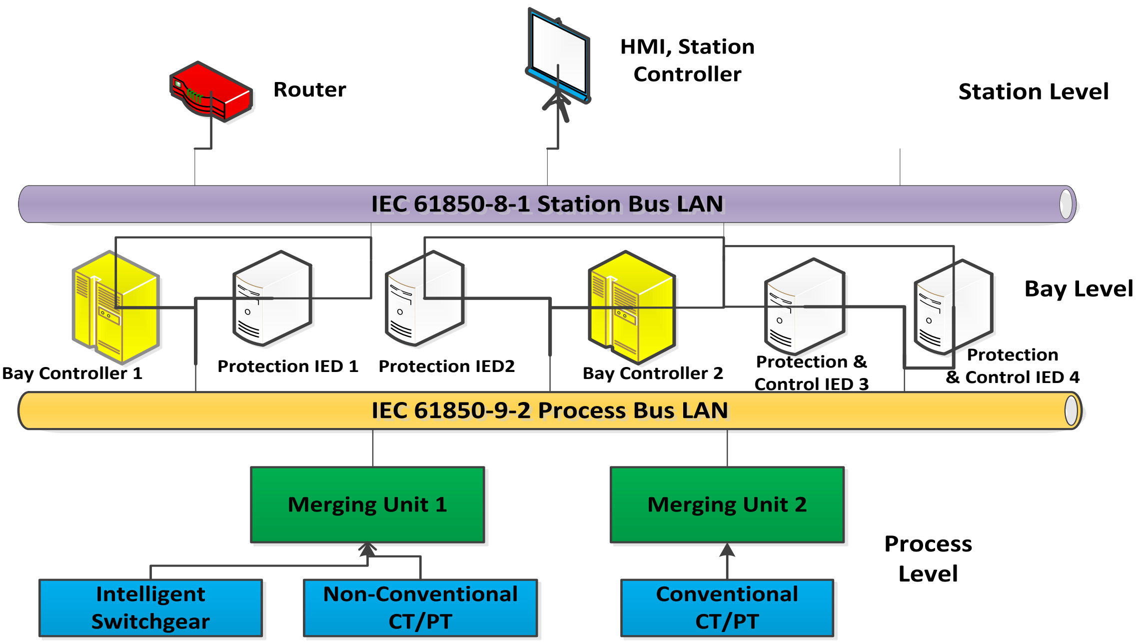

Figure 1. IEC 61850-9-2 Process Bus Concept

Fig. 1 illustrates the basic concept of the process bus. IEC 61850-9-2 process bus technology has replaced traditional analog, hardwired interfaces and conventional CTs/PTs at the process level with fiber optic communication links and Non-Conventional Instrument Transformers (NCITs), respectively. Merging unit provides an interface between these high voltage switchyard equipments and the secondary protection & control devices in SAS [3]. With this, any IED can collect and process the data from multiple MUs. IEC 61850-9-2 LE defines a base sample rate of 80 samples per power system cycle for basic protection and monitoring and a high rate of 256 samples per power system cycle for high frequency applications such as power quality and high-resolution oscillography [5].

IEC 61850-9-2 [3] is a more generalized implementation of SV data transfer. The dataset is user-defined by using the Substation Configuration Description Language (SCL). As a dataset, data values of various sizes and types can be integrated together. GOOSE messages are also able to share the process bus Ethernet LAN. The transmission of GOOSE messages is in accordance with the standard IEC 61850-8-1[11]. The Circuit Breaker Controllers (CBC) receives the GOOSE messages from protection IEDs to control the CBs at the process level.

2.1. Time Synchronization Among Process Bus Devices

The IEC 61850-9 standard proposes digital process bus, which means digitization of analog signals at the switchyard into the MUs. These digital SVs signals are communicated to bay level IEDs through process bus communication networks. SVs, generated from a MU located at different locations of a switchyard, should be synchronized to a common reference time stamp for a bay level P&C IEDs. The availability and accuracy of Time Synchronization source (TS) is crucial for the time stamping of SVs as it decides the quality of SVs presented to the bay level P&C IEDs for a variety of SAS applications, which include phasor monitoring and sampled value transport using digital process buses. Due to time synchronization of all SVs within a substation, any P&C IED can utilize SVs from any MU, and thus opens up new possibilities of digital protective relaying.

