REALISATION OF AN INTELLIGENT AND CONTINUOUS PROCESS CONNECTION IN SUBSTATIONS

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ABSTRACT

The rising digitization and subsequent use of IEC 61850 requires a flexible, network-based communication approach in the substations of electrical energy systems. However, the conventional process connection lacks flexibility and modularity when it comes to linking different devices. With the normal parallel-connected hardware a continuous engineering and consistent documentation in one tool is impossible. One of the resulting disadvantages is that modifications of hardware or communication must be handled in multiple documents.

The digitization allows more flexibility by regarding the connection of primary equipment and measuring values by using an Ethernet process bus. This process bus is realized as a new standard by using the communication standard IEC 61850, which defines a continuous engineering and documentation. In particular, it presents different requirements of the physical process bus approach. The novel process connection has to be magnetically resistant, continuously documented, comprehensible and modular in its structure.

This paper discusses different approaches that were developed in order to face the aforementioned challenges, while meeting present and future expectations and requirements. Furthermore, it describes a field-based star-topology process bus with different hardware approaches.

INTRODUCTION

The digitization has grown to be a major factor within the line of action of any distribution system operator. It allows capturing and processing large amount of data in order to build and operate an electrical grid effectively. [1] To this end, a multitude of new concepts need to be designed and implemented. This includes a new approach on data acquisition within the process level of the substations.

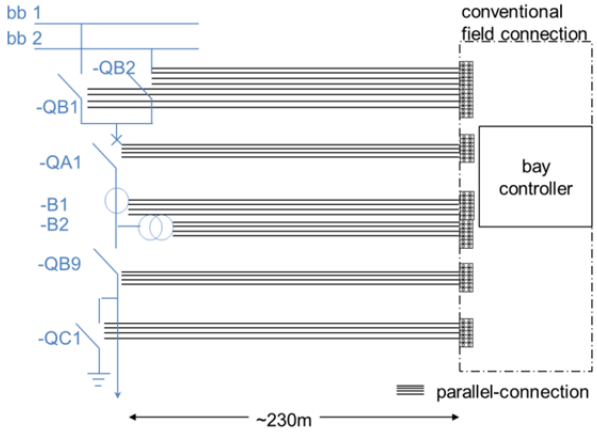

Figure 1: present process connection

Up until now the connection between the primary equipment and the conventional field control has been realized through parallel-connection, depicted in Figure 1. This classic concept neither provides flexibility nor modular expandability, which leads to additional effort and expenses for the integration of further functions and data. [2] To prevent the extra effort, a network-based approach seems appropriate. However, this approach must continue to ensure the functionality, maintainability and comprehensibility. Furthermore, currently there is no possibility to obtain a continuous overall documentation or engineering tool.

Within a research project of Westnetz GmbH all the relevant requirements regarding the process connection and the state of the art were taken into consideration. Hence, a whole concept was developed.

The contribution of this paper is the implementation of the IEC 61850 process bus. In addition, it offers further insights into the time synchronization and network utilization.

STATE OF THE ART

<u>The IEC 61850</u>

The IEC 61850 is a standard for the communication in electrical substation automation systems. The standard describes a continuous engineering process, general classifications, specifications for digital interfaces as well as the format for the exchange of information.

In particular, methods for fast sampled measured data (sampled values) and multicast message communications (GOOSE) are defined. [3, 4]
The consequent usage of IEC 61850 defines a separation into three layers, which leads to the definition of a station and a process bus (see Figure 2).

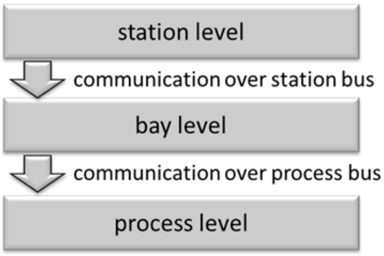

Figure 2: device levels and bus systems

The IEC 61850 is established as the best choice for the communication within the process bus, because its underlying object orientation is best suited to fulfil the requirements above. Therefore an adequate connecting medium and an appropriate structure for the IEC 61850 process bus communication need to be chosen. To this end, the requirements and boundaries of IEC 61850 setups have to be taken into account.

