Next step in IEC 61850:
Large applications and process bus applications

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ABSTRACT

Over the past few years, IEC 61850 has made its way into substation technology at a previously unknown pace. Today modern communication technology makes it possible to connect up to 200 devices or more with one another with full functionality, thereby enabling effective automation of substations.

IEC 61850 not only standardizes the transmission of communication, but offers a comprehensive solution that includes a complete substation data model and its own language for simplified engineering. One part of IEC 61850 which has thus far not been realized to a significant extent is the process bus, which is used to transmit digitized converter data to a protection device. Compared to the relatively slow data on the station bus, here data streams can be transmitted in a manner comparable to audio streams on the Internet while at the same time fulfilling high requirements for redundancy. This article will discuss the requirements and properties that must be taken into account when using this technology.

INDEX TERMS

IEC 61850, communication, trends, process bus, real time Ethernet, substation.
Introduction

After its passage in 2004, IEC 61850 enjoyed a triumphant welcome in the world of substation automation. As of today, over 500 installations in use worldwide demonstrate the wide acceptance of this series of international standards. However, use is related in almost all cases to the station bus, which networks the substation controller with field and protection devices. Over time the installations have grown larger and larger. In 2004 only 5-10 IEDs would communicate with a substation controller; nowadays there are installations with more than 200 IEDs in some cases, which don’t just communicate with several computers in the substation control center, but also directly with one other.

IEC 61850 Station Bus

The basis of all IEC 61850 communication is 100 MBit Ethernet and related protocols. Two types of communication are used in the station bus:

- Point-to-point communication with TCP/IP
- Multicast communication on Ethernet Layer 2

TCP/IP is a protocol in which a supervised connection is set up between two devices, making sure that in the case of network dropouts telegrams are repeated and the connection is monitored for availability. This is accomplished in the > 100 ms range and is absolutely adequate for commands, messages and fault recording. Network components of Ethernet, also called Ethernet switches, are able to recognize the paths of this communication and prevent the messages from being disseminated outside these paths.
IEC 61850 uses this type of communication from the IED to the substation controller and vice versa.

In the case of multicast communication on Ethernet Layer 2, a method generally known as Generic Object Oriented Substation Event (GOOSE) is used. In this case, a device sends a signal simultaneously to several consumers. The consequence of this multicast function, however, is that the Ethernet switches do not prevent the unrestricted dissemination of these messages. Additional measures are necessary to control the dissemination and impact of the messages in the network in a meaningful way.

**Use of multicast filters in the station bus with large installations**

In fact, with GOOSE the dynamic repetition of messages makes sure that the time intervals between repetitions of the same information become greater and greater (in the end they are in the range of seconds). As a result, this network load does not have an impact on installations of a normal size.

With substations having 100 or more IEDs, however, this can no longer be disregarded and careful structuring of the network is advisable along with the use of multicast filters in network transitions where applicable.

**Multicast filtering in the device**

At 100 MBit/s, GOOSE messages do not normally play a crucial role in the overall network load. However, there could be problems with devices that do not have integrated, dedicated multicast filters for filtering out undesired messages. With such a device, each GOOSE message generates an interrupt of its main process, regardless of whether or not the message is intended for the device. This is not established until the corresponding interrupt is processed, which in extreme cases can lead to a situation where the main process is blocked by interrupts.

Shrewd IEC 61850 manufacturers have connected appropriate filter mechanisms in series to circumvent this effect.

**Multicast filtering in the switch**

With larger installations, substructures are normally formed, which are allocated to the primary installation structure of voltage levels, areas and switch panels. On the one hand, this allocation is used for a step-by-step commissioning, and on the other hand, one should make sure that communication of the devices among one another with Goose can remain within such a subsystem as much as possible. In this case, there is the possibility of blocking these multicast addresses in the couplings points or the coupling switches to the backbone bus thereby preventing the uncontrolled spread of GOOSE messages to the entire network.
This can be accomplished selectively, i.e., GOOSE messages that are higher order can pass through these filters. However, this goes hand in hand with a certain parameterization effort by the creator of the system, who must be familiar with the functioning of multicast filters, and set and document them correctly.

