Switchgear Optimization Using IEC 61850-9-2 and Non-Conventional Measurements

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1. Introduction

With the introduction of the IEC 61850 standard, substations are moving into a new era of communication. All manufacturers can adapt their products to the same communication model and protocol, enabling the IEDs of different manufacturers to “talk with each other” and thus interoperate on the same station bus, replacing all previous proprietary protocols.

Driven by the new standard, substation communication bus architectures based on the Ethernet technology started to replace existing substation bus solutions based on the serial communication. The IEC 61850 standard defines the topologies and architectures to be employed in communication of devices in a substation automation system. The standard also includes the related system requirements and the underlying data model to be obtained the required substation functions. The standardized data modeling of substation functions including the communication interfaces pave the way to open infrastructures and interoperability of devices. The unique features of the IEC 61850 standard include self-describing intelligent electronic devices (IEDs) and a standardized Substation Configuration Language (SCL) which allows system engineering in a multi-vendor system where different IEDs are interoperable with each other.

IEC 61850 also includes a standard GOOSE (Generic Object Oriented Substation Event) service in the 8-1 profile for fast real-time communication between the IEDs. Additionally, the standard includes the communication between high voltage apparatus and IEDs, the so called process bus using the 9-2 profile. These profiles enable designing substation communication in a novel and flexible way to make the IED process data available to all other IEDs in the local network in a real-time manner. The GOOSE service has a high requirement in communication performance and the process bus has high requirements both on performance and bandwidth since it is used to transfer continuous sampled analogue values (SAV) from the primary process measurement to the IED using the measurement data.

Figure 1. Typical medium voltage switchgear

This paper presents an advanced usage of the IEC 61850 standard in a medium voltage switchgear, such as in Figure 1. The paper focuses on how to utilize the IEC 61850-8-1 and 9-2 profiles in combination of non-conventional instrument transformers. Also a full utilization of redundant communication networks and applications are considered.

2. Using IEC 61850-8-1 and 9-2 in medium voltage substation

The overall architecture of the substation network using IEC 61850 is rather straightforward. As shown in Figure 2 the system is divided into three levels. SCADA system interface and substation controller reside in the station level. Additionally, this level can be equipped with a separate station gateway which relays information between the substation and operator's network control center. SCADA and gateway functionality can also be integrated into the same device in the station level. From this level the operator executes remotely or locally control sequences to operate the underlying power network.

Protection and control IEDs are on the bay level. Today's modern IEDs also enable integrating both protection and control functionality into same IED but it is also possible to separate different functionality to different IEDs.

Process interfaces to high voltage apparatus are on the process level. Besides the conventional signal wiring between the process interface and IEDs, IEC 61850 introduces substation automation concept where data using local area network (LAN) can be exchanged between the devices interfacing process and devices utilizing process information. The Ethernet network is used in this case as a transport media for different type of process signals.