Practical guidelines or examples of a similar process bus realization do not exist yet. Nevertheless, other papers also discuss the process bus structure. For instance, a closed loop topology [5] and an overall star topology are evaluated. [6] Both topologies must also comply with the limitations of the standard, resulting in restrictions on the devices that can be used per field. However, from the authors point of view these implementations have different deficiencies, like the limitation, considering the direct implementation in substations.

So far, no comprehensive realization concept is known, which simultaneously fits the requirements of the IEC 61850 and of the substation configuration.

Connecting medium

Currently the Ethernet station bus is realized by copper wires or optical fiber cables.

In comparison with optical fibers, the copper wire connections have a high sensitivity to electromagnetic interference. Also, the possible transmission characteristic is lower than for optical fibers. However, this is no relevant disadvantage to date, since the current devices only support a 100 Mbit-network.

Optical fibers are characterized by a fast and secure data transmission, as they are insensitive to electromagnetic interference. Therefore, they are to be regarded as an ideal connecting medium for applications in power supply substations with a high degree of interference. [7]

Network topology

Different network topologies are currently being used in communication networks. One of the basic topologies is the mesh connected network. It is characterized by a direct communication links between all devices, which leads to low transmission times for any kind of data exchange. Still, it requires excessive effort and expenses for the installation and maintenance. [8]

Another topology is the ring or closed loop, where the communication partners are ganged using two-point connections. Hence, two communication interfaces are required per device, even though current devices provide only one. The high latency as well as the increased network load must be considered. In addition, the malfunction of one device will lead to a failure in the whole network. Therefore countermeasures, such as redundancies, must be used. [9]

The final topology to be considered is the star-topology. It is characterized by a central communication partner for all devices. A malfunction of one device does not lead to the failure of other devices. The network provides high transfer rates as well as a modular and easy expandability. This structure is well-suited for broadcast and multicast applications which are significant within the process bus. The increased probability of failure can be reduced by purposeful redundancies.

REQUIREMENTS FOR THE PROCESS CONNECTION

The main requirements are flexibility, expandability, ensured functionality, maintainability, comprehensibility, a complete documentation and adequate engineering tools. The entirety of these demands leads to a network-based approach, which gives rise to another set of requirements. Consequently, the network has to be insensitive against electromagnetic interference and the connections and configurations need to be documented continuously.

The process bus in substations should incorporate the integration of switching devices, circuit breakers and merging units. For a flexible recording of sampled values it is required that at least four merging units can be used simultaneously per field as well as the corresponding applications. An additional condition is that the communication must be reliable and expandable. The communication protocols used at the process bus level should be compliant to the already utilized protocols in the station bus, thereby synergies are generated.
Different specifications are required by the IEC 61850. One of them is the establishment of real-time

communication. Especially, the GOOSE and sampled values require a fast transmission time. It follows that a transmission time of less than three milliseconds must be ensured. Another demand is the precise time synchronization, which is mainly needed by the sampled values. [4,10]

Restricted by the network connections of the currently deployed and available devices, a network with a maximum 100 Mbps characteristic can be used. The IEC 61869-9 defines the maximum utilization of 24 measured values per 100 Mbps network. Otherwise, the network could be blocked due to excessive data traffic. [11]

CONCEPT OF THE PROCESS BUS

Exclusion of structures and connecting medium

First, some technologies, such as the copper wires, can be excluded due to the following reasons. Copper wires have a higher sensitivity to electromagnetic interference compared to the optical fiber cables and do not offer any advantages. Other connecting mediums, such as the power-line communication, were considered in the project, but are excluded due to their unreliability, their sensitivity to electromagnetic fields and the security risk of external attacks.

Furthermore, the mesh connected topology is precluded, as a result of a higher management and installation effort compared to the other structures. With regard to the IEC 61869-9 and the application in substations, the ring topology offers an insufficient number of connectable merging units (see „Requirements for the process connection“). Another exclusion criterion for this topology is the fact that an insufficient amount of devices with two network interfaces is available at the moment.

General description of the concept

A field-based star-connected process bus is defined and a fiber optic cable is chosen as the connecting medium on the process level, as it offers flexibility and a simple structure.

The communication protocols and the documentation is based on the IEC 61850. This ensures a standard overall documentation and a continuous data model. This leads to the fact, that Devices can be described with logical nodes (e.g Figure 3). The selected structure allows the extension and replacement of different devices and functions.

