IEC 61850 9-2 Process Bus: Basics, Applications and Benefits

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1 Introduction

The IEC 61850 standard Communication Networks and Systems for Utility Automation allows utilities to consider new designs for substations applicable for both new substation and refurbishments. The levels of functional integration and flexibility of communications based solutions bring significant advantages in costs in all stages of a project. This integration affects not only the design of the substation but almost every component and/or system in it such as protection, monitoring and control by replacing the hardwired interfaces with communication links. Furthermore the design of the high voltage installations can be reconsidered regarding the number and the location of switchgear components necessary to perform the primary function of a substation in a high voltage network. The use of high-speed peer-to-peer communications using Generic Substation Event (GSE) messages and sampled values from non-conventional or conventional sensors allows the development of distributed applications. In addition the use of optical local area networks leads in the direction of copper-less substations.

The paper focuses on the definitions of communication busses such as the station bus for the communication at the station level and between bays as well as the process bus for the communication between the high voltage process and components interacting with it. It analyses the substation communications architectures in substations with full implementation of IEC 61850, i.e. with station and process bus.

The different types of devices required for this communication architecture are described. The paper analyses the main functional modules in a conventional microprocessor relay and compares it with the implementation of protection functions in IEC 61850 based systems with distributed analogue values. Merging units that provide the interface between the current and voltage sensors and the intelligent electronic devices at the equipment, bay or substation level are described. The distribution of signal and data processing functions between the different devices for both architectures are analysed.

Some specific substation applications based on Sampled Analogue Values are described later in the paper and demonstrate the advantages of the new technology. Improvements in functionality, combined with practical elimination of performance or safety issues are covered in the paper

2 Conventional Substation Design

Conventional substations are designed using standard design procedures for the high voltage switchgear in combination with copper cables for all interfaces between primary and secondary equipment.

Several different types of circuits are used in the substation:

- Analogue (current and voltage)
- Binary – protection and control signals
- Power supply – DC or AC

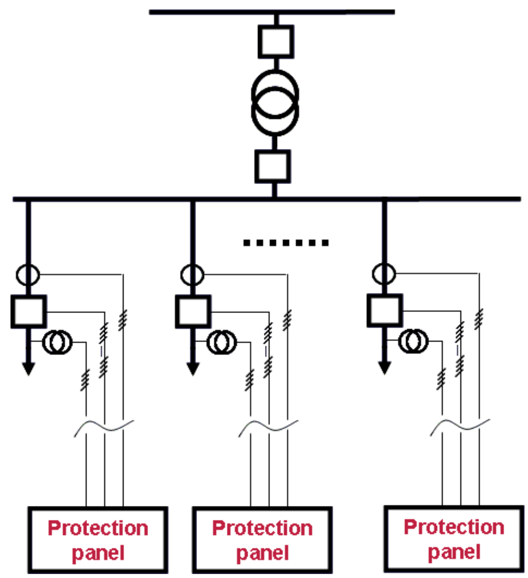

Fig. 1 Conventional substation design

Depending on the size of the substation the location of the switchgear components and the complexity of the protection and control system there can be a huge number of cables with different lengths and sizes that need to be designed, installed, commissioned, tested and maintained.

A typical conventional substation has multiple instrument transformers and breakers (Figure 1) associated with the protection, control, monitoring and other devices being connected from the yard to a control house with the individual equipment panels. The different types of cables described are used for the connections.

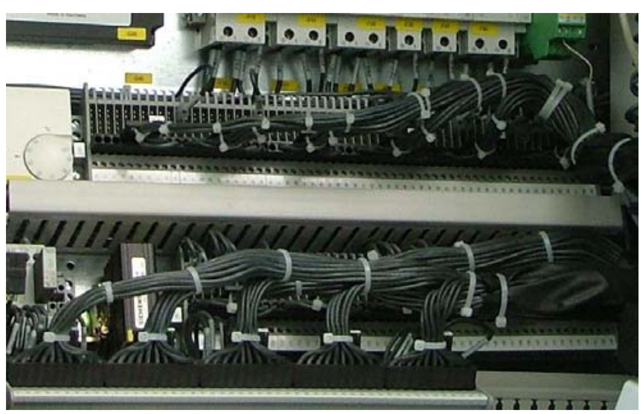

Fig. 2 Substation panel wiring

As can be seen from Figure 2, cables are cut to a specific length and bundled, which makes any required future modification very labour intensive. This is especially true in the process of refurbishing old substations where the cables insulation is starting to fail.