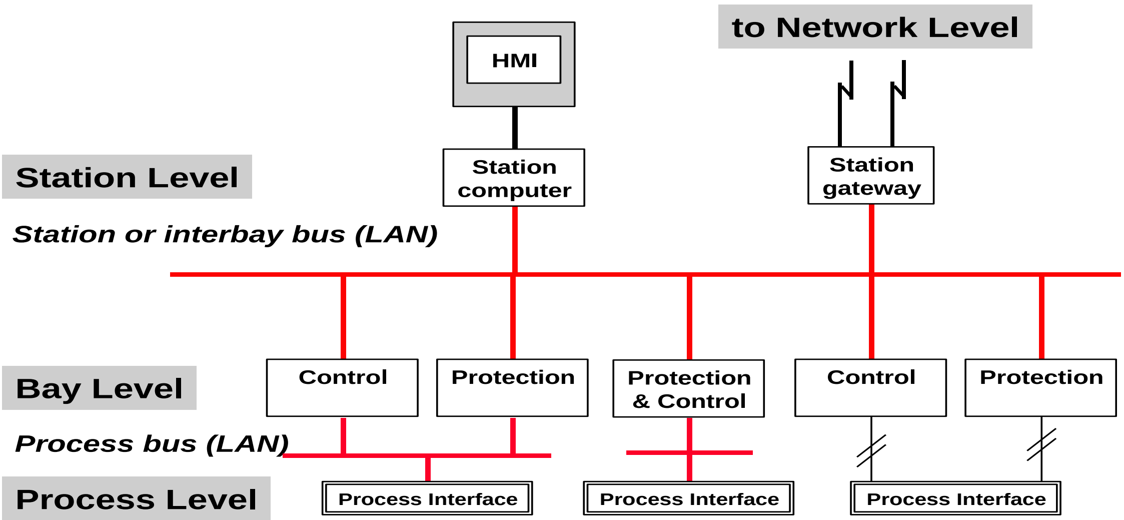

Figure 2. Overview of IEC 61850 system architecture

As in the bay level IEDs are sharing the same station bus it is today possible to replace the traditional galvanic wires and transmit signals between the IEDs in the station bus using horizontal communication. Today IEC 61850 GOOSE is used in increasing way in substations for sharing e.g. tripping, control interlocking, protection blocking or calculated measurement type of signals in a multitude of applications. The usage of GOOSE offers several advantages, for example reduced material costs in the switchgear, functional flexibility and improved performance. These advantages are explained further in several different articles and papers [2, 3].

Using Ethernet for process interfaces in the process level generally offers several advantages. First of all the usage of the process bus reduces the wiring between process interface and IEDs. The usage also enables the possibility to use safe fiber optic cable between the process and IED instead of a bundle of galvanic wires. It also gives flexibility for application and installation as the signals can be shared over LAN between all devices connected to the process bus. Changes in application do not require necessarily physical re-wiring which increases also operational safety and decreases the time required for modifications.

When using the IEC 61850 8-1 and 9-2 profiles in the station bus and process bus the same redundancy principles exists for both bay and process levels. In a fast Ethernet network same signals can be used by several IEDs which can e.g. employed for building application redundancy. This is possible as the IEDs publish GOOSE and SAV data in Ethernet multicast or broadcast messages to the local network. Communication redundancy can be built if the IEDs have two or more physical communication interfaces and are utilizing communication redundancy protocol.

In case of a long distance between digital process interface of primary equipment and station bus IED it is clearly beneficial to utilize communication fibers. This can be utilized e.g. for transformer and generator temperature supervision in medium voltage distribution substations. In high voltage transmission substations most of the process interfaces are in a separate room or in a switch yard, and thus substation design can hugely benefit from the usage of IEC 61850 in the process level.

In this paper we call the device sending current and voltage measurements as 9-2 sampled values a Merging Unit (MU). Further, we call the device sending process status values and receiving output commands using 8-1 or 9-2 profile to I/O interface Remote I/O (RIO). Both functionalities can be also combined into a same device enabling a true single process interface IED.

3. Implementation of advanced IEC 61850 usage in medium voltage substation

In a medium voltage substation the arrangement of the IEC 61850 system architecture is typically rather simple as the process level primary equipment resides in the same switchgear cubicle as the bay level IED. In this case it is not convenient to build a separate process bus for I/O and measurements. Instead the bay level protection and control IED I/O interface is utilized directly locally. In some cases it is possible to use separate RIO devices to supervise e.g. transformer which is located outside of the switchgear. Also if the bay level IED I/O interface is not sufficient it is possible to use RIO IEDs for additional remaining signals and transmit the signals using GOOSE to the main IED.

When considering today’s typical structure and design of a medium voltage switchgear few existing main trends can be seen. First, the usage of single busbar type setup is used in a majority of the installations. Faults in a busbar are today very rare and in the medium voltage level a double-busbar arrangement is mainly used in critical locations. Typically, the switchgear has two feeders to different bus sections which are separated by a bus coupler (figure 3). Secondly it is foreseen that the usage of non-conventional instrument transformers (NCIT) is increasing instead of conventional current and voltage transformers. NCIT’s, measurement sensors, have several advantages compared to the conventional instrument transformers, e.g. accuracy, costs, foot print, linearity and safety. The latest trend is the advanced usage of the IEC 61850 communication in the station bus. The advanced use of today means the full utilization of the GOOSE horizontal communication to all signaling between the IEDs in the bay level.

Using the above mentioned trends in a medium voltage substation, the end user gains benefits with decreased costs and accurate protection functionality. However, there is a possibility to further optimize the usage of the medium voltage switchgear with sensor technology and IEC 61850.