Furthermore, the concept realizes the n–1-rule by establishing a second process bus with the necessary protection functions and connections. While the first process bus uses a protection and control device, the second process bus only relies on a protection device. During normal operation the device in the first process bus takes over the control function, while the device in the second bus provides the protection function. If a communication or other kind of error occurs in the second bus, the protection and control device in the first bus takes over the protection functions (see Figure 3 or Figure 4).

At the moment, a redundant design of the control function is not necessary, due to the fact that the protection of the asset is ensured even without a functioning control system. Thus, the operation is allowed to continue in the short-term, while the malfunction must be corrected as soon as possible. If the operating concepts are changed, the redundancy of the control function can be implemented without much effort.

Conversion of existing substations with conventional primary equipment

The process bus can be designed modular as part of retrofitting work. For this purpose a protection and control device and a protection device with IEC 61850 support must be used. These devices are installed in the intelligent process processing (IPP), which is connected to the primary equipment by the redundant process bus systems, and are situated in the substation control building.

The measured values are connected to the bus system with stand-alone merging units (MU), while I/O-systems are being used to connect the switchgears and the circuit breaker. This secondary equipment is installed within the intelligent process connection (IPC) (see “Figure 3”) in the field. The redundant process bus includes the connection of the circuit breaker, the necessary measuring devices and the protection functionality.

The engineering methods described in IEC 61850 are applicable and lead to a continuous documentation in station bus and process bus up to the IPC.

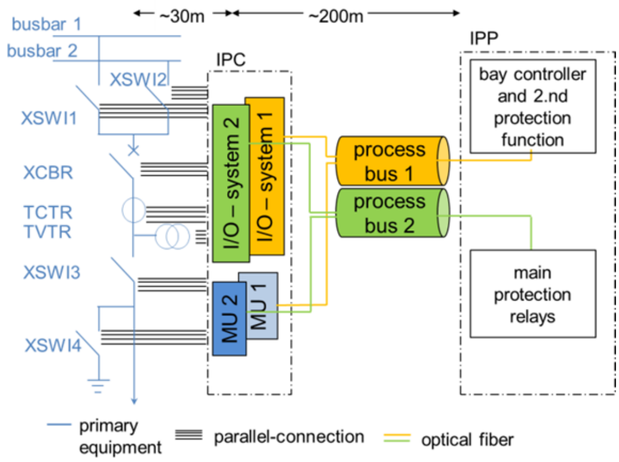

Figure 3: future process connection for old substations

This structure allows a staggered conversion to the intelligent substation. Within this process bus structure,

new functions and devices can be integrated with less effort than in the current system. Still, it may be necessary to make adjustments to the I/O-systems or to use additional stand-alone merging units.
It is also possible to replace conventional primary equipment and corresponding I/O-systems or merging units with non-conventional primary equipment. For instance, this leads to the potential of realizing an integration of measured values primarily with a stand-alone merging unit. As soon as the primary equipment is changed to a non-conventional instrument transformer the stand-alone merging unit is obsolete.

New substations with process bus

The concept of the process bus can be implemented directly and consistently during the construction of new substations. In this case two redundant process bus systems are being set up (chapter General description of the concept). The second bus only refers to the protective relevant elements, like the circuit breakers, measuring devices and protection relay.

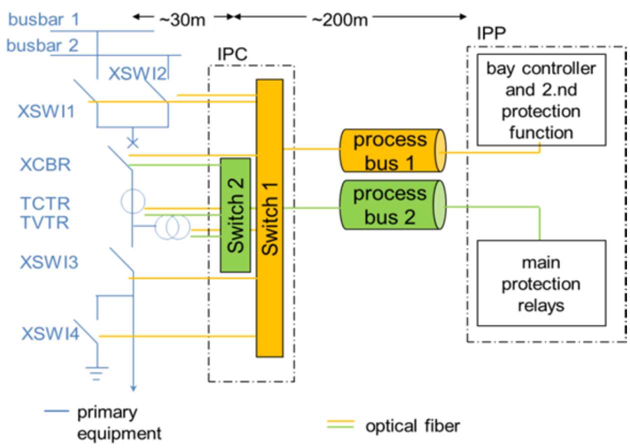

Figure 4: future process connection for new substations

This concept based on the usage of non-conventional converters and intelligent switches, which communicate directly over IEC 61850 on the process bus. Also the engineering methods described in the standard are applied. Hence, a continuous overall documentation with all connections and configurations is possible. The complete engineering of the station and process bus can be adapted with one tool.