The large amount of copper cables and the distances that they need to cover to provide the interface between the different devices exposes them to the impact of electromagnetic transients and the possibility for damages as a result of equipment failure or other events.

The design of the conventional substation needs to take into consideration the resistance of the cables in the process of selecting instrument transformers and protection equipment, as well as their connection to the instrument transformers and between themselves. The issues of CT saturation are of special importance to the operation of protection relays under maximum fault conditions.

Failures in the cables in the substation may lead to misoperation of protection or other devices. In some cases, such as an open CT circuit they represent a safety issue, especially when it occurs while the primary winding is energized. The induced secondary e.m.f. under these circumstances can be high enough to present a danger to people's life and equipment insulation.

The above is definitely not a complete list of all the issues that need to be taken into consideration in the design of a conventional substation. It is intended only to provide some examples that will help us better understand the impact of IEC 61850 in the substation.

In order to take full advantage of any new technology, it necessary to understand what it provides. The next part of the paper gives a short summary of some of the key concepts of the standard that have the most significant impact on the substation design.

3 IEC 61850 Substation Hierarchy

The development of different functions in the substation protection and control system is possible only when there is good understanding of both the problem domain and the IEC 61850 standard. It does not only define how data is communicated between functions in the substation, but also describes the functionality of the substation in an object-oriented approach. The concept of distributed functions is one of the key elements of the standard that allows for utilities to rethink and optimize their substation designs.

A function in an IEC 61850 based integrated protection and control system can be local to a specific primary device (distribution feeder, transformer, etc.) or distributed and based on communications between two or more IEDs over the substation local area network.

IEC 61850 defines several ways for data exchange between IEDs that can be used for different forms of distributed applications. They introduce a new concept that requires a different approach in order to define the individual components of the systems in substations.

As discussed earlier, the existing designs are based on hardwired interfaces between the high voltage equipment – transformers, breakers, instrument transformers, etc. and the rest of the substation devices.

Considering the requirements for the reliability, availability and maintainability of functions, it is clear that in conventional systems numerous primary and backup devices need to be installed and wired to the substation. The equipment and the equipment that they interface with must then be tested and maintained.

The interface requirements of many of these devices differ. As a result specific multi core instrument transformers were developed that allow for accurate metering of the energy or other system parameters on the one hand and provide a high dynamic range used by e.g. protection devices.

With the introduction of IEC 61850 several different interfaces have been defined that can be used for various substation applications using dedicated or shared physical connections - the communications links between the physical devices. The allocation of functions between different physical devices defines the requirements for the physical interfaces, and in some cases may be implemented into more than one physical Local Area Network (LAN).

The functions in the substation can be distributed between Intelligent Electronic Devices (IEDs) on the same, or on different levels of the substation functional hierarchy – Station, Bay or Process.

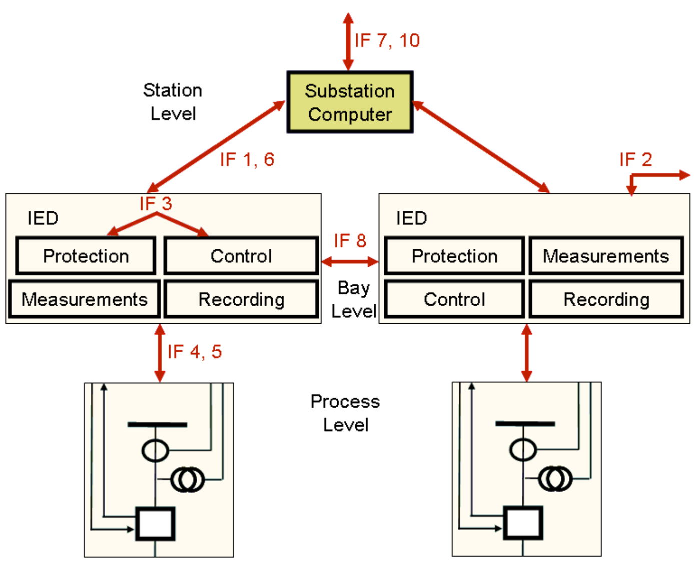

Fig. 3 Logical interfaces in IEC 61850

These levels and the logical interfaces are shown by the logical interpretation of Figure 3. The logical interfaces of specific interest to distributed applications based on process bus are defined [1] as Interface **IF4**: CT and VT instantaneous data exchange (especially samples) between process and bay level. A significant improvement in functionality and reduction of the cost of integrated substation protection and control systems can be achieved based on the IEC 61850 based communications as described below.

