Communication Technology in Substations - Actual Developments from the View of Testing

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The Triumphal Procession of the Digital Communication Technology

The development of the technology during the last decades was essentially determined by the overwhelming success of digital signal processing and communication technologies. For example, the Audio-CD has almost completely superseded the LP. Another example, when making a telephone call, no longer does a "voice current" flow through directly switched wires, but sampled values are routed in data packets through a broadband network from subscriber to subscriber.

Also, the advanced protection test systems derive their universal usability and capabilities from digital signal processing.

On the other hand, the immediate benefit of digital signal processing is not always obvious. Listening to music was already possible with Vinyl-Recordings and phone-conversations could also be made with the analog telephone system. Why then the change to digital technology? The digital technology provides many additional benefits. Means for error detection and error correction lead to increased reliability and noise immunity, connections are established faster, and the utilization of the available bandwidth is optimized, etc.

It can be assumed that the benefits of digital protection relays were also doubted when they were first announced. Today, numerical relays are state-of-the-art technology and their advantages over electromechanical and static relays are undisputed.

Other applications, like mobile telephony became available to a large user community only through digital signal processing, the "mobile" phones with analog technology were too clumsy, and above all, much too expensive.

The list of examples could be extended as desired. Even if the technical arguments and benefits are doubted in some cases, in the end remains the cost argument, which brings the breakthrough for the digital technology.

The high complexity of digital systems is only a problem during the introductory phase. The users mostly remain unaffected by the inner, digital nature of the product, as they generally benefit from the above-mentioned additional functionality and the experts soon get new tools in their hand to master the new technology.

Possibilities for Applications in a Substation

Someone may ask, what do we need communication technology in a substation for? We can measure currents and voltages, transmit the values to the meters and protection devices, process them and issue commands via contacts and wires. It works this way also, and it works quite well.

In a today's substation, the transmission of measured values is performed mainly in analog and via hardwired connections. Situations like this scream to be investigated for possibilities to apply digital communication technologies.

Analog measured values are mainly transferred from the CTs and PTs to the meters and protection devices. In the future, unconventional CTs and PTs will be more commonly used. In these devices, a signal conditioning takes place that is generally performed by a processor and the data will be available in digital form anyway. So it makes no sense to convert the data again into analog values and then transfer them via the classical 120V (100V) / 5A (1A) interface.

Binary data are mainly issued as commands from protection devices or from feeder equipment (e.g. CBs) to signal their operating status. The transmission is done via relay contacts and hardwired connections.

The measured values from the CTs and PTs and the commands and status signals between protective devices and feeder equipment should be transferred in digital form in the future. They will be wrapped into data packets and interchanged over the *process bus*. The whole wiring between the devices is reduced to the network. This provides enormous savings in materials and efforts for installation and commissioning.

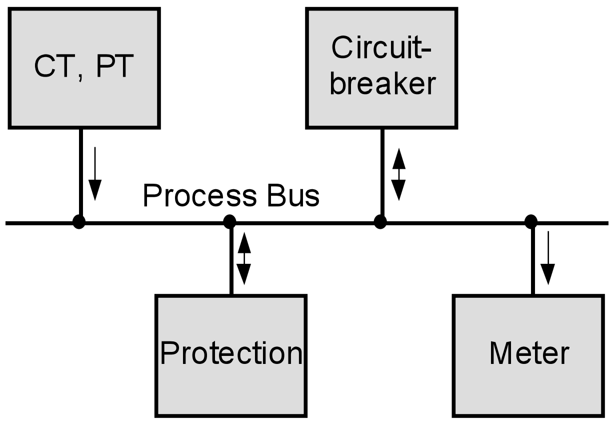

Figure 1: IEDs interchange all data via the process bus.

The meters and protection devices become fully electronic units, which communicate solely via the network interface with each other. To label devices of this kind, the expression *Intelligent Electronic Device* (IED) was introduced.

Special Requirements for Communication Technology in Substations

The application in a substation demands special requirements on the reliability of the used systems.

In voice telephony, a comparably high error rate can be accepted. A garbled word can be reconstructed from the context or can be repeated upon request. If a call is interrupted, it can be re-dialed and resumed.

Contrary to that, the stakes in a substation are really high; sanity, the well being of people and highly valued tangibles are concerned. The process values must be supervised without any interruption and the commands must be immediately transmitted and executed. Much effort and experience was necessary to adapt the current technology to these high requirements. A new system must first prove that it conforms to these special requirements at least as good.

In this context, Ethernet should be mentioned now. Ethernet is the technology on which the majority of the computer networks in use today is based.

