Substation Automation based on IEC 61850 with new process-close Technologies

Lars Andersson, Christoph Brunner, *Member, IEEE,* and Fred Engler

#

Abstract -- **New technologies in primary equipment like non-conventional instrument transformers require new interfaces to the substation automation system. The future standard IEC61850 perfectly supports this requirement. With the introduction of the new technologies and the use of IEC61850, a more decentralized architecture of the substation automation system will be possible. This provides several benefits but a careful system design is required to maintain the overall reliability of the system.**

Index Terms -- IEC61850, non-conventional instrument transformers, protection and control, substation automation, reliability.

I. Introduction

THE transmission and distribution substation of the future is currently influenced by two issues. The future standard IEC61850 will introduce commercial communication technologies in the substation automation system. This will be the basis for new applications supporting not only the operation but also the maintenance of the substation. New technologies used in primary equipment will require new interfaces. This will enable a significant reduction of copper wiring in the substation and a better diagnosis of the equipment. In a first part of the document, these issues will be introduced and the influence on future transmission and distribution substations will be discussed.

The new approach for a substation provides several benefits. But a more decentralized approach may also influence the overall system reliability. A second part of the document will discuss the benefits and the impact on system reliability.

II. New Technologies

In this section, new technologies affecting the design of the new generation of substations are presented.

A. New Communication Technology

IEC61850 is the new standard for communication networks and systems in substations. The core components of the standard are:

- An object model describing the information available from the different primary equipment and from the substation automation functions.
- A specification of the communication between the intelligent electronic devices (IEDs) of the substation automation system.
- A configuration language used to exchange configuration information between the engineering tools used for the substation engineering as well as for the engineering of the network control centers.

To be able to draw benefits from a standard solution, the solution must cover all relevant requirements both today and in the future. It must, with other words, be future proof. The open approach of the IEC61850 is focused on assuring this.

The objective of the standard is to design a communication system that provides interoperability between the functions to be performed in a substation but residing in equipment (physical devices) from different suppliers, meeting the same functional and operational requirements. To reach that goal, the functions of a substation are split into sub-functions (logical nodes, LNs). LNs are the core elements of the data model. IEC61850 standardizes data assigned to LNs. These data are the basis for the information exchange within the substation automation system.

A typical substation automation function is executed by different LNs exchanging information. An example for a protection function is shown in Fig. 1. The participating LNs are distance protection function (PDIS), current transformer (TCTR), voltage transformer (TVTR) and circuit breaker (XCBR). The allocation of the LNs to physical devices is a choice of the device manufacturer and typically depend on substation technology and operational conditions.

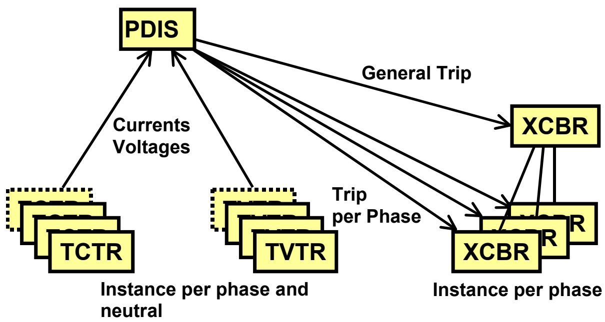

Fig. 1. Example for logical nodes participating in a protection function

In addition to the LNs, the standard introduces logical devices (LDs) and physical devices (PDs). The logical devices are collections of logical nodes and are always implemented in

L. Andersson, Ch. Brunner and F. Engler are with ABB Switzerland Ltd, Brown Boveri Strasse 5, CH-8050 Zurich, Switzerland
E-mail: christoph.brunner@ch.abb.com; fax: +41 58 588 3044

one physical device. One physical device can however contain several different logical devices. In a modelling stage where it is not yet clear which physical devices will be used - will i.e. separate physical devices for control and protection or one combined protection and control device as in Fig. 2. be used - logical devices can be used to collect the logical nodes that conceptually belong together.