4 IEC 61850 Process Bus

Non-conventional instrument transformers with digital interface based on IEC 61850-9-2 [3] (Process Bus) result in further improvements and can help eliminate some of the issues related to the conflicting requirements of protection and metering IEDs.

The interface of the instrument transformers (both conventional and non-conventional) with different types of substation protection, control, monitoring and recording equipment is through a device called a Merging Unit. This is defined in IEC 61850-9-1 as:

"Merging unit: interface unit that accepts multiple analogue CT/VT and binary inputs and produces multiple time synchronized serial unidirectional multi-drop digital point to point outputs to provide data communication via the logical interfaces 4 and 5".

Existing Merging Units have the following functionality:

- Signal processing of all sensors – conventional or non-conventional
- Synchronization of all measurements – 3 currents and 3 voltages
- Analogue interface – high and low level signals
- Digital interface – IEC 60044-8 or IEC 61850-9-2

It is important to be able to interface with both conventional and non-conventional sensors in order to allow the implementation of the system in existing or new substations.

The Merging unit has similar elements (as can be seen from Figure 4) and can be considered as the analogue input module of a conventional protection or other multifunctional IED. The difference is that in this case the substation LAN performs as the digital data bus between the input module and the protection or functions in the device. They are located in different devices, just representing the typical IEC 61850 distributed functionality.

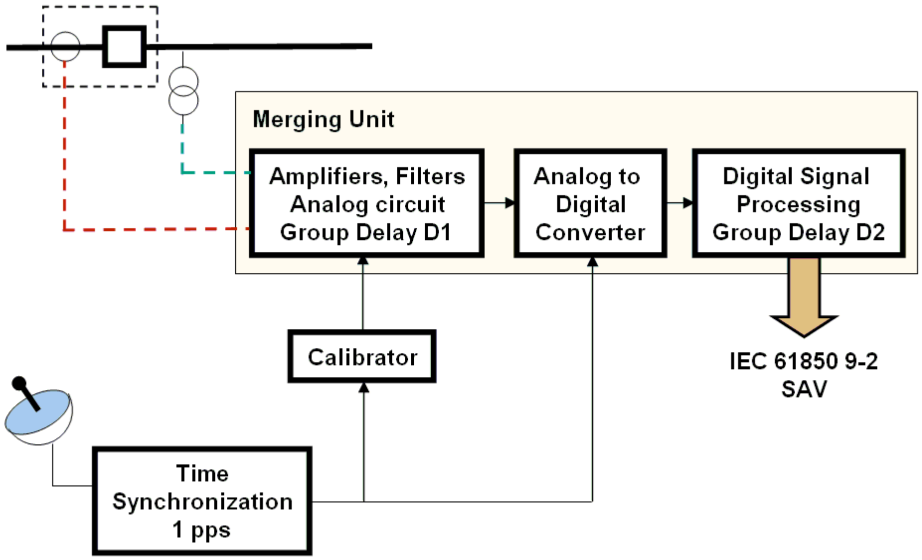

Fig. 4 Merging unit

There are several important differences between the data sampling in a microprocessor based relay and the process bus as defined in IEC 61850:

- While in the relays the sampling is controlled by the IED and is usually using frequency tracking, in IEC 61850 all interface or merging units are time synchronized with accuracy better than 1 microsecond and use a fixed number of samples per cycle at the nominal frequency
- The sampled values in the IED are exchanged directly between the A/D converter and the processor, while in IEC 61850 they are transmitted using typically multicast from the merging unit (publisher) to all IEDs (subscribers) that need these sampled values

Interoperability between merging units and protection, control, monitoring or recording devices is ensured through documents providing implementation guidelines. Two modes of sending sampled values between a merging unit and a device that uses the data are defined. For protection applications the merging units send 80 samples/cycle in 80 messages/cycle, i.e each Ethernet frame has the MAC Client Data contain a single set of V and I samples. For waveform recording applications such sampling rate may not be sufficient. That is why 256 samples/cycle can be sent in groups of 8 sets of samples per Ethernet frame sent 32 times/cycle [2].