The classic Ethernet has not been designed for real-time applications. Its behavior regarding time is, as experts call it, non-deterministic, therefore it is not possible to specify a guaranteed time response. Besides that, it is democratic; all devices on the net have same rights. But where clear priorities should be valid, democracy appears as anarchy. In the area of industrial process control, deterministic networks with hierarchical structures have been developed with considerable efforts to serve time critical and security relevant applications.

For these reasons, it was first doubted if Ethernet would be usable for applications in substations. Which protection engineer would question that his application is extremely time critical and security relevant?

It could even be argued that somebody who considers systems like Ethernet does not take these things seriously. The promoters of Ethernet in the substations had to face such reproaches. Today, those concerns are widely dispelled. Such discussions among experts satisfy the skeptics and are used as arguments for remaining at the status quo.

The Advantages of the New Technology

The classical technology is essentially based on the use of mechanical and magnetic components, both of which bring a lot of disadvantages with them.

Mechanical components, which in this case means mainly the output relays, have generally a higher failure rate than electronic components and work comparably slower. Mechanical output relays have a significant response time.

Magnetic components, which in this case mean the input transformers, are heavy, big, and expensive and influence the accuracy of the signal processing chain.

The input transformers and output relays consume most of the space in today's protective relay and because of their large masses, it is not so easy to mount them vibration proof, so that the device can conform to shock and vibration standards regarding like the IEC 60068-2.

With digital communication, the input transformers and output relays can be omitted. The construction of the devices is very much simplified.

The data become digitized once at the beginning of the processing chain and then they can be disturbance proof transmitted and processed with defined accuracy.

Actual Efforts

Because of the arguments stated above, many manufacturers have started the development of process bus systems or have at least begun to investigate them.

Vendor specific systems evolved out of this, which are also offered on the market. These are proprietary systems, also called legacy systems. Their drawback is the lack of interoperability; devices from different manufacturers cannot be combined with each other. This is, of course, a very undesirable situation for the user. As soon as he has decided to purchase a system from one vendor, he has to obtain all components from this vendor, including maintenance and service. The drawbacks of such a situation for the user are obvious and stand in the way of spreading the new technology.

UCA – Utility Communication Architecture

UCA is an initiative, which was mainly set up by utilities in the U.S.A. These utilities, as the users of future digital communication technology in substations, wanted to counteract the growth of proprietary systems in advance. For this, proposed standards were worked out to ensure the interoperability of devices from different vendors. In the meanwhile, some commercial available products evolved from this base.

The main items of UCA shall be repeated:

- It is an initiative of the users. Of course, the vendors are involved in the developments, but the future customers can determine the directions of the technical developments.
- No proprietary solutions must evolve. All devices must be interoperable.
- Wherever possible, currently available technologies should be used. This was one reason for selecting Ethernet as the transport network for the substation LAN and process bus.
- A fast realization of the developed standards should take place. During regularly scheduled *Interoperability Demonstration Meetings*, the vendors come together to test the interoperability of their devices.

Two essential concepts have been worked out under the rule of UCA:

GOMSFE (Generic Object Model for Substation Feeder Equipment) is a collection of objects, which model the elements of substation devices with their parameters. All vendors make the data of their devices available in the same way. One program, the *Object Browser,* can then be used for setup and supervision of all devices.

GOOSE (Generic Object Oriented Substation Event) is a data packet with 96 digital status signals. For example, such a packet carries a trip command. The packets are transmitted from the sending device without specifying a distinct receiver (*Broadcast* or *Multicast*). This method requires no configuration of the data stream. The potential receivers have to listen to the packets on the network, filter out the data relevant for them, and to react accordingly on their own.

IEC 61850

The IEC has undertaken steps on their own, to bring communication technology in substations to standardization. The technical committee number 57 (TC 57) works on the standard IEC 61850. This standard is divided into ten parts, which can be roughly summarized as follows:

- Part 1 to 4: Glossary, General, Basics
- Part 5: Communication requirements
- Part 6: Configuration
- Part 7: Communication networks and systems
- Part 8 and 9: Specific communication service mappings (SCSM)
- Part 10: Conformance Testing

As can be easily seen from the above list, the approach of the IEC is essentially more comprehensive than UCA and covers also the transmission of digitized measured values from CTs and PTs to IEDs. Anyhow, IEC 61850 is not opposed to UCA, even contrary, UCA will be built into the IEC standard at the respective places. This way, GOMSFE will incorporate parts 7-3 and 7-4, the transport mechanism defined in UCA will merge into parts 7-2 and 8-1.

In Germany and in the Netherlands, research projects (OCIS, PINOCIO) have been performed with participation of utilities, vendors and scientific institutes. During this, also deterministic bus systems were investigated along with Ethernet as proposals for part 8 of the standard, but these options are now out of discussion. What remains is part 8-1, which has been taken over from UCA.