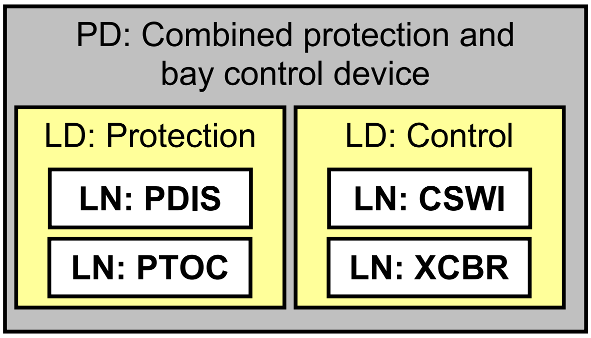

Fig. 2. Example of model with PD, LD and LN
(CSWI: switch controller; PTOC: overcurrent protection)

The concept of the LNs that may be freely allocated to physical devices supports the complete range from a centralized RTU based architecture with one computational element and parallel wiring from the primary equipment to a fully distributed architecture with intelligent sensors and actuators connected via a process bus.

All applications defined today for substation automation are included and supported in the standard. The standard also has an object model and set of rules that makes it possible to extend the scope of the standard and include new applications in the future, without a need for additions or changes to the standard itself. Slowly changing application functions must be strictly separated from the fast advancing communication technology. This safeguards investment in the applications while at the same time allows using up-to-date communication technology. The approach to achieve this is shown in Fig. 3.

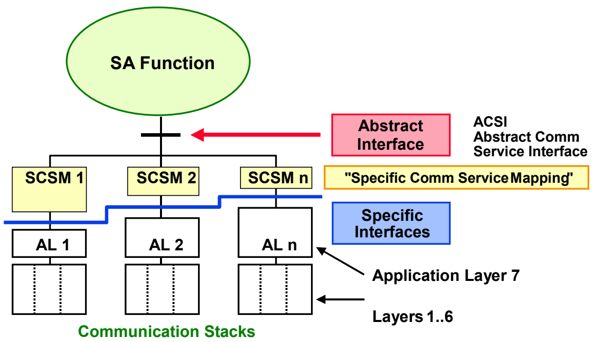

Fig. 3. ACSI: Abstract Communications Services Interface;
this interface separates the SA functions from the communication

The ACSI separates the SA applications from the communication. In a real implementation this interface is mapped to an existing communication stack. This mapping is realized in the Specific Communication Service Mapping (SCSM). IEC61850 currently specifies two mappings: the IEC61850-9 for the transmission of sampled values and IEC61850-8 for all other communication services, including the transmission of station wide events.

IEC61850 consists of 14 different parts. The basic parts including the object model and the abstract communication service specification have been approved as international standard. The communication mappings and the configuration language will be accepted by the end of 2003.

B. *New technologies in primary equipment*

Non–conventional instrument transformers (i.e. galvanic ones like Rogowski coils and capacitive voltage dividers or optical ones like MOCTs and FOVTs) impose new requirements on the interface towards protection relays and control units.

New technologies used in the drives for circuit breakers like drive operating mechanisms controlled by servomotors require electronics in the primary equipment. This is an opportunity to put a communication interface directly into the circuit breaker drive. The new interfaces will typically support serial communication links according to the specification of IEC61850. The use of such new high voltage apparatus - containing electronics - in the primary equipment together with the powerful communication interfaces according to IEC61850 makes a better diagnosis of the equipment possible.

III. Future Architecture of Substation Automation Systems

The introduction of the new technologies mentioned in the previous clause will lead to a more decentralized architecture of the substation automation system and will enable a significant reduction of copper wiring in the substation.

A. *Architecture Overview*

The introduction of numerical relays and communication technology some 15 years ago has led to system architectures similar to what is shown in Fig. 4. The same architecture can also be used with IEC61850.

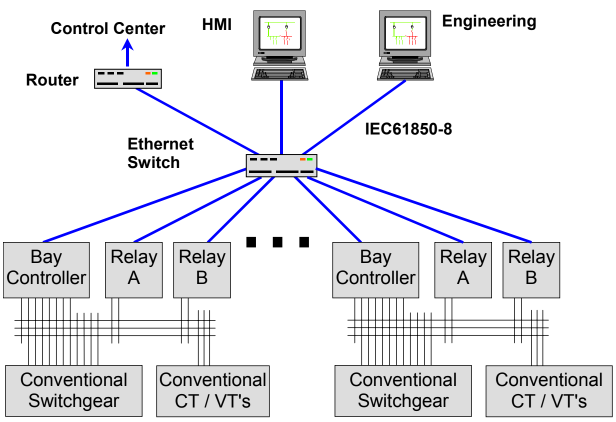

Fig. 4. Station bus and conventional wiring to the process

Non-conventional instrument transformers will in a first step be connected through serial point-to-point connections according to IEC61850-9 to the relays. This results in the architecture as shown in Fig. 5.