Automatically setting multicast filters to the Ethernet Layer 2 that is key for GOOSE is currently not available. It is not clear yet to what extent the GMRP protocol will gain acceptance in the area of substation automation as compared to manually setting the few multicast filters.

**VLANs as an alternative?**

Using so-called virtual LANs (VLANs) is another possibility for separating the load. In this case, the ports of the switches are assigned to specific connection circuits (virtual networks).

This is not reserving bandwidth in the overall network, however. It is only meant to protect terminal equipment from undesired message traffic, like (in the other direction) denying the terminal equipment access to other virtual networks. (In this case, filtering in the terminal equipment itself would not be necessary.)

Thought through to the end, however, the interfaces of the switches to the terminal equipment would also have to be able to be simultaneously cleared for several VLANs in order to, e.g., receive GOOSE messages from one VLAN, but also to be able to communicate with the substation controller at the same time. But this controller in turn should not receive any GOOSE messages.

Thus, even though using VLANs also solves the multicast problem, it requires very involved project planning, and therefore it offers no advantage over multicast filters with respect to disconnecting the communication load.
IEC 61850 Process Bus

Part 9-2 of IEC 61850 describes how sampled values can be transferred, as a replacement for a conventional analog interface, by what is known as Merging Unit via an Ethernet network to protection devices. In addition, the process bus also contains other components that are connected there because they are part of the primary technology.

These are for example the CBC (Circuit Breaker Controller), DSC (Disconnector Controller) and the monitoring devices that are all defined in IEC 62271-3.

They should all cooperate in a system and be used near the primary devices.

CBC, DC and monitoring can be addressed via GOOSE or transmit their data via TCP/IP; sampled values are by definition in Part 9-2 Multicasts similar to GOOSE, but as a constant data stream.

The sampling frequency in this case is 4 or 4.8 kHz (50/60 Hz). Sampling frequencies of up to 16 kHz or more are provided for demanding tasks. However, with respect to GOOSE, the transmission of sampled values has a completely different dimension with regard to communication network load.

While, in the case of GOOSE, in a stationary case (no change in status), a message is sent every second, the sampled values generated by a merging unit from conventional or non-conventional converters are a continuous data stream, which, in the case of a 4 kHz sampling rate according to Part 9-2 LE (“Light Edition” of UCA International) represents a load on the network with up to 6 MBit/s.

As a result, it is absolutely necessary for the process bus to be separated from the station bus with respect to sampled values.

On the other hand, the ability for a lot of data to pass through to the higher-order system must be retained; it must be possible, for example, to transmit the monitoring data from a transformer or a circuit breaker to an evaluation PC.

The requirements for the process bus are as follows:

- High environmental requirements for the terminal equipment (electromagnetic compatibility, temperature, shock, where applicable) in the area of the primary system
- Adequate bandwidth for several SV data streams
- Highly prioritized trip signals for transmitting from the protection device to the CBC
- Permeability of data to the station bus/data filtering at the coupling point
- Simultaneous TCP/IP traffic for normal control and status signal traffic as well as reports on the process bus
- Download/upload channel for setting or parameterizing functions
- Highly precise time synchronization
- Redundancy

Equipment with process bus capability

In addition to the strict requirements with regard to temperature and electromagnetic compatibility, the communication interface must also have process bus capability. Naturally, it must be able to process the data from several SVs in a timely manner. However, the multicast filters described above should be integrated in order to keep the device from being prevented from executing its original task because of too many message interrupts.
Network components with process bus capability

The same high requirements and loads with respect to environmental conditions apply to the network components in just the same way as they do to terminal equipment. A continuous fiber optic structure should be provided from the primary system to the substation control center. Regarding the required resistance to thermal shock on the connections of switching devices, the connection technology of the MTRJ plugs currently available will develop in the direction of compact LC duplex plugs. The advantage of these plugs as compared to stable ST plug technology, which is also available, is that a plug incorporates both direction fibers, and the send and receive directions cannot get mixed up.