The sampled analog values model applies to the exchange of values of a DATA-SET. The difference in this case is that the data of the data set are of the common data class SAV (sampled analogue value as defined in part IEC 61850-7-3). A buffer structure is defined for the transmission of the sampled values that are the output from the instrument transformer logical nodes TCTR and TVTR (Figure 5).

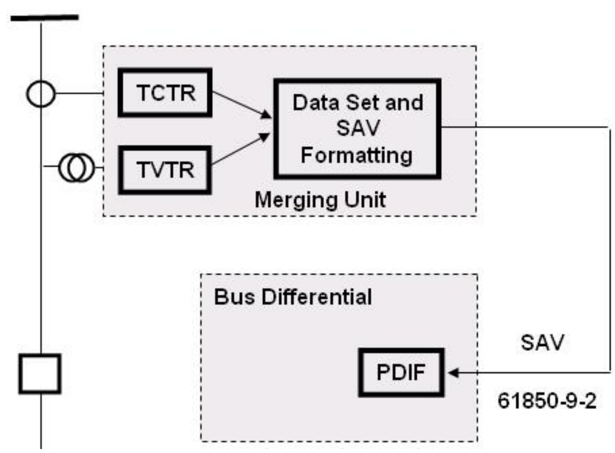

Fig. **5** Bus differential based on Sampled Analog Values

The information exchange for sampled values is based on a publisher/subscriber mechanism. The publisher writes the values in a local buffer at the sending side (see Figure 5), while the subscriber reads the values from a local buffer at the receiving side. A time stamp is added to the values, so that the subscriber can check the timeliness of the values and use them to align the samples for further processing. The communication system shall be responsible to update the local buffers of the subscribers. A sampled value control (SVC) in the publisher is used to control the communication procedure.

The currents and voltages from TCTR and TVTR accordingly are delivered as sampled values over the substation LAN. In this case the network becomes the data bus that provides the interface between the instrument transformer logical nodes and the different logical nodes that are used to model the functional elements of the IED.

Depending on the specific requirements of the substation, the user can design it with different communications architectures as described in the next section of the paper.

5 IEC 61850 Substation Architectures

IEC 61850 is being implemented gradually by starting with adaptation of existing IEDs to support the new communications standard over the station bus and at the same time introducing some first process bus based solutions. The specifics of the two types of systems are described in the following two sections of this part of the paper.

Station Bus Based Architecture

Full advantage of all the features available in the new communications standard can be taken if both the station and process bus are used.

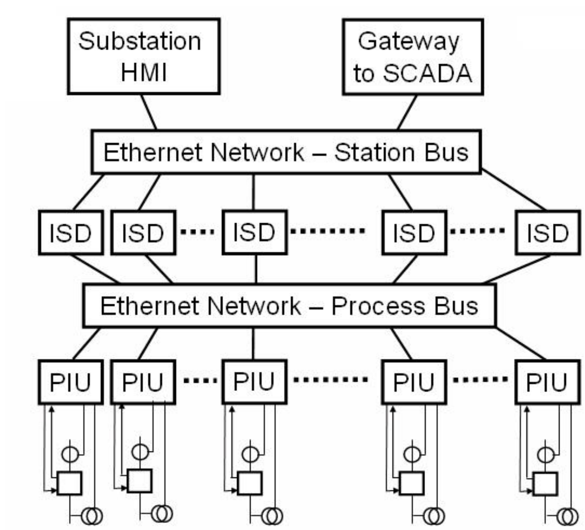

Fig. 6 Station and Process bus functional architecture

IEC 61850 communications based distributed applications involve several different devices connected to a substation local area network as shown in the simplified block diagram in Figure 6.

A Merging Unit (MU) will process the sensor inputs, generate the sampled values for the 3 phase currents and voltages, format a communications message and multicast it on the substation LAN.

A binary input/output unit (IOU) can be used to monitor the status of the breaker and trip or close it when necessary based on the GOOSE messages it receives from the different IEDs.

The merging unit and the input/output unit can be combined in a single device – a process interface unit (PIU) as shown in Figure 6.