The P&C IEDs demands a few micro-seconds of time synchronization accuracy as per "*9-2 LE*" process bus implementation guideline adopted by most manufacturers, for the operation of substation applications with optimal performance. External Time synchronization based on (Inter Range Instrumentation Group-B (IRIG-B) protocol [12] and time synchronization over Ethernet data networks using IEEE 1588 based (Precision Time Protocol version 2) PTPv2 [13] are two major solutions available currently to achieve accuracy in the range of 1µs. However, IEEE 1588 PTPv2 [14-15] protocol offer better accuracy and scalability compared to the currently used time synchronization technologies such as the Simple Network Time Protocol /Network Time Protocol (SNTP/NTP) [16] and IRIG-B (a high-precision serial protocol).

Network based PTP; IEEE 1588 TS system is designed to synchronize distributed clocks with an accuracy of sub-microsecond across a packet switched communication network, with relatively low network and computing capacity. It also facilitates distribution of common frequency, common phase-alignment, and common Time-of-Day (TOD). Moreover, unlike IRIG-B, there is no need for dedicated cabling infrastructure network for time synchronization information. However, the Ethernet switches used for data communication should have IEEE 1588 v2 capability [17].

2.2. Time-Critical Svs and GOOSE Messages over Process Bus Network

Process bus communication network is critical for the transmission of mission critical messages i.e., GOOSE and SVs in *'all-digital'* substation automation applications. GOOSE is an event triggered type message that is sent when certain event like state change occurs; whereas, SV is time triggered and is sent as a continuous stream at a specified sampling rate. Since, the sampling frequency is very high (4000Hz for 50 Hz power system), the transmission of SVs over the digital process bus network results in a large amount of data, and hence occupies a significant portion of the communication channel bandwidth. For instance, In 100 Mbps network, the theoretical limit on the number of MUs is 22 (97.2 Mb/s) with a 50 Hz power system and 126-byte sampled value frames.

IEC 61850-5 [10] specifies a strict time performance requirements for the delivery of IEC 61850 messages, including the time critical GOOSE and SVs. The message transmission time depends on the type of the message and the application performance class. GOOSE (Type 1 A "Trip" messages) and SVs (Type 4 "raw data messages") for P2 and P3 applications must have a total transmission time below 3 ms. This transmission time involved the time taken to transfer the message from the publishers (MUs/NCITs at process level) to the subscribers (protection and control (P&C) IEDs at bay level). This must meet the 61850-5 acceptable maximum delay performance requirements under any network operating conditions, i.e., the transmission of these mission sensitive messages should not be affected by the presence of other (client/server) network traffic flows over the process bus network. Thus, the GOOSE and SVs messages have high priority, reliable, and safe transmission needs, and the benefits will not be realized if the performance of process bus network is inadequate [18].

The protection devices over a process bus network such as P&C IEDs, MUs, and Ethernet switches should support multicasting of time critical messages. GOOSE and SVs communication is based on publisher/subscriber mechanism, in which the publisher (IED or MU) multicasts or publishes the same message to all subscribed IEDs. Since, the time critical messages are directly mapped to data link layer 2, all IEDs and MUs should support Ethernet data link layer-2 multicasting capability. This can be achieved through Ethernet MAC (Media Access Control) source and destination addresses, which are defined in the Ethernet packet frame. Multicasting enables simultaneous delivery of the same information from the publisher to the several subscribed devices in its peer group, i.e., the same message need not be repeated several times to different locations. Thus, multicasting nature of GOOSE and SVs brings a significant reduction in the network traffic.

2.3 Challenges over Process Bus Network

The standard defines different types of communication services like client/server, GOOSE, SVs depending on their performance requirements. To support this, IEC 61850 follows a communication approach in which the abstract data models and services are mapped to real communication protocols such as MMS, TCP/IP, and Ethernet.

GOOSE and SV messages, as discussed in previous subsection, have real-time performance requirements. Thus to reduce the additional overhead caused by TCP/IP layers, GOOSE and SVs messages are directly mapped on

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the Ethernet link layer of ISO/OSI based seven layers communication stack. However, this elimination of TCP/IP layers reduces the reliability of packet transmission. Therefore, to enhance the transmission reliability of GOOSE, the same GOOSE message is repeated several times according to the IEC 61850-8-1 standard; whereas, the same SV is not repeated as they are time triggered and transmitted at sampling frequency rate (80 samples per cycle for protection applications); which reduces the transmission reliability of SVs over the process bus network. Thus, due to the low transmission reliability and large volume of SV traffic, there may be a loss or delay of SV packets over the process bus network [19].