The Ethernet network in combination with IEC 61850 allows a simple integration and configuration of new intelligent functions. The effort is limited to the connection of the required hardware and the configuration of the new function.

Advantages and requirements of the concept

The field-based star-connected process bus allows a fast and intuitive assignment of the devices and the communication. This helps to prevent errors due to confusion or the disregard of interactions. In the event of a fault, its spread onto other fields is prevented, since there are no connections between them within the process bus.

This separation also ensures that the maximum permitted number of measured variables is not exceeded. Therefore errors due to excessive network loads, which can result in malfunctions, are not to be expected. In the worst case, a significantly extended transmission time of GOOSE messages and sampled values can lead to permanently damaged primary equipment.
The use of the process bus does not require any change in the operation management. However, fully network-based communication simplifies the testing of decentralized control approaches. By providing the process data via multicast, no separate connection of the devices is needed and the systems can use all data on the process bus directly.

This new communication capability also ensures the foundation for the realization of new functions, such as the monitoring of transformers or a predictive maintenance, because new data can be recorded and made available to all devices easily.

VALIDATION

Within the scope of the research project, tests with different process bus approaches were carried out in the laboratory.

One result is that the first functional failures were already detected when using three merging units of different manufacturers, which are communicating simultaneously over a process bus. One of the merging units had an error due to missing sample value packets. It could be ascertained that the merging unit had already been overloaded by reading the network traffic from the other two merging units. The usage of a ring-structure process bus would therefore lead to problems in any case since more than two merging units are used in a substation.

The selected star-connected process bus ensured the function due to the field limitation. However, this topology also assumes that merging units can be operated with at least two others in a network.
The selected concept of a field-based star-connected process bus was tested theoretically and also by the means of laboratory tests. On the basis of the comparison of the requirements and the theoretical realization possibility, as well as the results of the laboratory test, so far no weak points were recognized in the concept.

Furthermore, the use of the standard revealed that the documentation of the network components was not sufficiently considered before. Within the network components, different configurations must be installed which are not documentable with the current standard.

These include, for example, the management of time synchronization, usage of IEEE 802.1Q for VLANs and priority tagging.

For the planning of a substation, it is increasingly important to take into account that significant processing delays occur in the network elements. In the worst case, this can lead to an excessive long tripping time in the event of a failure and there by permanently damage the substation.

As it was noted in the laboratory tests, some of the devices react differently than others during increased network traffic. Therefore, additional information needs to be provided on how many devices can be used within a network without affecting performance.

Furthermore, the basic conditions must be designed in such a way that measured values are assigned to the right time points and are thereby correctly evaluated. This is particularly relevant for differential protection functions. A possible realization of time synchronization is described in IEC 61850-9-3 (May 2016). Also, from the edition 2.1 of IEC 61850-9-2 (September 2016 CDV status), additional information on the clock ID is provided in the sampled values stream in order to prevent sample values from being synchronized by different clocks. The current work in this area shows that these aspects are of high relevance.

CONCLUSIONS AND OUTLOOK

Due to the digitization and subsequent need for a process bus, an increased use of network technology in substations is necessary. In compliance with the state of the art, logical network segmentation has to be utilised. This disburdens the communicational interfaces of the devices and simultaneously provides increased security. The need for configuration results in the demand of a documentation of network components within the IEC 61850, which should be extended accordingly.
The developed intelligent process bus provides a clear, state of the art solution, which enables the simple integration of new functions due to its modular structure and the object oriented data model. This ensures that installed components, including conventional and unconventional primary technology, can be easily replaced by new ones in the future. By combining these aspects a sustainable and functional concept is achieved.

The novel process connection is made magnetically resistant by the use of optical fibers and the IEC 61850 supports a continuous documentation and engineering. Due to the field based star-connected process bus, the comprehensibility and modularity of the system is enhanced.

Based on the findings of the research project, two solutions were developed. The first one represents the adaptation of the results for existing primary technology, employing merging units and an I/O-system. The second solution represents the consistent implementation of the IEC 61850 on process bus level, by combining innovative primary equipment, like intelligent switches and unconventional converters. It signifies a new trend for future substations and acts as a basis for future technologies.

The implementation of the field-based star-topology process bus discussed in this paper is currently being planned within a large research project at Westnetz. Through this further proceeding the use of these forward-looking technology under real conditions should be verified. First results are expected by 2018.

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