All multifunctional IEDs will then receive sampled values messages and binary status messages, the ones that have subscribed to this data then process the data (including re-sampling in most of the cases), make a decision and operate by sending a GSE message to the IOU to trip the breaker or perform any other required action.

Figure 7 is an illustration of how the substation design changes when the full implementation of IEC 61850 takes place. All copper cables used for analogue and binary signals exchange between devices are replaced by communication messages over fibre. If the DC circuits between the substation battery and the IEDs or breakers are put aside, “copper-less” substation is a fact.

The next possible step when using station and process bus is the optimization of the switchgear. In order for the protection, control and monitoring functions in a substation to operate correctly several instrument transformers are placed throughout the high voltage installation. However with the capability to send voltage and current measurements as sampled values over a local area network it is possible to eliminate some of these instrument transformers. One example is the voltage measurements needed by distance protections. Traditionally voltage transformers are installed in each outgoing feeder. However if voltage transformers are installed on the busbar, the voltage measurements can be transmitted over the local area network to each function requiring these measurements. Such concepts are not new. In conventional substations this can also be realized but it would require large amounts of cables and auxiliary relays limiting or even eliminating the benefit of having less voltage transformers.

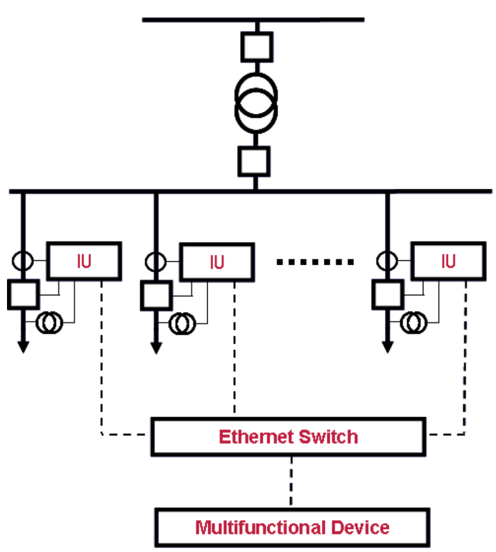

Fig. 7 Substation design with process and station bus

6 IEC 61850 Process Bus Benefits

Process bus based applications offer some important advantages over conventional hard wired analog circuits. The first very important one is the significant reduction in the cost of the system due to the fact that multiple copper cables are replaced with a small number of fiber optic cables.

Using a process bus also results in the practical elimination of CT saturation because of the elimination of the current leads resistance. Traditionally the CT knee-point voltage is a function of the resistance of the different components of the current circuit:

$$V_K = f\,(R_{CT}, R_L, R_{RP})$$

Where:

V_K = Required CT knee-point voltage (volts)

R_{CT} = Resistance of the current transformer secondary winding (ohms)

R_L = Resistance of a single lead from relay to current transformer (ohms)

R_{RP} = Impedance of a relay phase current input

In some cases R_L is multiplied by 2 and plays a key role in determining the CT requirements.

In this case the CT secondary is connected to the phase current inputs of the Merging Units and R_L is practically equal to zero. The knee-voltage then will be only dependent on

$$V_K = f\,(R_{CT}, R_{RP})$$

The impedance of the merging unit current inputs R_{RP} is very small, thus resulting in the significant reduction in the possibility for CT saturation and all associated with it protection issues.

Process bus based solutions also improve the safety of the substation by eliminating one of the main safety related problems - an open current circuit condition. Since the only current circuit is between the secondary of a current transformer and the input of the merging unit is located right next to it, the probability for an open current circuit condition is very small. It becomes non-existent if optical current sensors are used.

Last, but not least, the process bus improves the flexibility of the protection, monitoring and control systems. Since current circuits can not be easily switched due to open circuit concerns, the application of bus differential protection, as well as some backup protection schemes becomes more complicated. The above is not an issue with process bus, because any changes will only require modifications in the subscription of the protection IEDs receiving the sampled analogue values over IEC 61850 9-2.

Fig. 8 IED Station and Process Bus interfaces

7 Testing of Process Bus Based Devices and Systems

The testing of devices and systems based on IEC 61850 process bus requires a new range of tools that can be used to test the different components of such solutions.