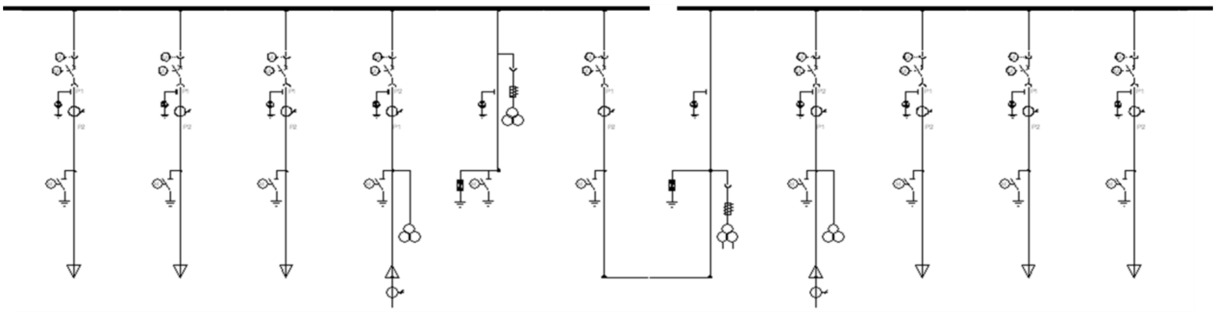

Figure 3. Single busbar switchgear arrangement.

The remaining issue with the sensor usage is the measurement of voltages in each bay in case a voltage based protection is also required. The currents are measured in each incoming and out-going feeder but in principle the voltage measurement is only required from one location of the bus section. When the sensors are used either the low-level voltage signals are shared with separate signal cables from one bay to others or each bay has both voltage and current sensors (combisensor). In both cases the installation costs rise due to the complex hard-wired switchgear signaling or the need of both NCIT types.

To overcome the increased costs when using sensors a further usage of IEC 61850 can greatly help. The next step in the IEC 61850 usage introduces the utilization of the 9-2 profile in a medium voltage substation station bus. As described earlier the IEDs require in multitude of protection and control applications voltage values from one point of the busbar. When applying the 9-2 publisher functionality to incoming feeder and to outgoing feeders the 9-2 subscribing functionality it is possible to share the busbar voltage value between all IEDs using the common station bus. In this communication scheme the incoming feeder sends voltage values to other IEDs in the station bus and the outgoing feeders are only measuring the currents locally (figure 4).

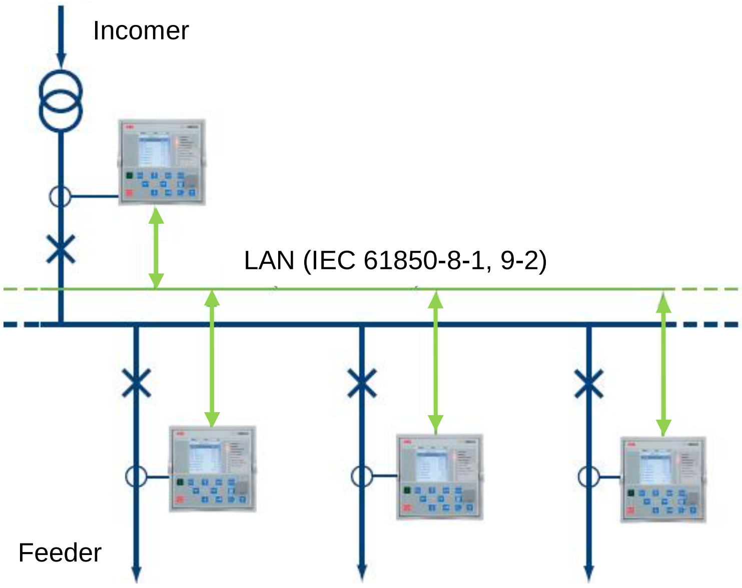

Figure 4. Shared Ethernet network for station and process bus

With this setup it is possible to minimize the amount of needed sensors in switchgear and transfer all signaling using common IEC 61850 station bus thus greatly simplifying the switchgear design. In this scheme the 9-2 publishers have both current and voltage sensors and subscriber's current sensors only. IEDs work at the same time as bay level IED's and process level MU's.

4. Usage of 9-2 in medium voltage substation

As discussed earlier economically the most convenient way to utilize the 9-2 profile sampled values in a medium voltage substation is to combine both station bus and process bus into the same Ethernet network. In the link layer the most common technology used in the substation Ethernet is the deterministic switched network with 100 Mb fiber optic cables (100FX). This is a suitable bandwidth for today's applications. In the published IEC 61850 edition 2 part 8-1 also 1Gb interfaces in the IEDs are foreseen which will enable further possibilities in applications using Ethernet station and process bus.