By this, Ethernet as network for the process bus has established itself also in the IEC standard. However, for many applications the use of Fast Ethernet (100MBit/s) can be foreseen. For guiding the data streams and therefor reducing the collisions, the use of switches is proposed for many applications. Future versions of Ethernet will also offer possibilities for priorization. With this, a controlled time behavior can be achieved, admittedly for the price of the necessary efforts for configuration.

The activities regarding the transmission of digitized measured values to IEDs as described in part 9-1, especially in connection with non-conventional CTs and PTs could show practical effects quite soon.

IEC 61850-9-1 uses the *Universal Data Set* (UDS), a data frame which has been taken from the standard IEC 60044-8 and which contains the sampled values of the currents and voltages in the three phase network. The CTs and PTs itself are connected to a so-called *Merging Unit* (MU) which collects the data and transfers them via Ethernet to the IEDs.

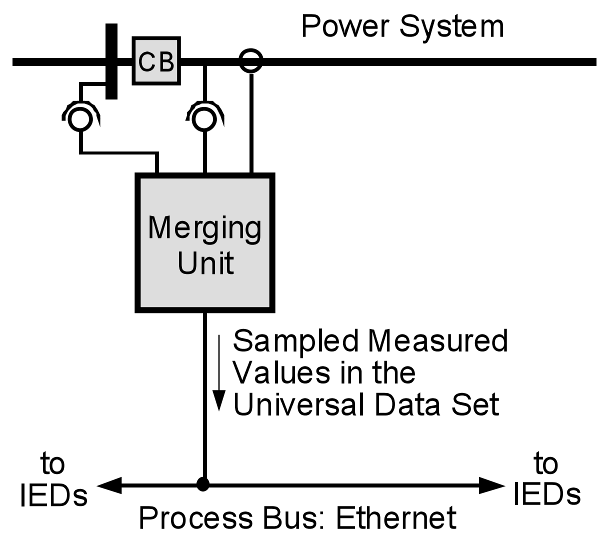

Figure 2: The Merging Unit collects the data from the CTs and PTs and transfers them via Ethernet to one or more connected IEDs.

The first products on this basis have been already announced.

Two Worlds

As in many cases where ideas from different parts of the world come together, a competitions of ideas and cultures also takes place in this field.

Different focuses can be seen with the American and European promoters of the initiatives.

The Americans follow a straightforward philosophy: Keep it Simple! The focus is on a quick implementation of real products by using existing, wide spread technologies (Ethernet). Concentration is aimed on actual problems, which have to be currently addressed. UCA stresses more upon binary signals and measured quantities. Under this condition some products have already been developed and are on the market.

The Europeans strive for comprehensive coverage, also of future applications. Flexibility, configurability, and object orientation are guidelines. A big importance is placed on the transmission of real-time data; the related developments in the laboratories make the most progress into this direction. Products are announced, but are not yet available.

Effects on Testing

Advanced test system manufacturers observe with great attention the development of the standards and the appearance of related products. What matters the most in the future is to support the users with high quality test equipment.

For the products already in the market in significant numbers, which are IEDs according to the UCA standard, a test solution has been already developed. It is a protection test set with an Ethernet interface, which can receive and evaluate GOOSE messages.

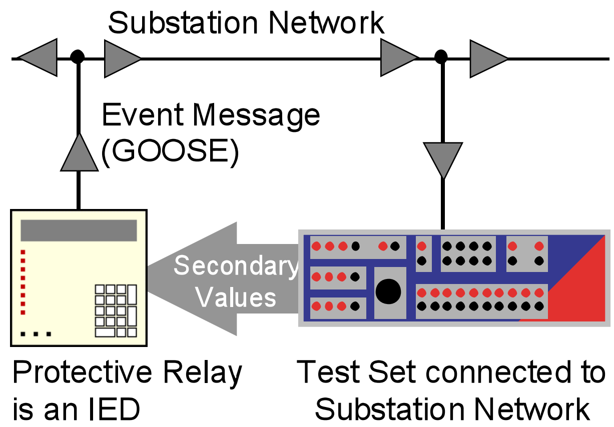

Figure 3: Protection testing with IEDs. The protective relay sends the trip command in a GOOSE packet via the network.

At the last Interoperability Demonstration at the end of May 2001 in Vancouver, these devices attracted great interest.

The software architecture of the presented system allows using the status information filtered out of the data packets like binary inputs. The test programs are not aware of the real origin of the binary signals. This provides two significant advantages:

- all present test modules are also available for testing UCA relays.
- the users can still work with the same test programs; the training effort for entering the new technology is minimal.

This test solution is currently only offered by a single test system manufacturer which again confirms its technology leadership by this.

The consequent development of the test systems assures the user the support for his test tasks in the future