The testing requirements depend on the functionality that is being tested, as well as on the purpose of the test:

- Type or acceptance testing
- Integration testing
- Factory acceptance testing
- Site acceptance testing
- Maintenance testing

A range of tools and simulators are required to perform these test. The configuration of the test relies on the ICD, CID and SCD files defined in the standard.

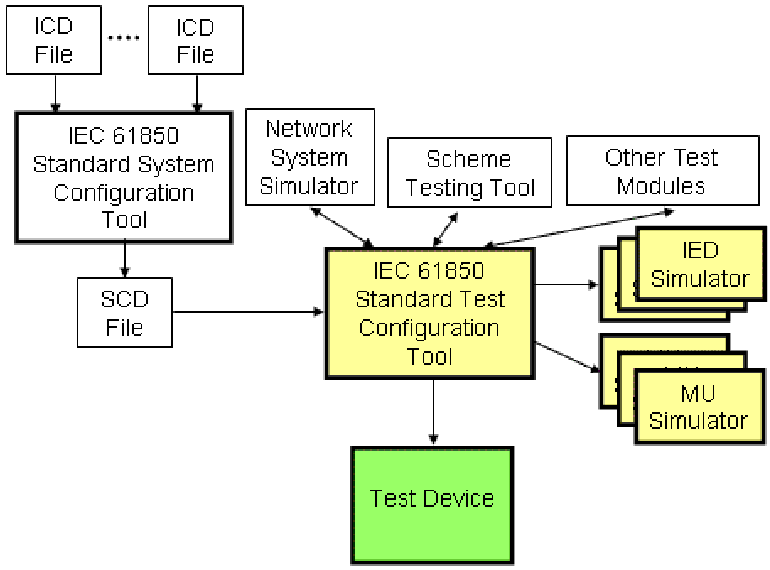

Fig. 9 IEC 61850 test configuration process

Figure 9 also shows the Merging Units simulators required in the case of testing of IEDs with process bus implementation of IEC 61850.

A network simulator, a state sequence simulator or scheme testing tool can be used to produce the sampled values with a sampling rate of 80 samples/cycle or 256 samples/cycle as required by the type of device or function being tested. The test device formats the Ethernet message according to IEC 61850 9-2 LE and publishes the sampled analog values over the network for testing.

Testing of devices with hybrid or full implementation can be combined with the testing of a merging unit. In this case the analog signals from the test device will be hardwired to the Merging Unit. The process bus based function will be performed by the IEC 61850 based ISD that will send a GOOSE message to an IO Unit that will operate a relay output to control the process (trip the breaker).

The test device monitors different elements of the distributed function and can analyze their performance, as well as the overall function operating time.

When the multifunctional ISD with the tested function operates, it will send a GOOSE message to the interface unit that will control the process. The test device will subscribe and capture this message and also detect the operation of the binary output of the interface unit.

The difference between these two times can be used to calculate the required time to send a GOOSE message over the network, process it in the interface unit and operate the binary output. The test setup will look like the block diagram shown in Figure 10.

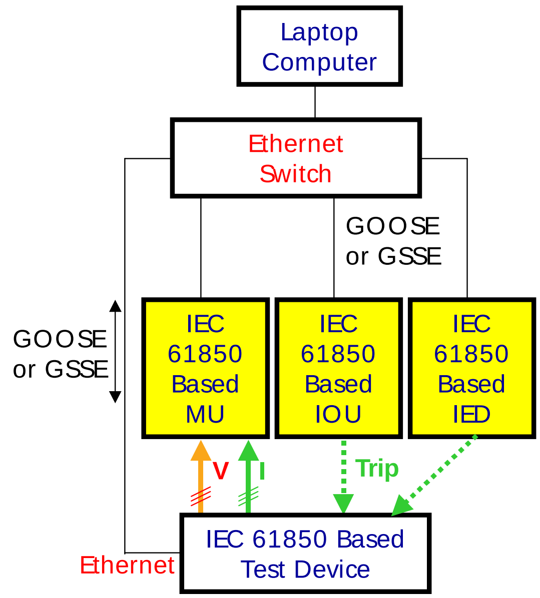

Fig. 10 IEC 61850 process and station bus test setup

If the tested IEC 61850 based IED also has a binary output, the test device can monitor it as well. This can provide valuable information in the overall performance evaluation process.