III. QOS FEATURES OF SWITCHED ETHERNET TECHNOLOGY

As discussed in previous section, real time performance of process bus communication network is vital for the transmission of SV data from the conventional or NCITs to the bay level IEDs, and for the transmission of trip commands to the circuit breaker IEDs at process level by high speed GOOSE messages according to IEC 61850-8-1.Therefore, Network traffic management is critical in a process bus environment and this is often achieved through QoS features of switched Ethernet like priority tagging (IEEE 802.1P), VLAN (IEEE 802.1Q) and multicast addresses filtering of the Ethernet frames. Full duplex and collision free environment allow devices connected to the switch to simultaneously send and receive data without suffering collision. VLAN and multicast filtering allows the prioritization and segregation of network traffic, and also reduce the processing workload of IEDs as they have to process only those multicast frames they actually needed.

Also, substation and its communication architecture play an important role in maintaining high reliability, and availability of the power supply. Thus, a high performance SCN that supports the real time data transfer and others functionalities in SASs is crucial. Ethernet provides high flexibility regarding communication architectures, as well as incorporation of fast growing communication technologies. Ali *et al.* [20-22] proposed an Ethernet enabled fast and reliable SCN architecture for protection, control and monitoring of electric power substation. Recently, Ali *et al.* [23] proposed an innovative IEC 61850 SCN architecture for efficient energy system automation. Therefore, the development of Ethernet technology provides an opportunity to design new and innovative communication systems for power system protection applications.

Although these features enhances the transmission reliability of GOOSE and SVs messages, but they do not ensure the deterministic communication delays and packet loss on the network during worst case conditions. It is demonstrated that the SV loss at the protection relay can have some kind of measuring blackout for the entire measuring window, and hence SV packet loss/delay may have an adverse impact on protective relaying [24-25]. Thus, it is important to investigate the feasibility of process bus network for implementing substation protection systems under different dynamic power system conditions. References [26-27] investigate the performance of process bus SVs and GOOSE communication based *‘all-digital’* substation protection applications through laboratory implementation. Now the following section will discuss the major impact of process bus communication on substation performance.

IV. MAJOR IMPACT OF PROCESS BUS ON SUBSTATION PERFORMANCE

The process bus offers several benefits over traditional hardwired analog circuits in implementing substation automation and protection applications. Since, process bus utilizes fiber optic communication media and also facilitates the implementation of optical/electronic based NCITs at the process level. It brings overall cost reduction and flexibility in performing substation operations. The integration of substation data through merging unit enables to replace a number of instruments transformers at the process level by a fewer ones to achieve lower installation, maintenance and transducer costs [28-31]. It eliminates costly and complicated RTUs in substation that needs to be configured manually and has high maintenance cost.

The selection of conventional CTs/PTs and protection equipment in the design of protection and control schemes in conventional substations must take into consideration the resistance of cables and also faced the issues of reduced reliability and performance due to CT saturation, failures in the cables and open CT problems. Thus, process bus resolves the issues related to conventional instruments transformers, and hence improves safety at substations.

Further, process bus provides an accessibility of any process data such as SVs, binary status and control signals to any IED at the bay level in IEC 61850 SAS. By applying this new standard, an integrated protection system can be established. Thus, simple wiring and signal flexibility in the substation architecture provides tremendous opportunities for the substation designer to enhance distributed P&C substation applications. Directional comparison faster bus protection schemes, breaker failure protection, distributed waveform recording during abnormal conditions in a network, recording of system parameters variations for planning studies in power system are some process bus based applications, that bring significant benefits in terms of high reliability, flexibility and security, for power grid operations[32-34].

V. CONCLUSION

This paper has presented an important extract of the major features possessed by IEC 61850-9-2 process bus communication and investigated its impact on the design, operation and performance of IEC 61850 substation automation systems. IEC 61850-9-2 process bus offers several benefits such as reduction in overall losses, savings in overall life-cycle cost, new and improved functionality in designing modern SASs. Also, it has been identified that the deployment of real-time communication services, i.e. GOOSE and Sampled Values (SVs) over the process bus network have made a strong impact on the design, operation, reliability and performance of innovative '*all-digital*' distributed substation protection applications.

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