The IEC 61850 standard provides a framework for how the 9-2 profile can be used but leaves the exact details open to vendors. To enable a simple interoperability between the vendors the UCAIug (Utility Communications Architecture International Users Group) Implementation Guideline 9-2LE (lite edition) uses two different sampling rates for the Merging Unit; 80 samples per cycle for protection applications and 256 samples per cycle for power quality analysis and recording applications. For the application referred in this paper a single publisher of SAV is used, which leaves a plenty of space to communication network bandwidth for other types of communication services, e.g. FTP, MMS and GOOSE. These services do not consume, even in disturbance situation, considerable part of available bandwidth in 100 Mb network. It is expected that the IEEE 802.1Q VLAN (Virtual LAN) tagging and priorities are used in the Ethernet network to restrict the broadcasting of the SAV frames and to give sampled values the highest priority. Multicast filtering in the Ethernet switches is also one technique which can be used to limit the broadcasting of SAV frames.

The calculated network bandwidth consumption for the single 9-2LE publisher, sending 80 samples per nominal cycle in 50Hz power system, is 5.3 Mb/s. Theoretically 18 SAV publishers could exist in maximum. This case does not leave room for other communication services and in the other side it is too low amount of MUs for larger protection applications, e.g. busbar protection. An optimal solution considering distribution protection applications is in utilizing lower sampling rate. The IEC 61850 standard part 9-2 does not define a particular sampling rate and in this paper also a lower sampling rate is proposed in addition to defined in 9-2LE.

The 9-2LE sampling rate of 256 samples per nominal is defined to be a packed frame with 8 samples in each frame sent 32 times per nominal cycle in 50Hz power system. For described application of sharing voltage values through the shared network it is sufficient to send a single sample of 32 times per nominal cycle. The generated network load of such SAV publisher in 50Hz power system is 2.1Mb/s. With this sampling rate 100Mb network can theoretically have up to 47 SAV publishers without compromising required accuracy in the distribution automation applications (table 1). With this sampling rate THD (Total Harmonic Distortion) and harmonics spectrum can be supported up to higher harmonics covering the typical needs for power quality applications in the distribution automation.

Samples per cycle	Sample Rate in 50Hz power network frequency (sample/s)	Bandwidth consumption (Mb/s) of single SAV publisher	Bandwidth consumption (%)
256	12800	12,5	12,5%
80	4000	5.3	5,3%
32	1600	2.1	2.1%

Table 1. Different SAV rates vs. Ethernet bandwidth consumption

To further optimize the sampling rate and network load it could be possible to pack the samples to the same SAV frame. When sending 8 samples in one frame four times per nominal cycle it is possible to minimize the generated overhead of the Ethernet frames and the total amount of sent SAV frames.

In the application described in this paper one IED consists of protection and control part including IEC 61850 MMS and the GOOSE profiles with parallel of MU publisher or subscriber functionality. This IED uses the same analogue input samples for protection and to publish voltage values for other IEDs in station bus to subscribe to. In case the IED internal hardware and firmware introduce delays for value sampling, the delays need to be compensated in the samples before sending as described in 9-2LE. Other IEDs are configured to receive samples and utilize values in the application as they would be coming locally from physical inputs. The delay of the total communication path between the publisher and subscriber must be kept minimal in the IEDs measurement chains and in the network as it introduces an additional delay to the IED protection application (figure 5). The network is not an issue in a modern closed switched Ethernet with mentioned bandwidth consumption for the application of sharing sampled voltage values.

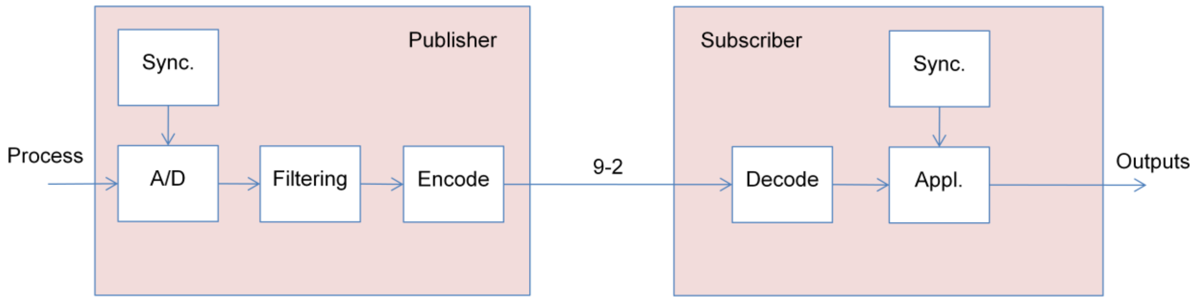

Figure 5. IED block diagram for the 9-2 handling

As defined in IEC 61850-9-2 the user defines a dataset with four currents and four voltages which is sent in each SAV frame. In the application of sharing of voltage values it is possible to reduce the size of the SAV frame and include only voltage values. To be interoperable to the 9-2LE dataset definition current values can anyhow be included but in the used application the subscriber does not utilize the current values in the application as the current values are sampled from the IED local physical inputs.