Bandwidth is an important subject because of the high load from the constant SV data streams. One of the solutions is using central switch components having gigabit capability. In this case, all devices are coupled point-to-point with the central switch, which can provide full gigabit power internally. The SV and GOOSE messages that are identified by priority tagging (802.1p) are given priority with respect to routing over other messages such as file transfers based on TCP/IP. Since most messages are prioritized on the process bus, there is, however, a risk in the switches that the buffer for prioritized messages will overflow at some point. Even though transmission of sampled values may be delayed in the range of 1-2 ms, no dropouts may occur. Trip messages from the protection device to the CBC per GOOSE message should have a higher priority when this technology is used in order to be able to bypass the SV stream and land in a special buffer in the switch.

Another possibility for disconnecting the load is using virtual LANs (VLANs). However, as already discussed with respect to the station bus, only the terminal equipment interface is protected from overload in this case and parameterizing is very complicated.

Time synchronization and redundancy

IEC 61850-9-2 requires that the detection unit of the sampled values, commonly known as the merging unit, be synchronized precisely to 1 µs. Every second a counter having this precision is set to 0 and incremented for each sample. As a result, a protection device is able to produce the time coincidence from two SV data streams and execute corresponding calculations.

If a deliberately star-shaped FO infrastructure is established today for distributing 1pps signals, then in the next few years the use of IEEE 1588 will find its way into substations and provide precise 1 µs or better time synchronization via Ethernet. IEEE 1588 is a comprehensive standard, which must be used to develop a profile for use in substations. There is already a working group dealing with this subject in the IEEE PSRC (Power System Relaying Committee).

The prerequisite for use, however, is implementing this protocol in Ethernet switches and terminal equipment. Initial implementations have shown that synchronization with a precision of 20-30 ns per Ethernet switch (i.e., 60 ns for 3 switches in series) can be achieved.

IEEE 1588 is also used in the field of IEEE P802.1AS (Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks) and as a result, wide availability can be expected in the next few years.
In order to meet the n-1 criterion for the protection function, measures for redundancy must naturally be provided.

In maximum voltage switching stations, all converters, protection devices and the associated infrastructure are normally doubled. Of course, this is also easily possible for the process bus, whereby Devices A and B are divided between the two bus systems.

Another possibility is implementing two Ethernet interfaces in the devices and sending and/or receiving the messages twice. The redundant information will be rejected.

In this case, it is irrelevant whether the messages are transmitted over two lines (PRP protocol) or in ring redundancy (Profinet Isynchronous Real Time redundancy).

**What should the user do?**

There are many ways to reach this goal. Naturally, functioning configurations can already be established with a double Ethernet system in small installations with 100 MBit/s or GBit/s switches.

Time synchronization is only required if the protection really must correlate samples from two merging units. This is then possible with an extra 1pps FO structure (it should then be doubled). Entering the world of the process bus is then possible.

![Diagram of a process bus system](image)

**Figure 3: Use of real time Ethernet in the process bus area**

The approach of realizing a highly available system with redundancy, IEEE 1588 synchronization via the Ethernet as well as actually reserving bandwidth for sampled values and trip messages is extremely attractive both technically as well as economically, but only
possible with real-time Ethernet. In addition, such a system offers TCP/IP data transfer for parameter information via the same interface.

With Profinet isochronous real time (IRT), IEC 61784-2 (CP/3/6) already available as a prototype, it remains to be seen what effect future standardization in the field of Ethernet audio-video bridging (IEEE 802.1 AV) will have on automation technology in general and on process bus technology in particular.

The 50 or 60 Hz and the associated harmonics is the same as digitized music for electronics – but music with somewhat more power behind it.

References

[8] www.61850.com