The testing of the merging unit (MU) in this case will require comparison between the analog signal waveform applied to it and the IEC 61850 9-2 LE messages sent by the merging unit. The test device needs to subscribe to these messages and perform the comparison and evaluation. It should include not only the accuracy of representation of the waveform, but also any phase shift that may be the result of the processing of analog signals in the MU The time stamps of the sampled values will be used for this purpose. Accurate time synchronization of both the test device and test object is essential for the testing of the merging unit.

8 Conclusions

IEC 61850 is a communications standard that allows the development of new approaches for the design of new substations and refurbishment of old ones. A new range of protection and control applications results in significant benefits compared to conventional hard wired solutions.

It supports interoperability between devices from different manufacturers in the substation which is required in order to improve the efficiency of microprocessor based relays applications and implement new distributed functions.

Sampled Measured Values communicated from Merging Units to different protection devices connected to the substation Process bus replace the copper wiring between the instrument transformers in the substation yard and the IEDs.

Such systems provide some significant advantages over conventional protection and control systems used to perform the same functions in the substations:

- Reduced wiring, installation, maintenance and commissioning costs
- Optimization possibilities in the design of the high voltage system in a substation
- Easy adaptation to changing bus configuration in the substation and practical elimination of CT saturation and open circuit

References

[1] INTERNATIONAL STANDARD IEC 61850-9-1, Communication networks and systems in substations – Part 9-1: Specific Communication System Mapping (SCSM) – Sampled values over serial unidirectional multidrop point-to-point link, First edition 2003-05

[2] INTERNATIONAL STANDARD IEC 61850-9-2, Communication networks and systems in substations – Part 9-2: Specific Communication System Mapping (SCSM) – Sampled values over ISO/IEC 8802-3, First edition 2003-05

[3] IEC 61850-9-2 LE: Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2, UCA International Users Group

Biography

Alexander Apostolov received MS degree in Electrical Engineering, MS in Applied Mathematics and Ph.D. from the Technical University in Sofia, Bulgaria. He has worked for fourteen years in the Protection & Control Section of Energoproject Research and Design Institute, Sofia, Bulgaria. From 1990-94 he was Lead Engineer in the Protection Engineering Group, New York State Electric & Gas where he worked on the protection of the six-phase line, application of microprocessor relays, programmable logic and artificial intelligence in protection. 1994-95 he was Manager of Relay Applications Engineering at Rochester - Integrated Systems Division. 1995-96 he was Principal Engineer at Tasnet. 1996 – 2006 he was Principal Applications Engineer at AREVA T&D Automation. He is presently Principal Engineer at OMICRON electronics in Los Angeles, CA.

He is IEEE Fellow and Member of the Power Systems Relaying Committee and Substations C0 Subcommittee. He is the immediate past Chairman of the Relay Communications Subcommittee, serves on many IEEE PES Working Groups and is Chairman of Working Group C9: Guide for Abnormal Frequency Load Shedding and Restoration (IEEE Standard C37.117). He is Member of CIGRE and Convener of CIGRE WG B5.13 “Acceptable Functional Integration in Transmission Line Protection” and member of CIGRE WG B5.07, B5.09, B5.35. He is member of IEC TC57 WG 10, 17, 18 and 19. He is Chairman of the Technical Publications Subcommittee of the UCA International Users Group. He holds three patents and has authored and presented 300 technical papers. He is also Editor-in-Chief of the industry magazine PAC World.

Benton Vandiver III received his BSEE from the University of Houston in 1979.

He began his engineering career with Houston Lighting & Power in 1978, developing relay & control protection systems for all levels of transmission, distribution, and generation. He developed extensive knowledge in the application, setting, testing, modeling, and design of traditional and digital relaying systems used in all types of power system protection. In 1991 he joined Multilin Corp. as a Project Manager responsible for design and development of a new family of utility grade digital relays. In 1995 he joined OMICRON electronics in Houston, TX with the primary responsibilities of sales, training, and marketing in North & South America of the CMC Test System.

Now as Technical Director he is responsible for regional strategic sales, regional product development and training with a focus on CMC applications. He is a registered Professional Engineer in Texas, long time member of IEEE / PSRC and is past chair of Working Group H5-C Common Data Format for IED Sampled Data. He is also a standing member of the USNC and CIGRE. He holds a US Patent for “Communication-based Testing of IED’s” and has authored or co-authored over 80 technical papers/articles in North America.