To achieve the required sample accuracy +/- 4us, 9-2LE defines an accurate 1PPS time synchronization method. This is widely available, however, in modern Ethernet +/-1us time synchronization accuracy is also achievable with using IEEE 1588 Precision Time Protocol (PTP). With today’s station bus network accurate time synchronization mechanism can be taken into use in efficient way as no separate network or wiring is not required. IEEE 1588 includes also support of redundant clocks which increases the availability for critical service. If the grand master clock fails it is also possible for the selected IEDs to work as master clock [5].

To further increase the availability of the application a redundant Ethernet communication can be established. The most cost-efficient way to do this is the HSR protocol which is referred in the IEC 61850 edition 2. With HSR a bump-less redundant Ethernet ring is built between the IEDs. Every IED has two Ethernet ports being able to forward traffic not belonging to it (figure 6). To achieve the IEEE 1588 time accuracy requirement all IEDs must include the IEEE 1588 transparent clock functionality.

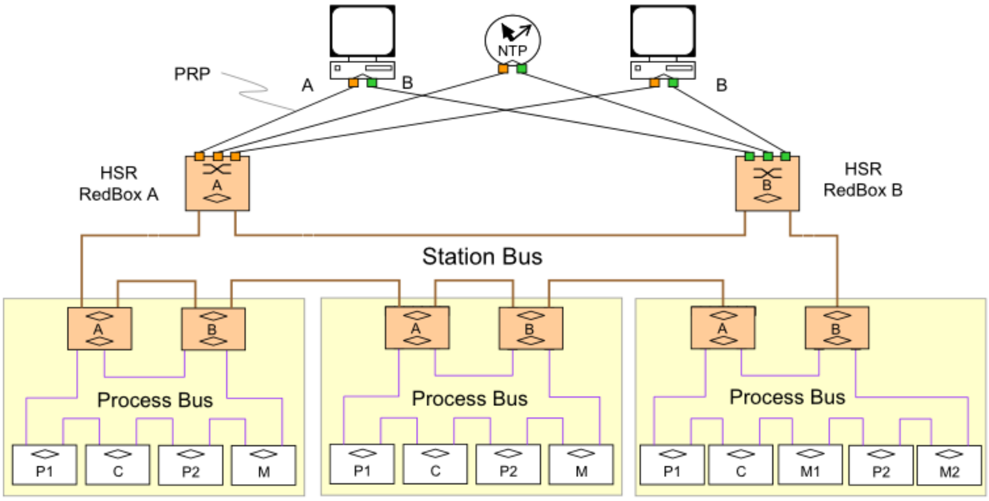

Figure 6. HSR network

What must be considered in HSR is that it in practice it halves the available bandwidth of 100 Mb/s to 50 Mb/s as all frames are sent two times to network. This is not an issue in the application described in this paper as there is only one SAV publisher. In future with 1Gb networks the bandwidth utilization with higher sampler rates and multiple SAV streams in combined process and station bus is not foreseen to be an issue in the substation local networks.

In critical implementations it is additionally possible to utilize two different 9-2 streams in a redundant way. This means that the voltage values from the busbar are sampled and published from two locations and in case one publisher is not available e.g. for maintenance, the application switches automatically to other available stream. In this way also the application redundancy is achieved. Also if the busbar is divided with a bus coupler it is possible to receive samples from the SAV source from other side of the bus coupler in case it is switched on and the original incoming feeder is not active.

4. Conclusion

With the IEC 61850-8-1 and 9-2 profiles cost-efficient solutions can be established with the sensor technology, as hardwired signal paths are replaced by a single LAN network, also in case of voltage measurements.

Utilizing IEC 61850 provides signalling performance, speed which can be faster than in traditional hardwired system. Additionally, it provides increased operating reliability of the protection through continuous supervision of the communication and the data integrity of the GOOSE and SAV messages.

Furthermore, flexible protection schemes can be implemented through software configuration rather than hardwired signal paths. This makes the system easily extendable and on demand reconfigurable to meet the needs of protection system changes as well as changes in the substation configurations and network topologies.

5. References

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