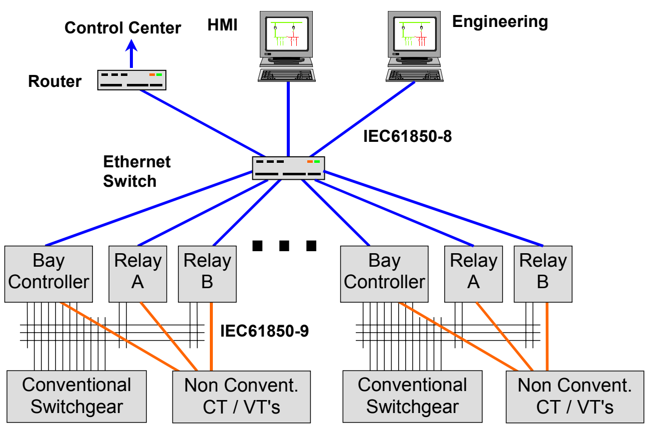

Fig. 5. IEC61850-8 station bus and IEC61850-9 links to non-conventional instrument transformers

The next step, where the drives of the switchgear are equipped with a communication interface may result in the architecture as shown in Fig. 6. A bus-like communication between the bay level functions and the process close equipment will further reduce copper wiring and will simplify the connection topology.

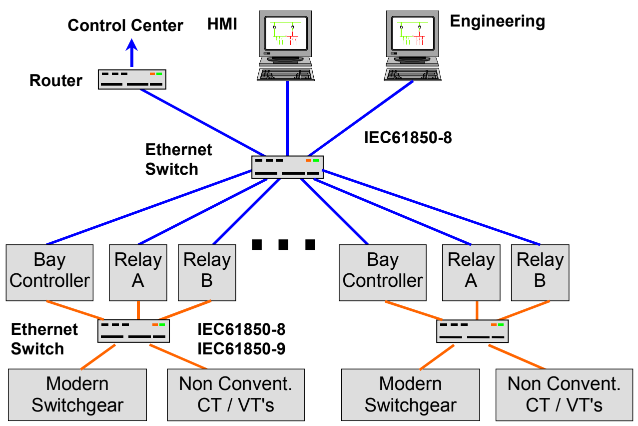

Fig. 6. Hierarchical communication networks with IEC61850-8 as station bus and a process bus using both IEC 61850-8 and IEC61850-9

Since IEC61850 uses the same communication technology for the station bus and the process bus, the final system architecture may be as shown in Fig. 7. This will allow a seamless data access within the substation. Also architectures based on a ring topology are possible.

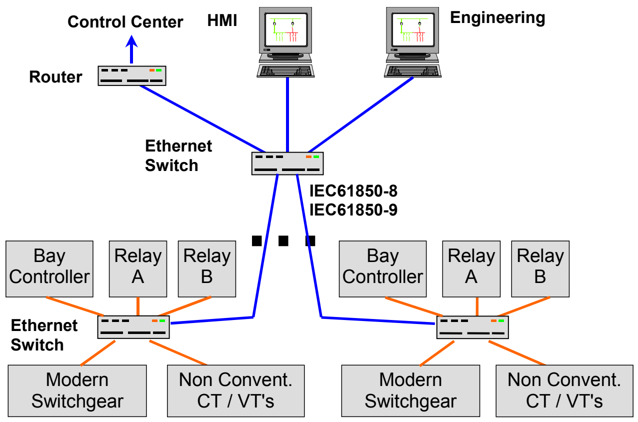

Fig. 7. One single, station wide communication network using both IEC61850-8 and IEC61850-9

B. *Process close Architecture Details*

At the process level there is a merging unit (MU) connecting the voltage and current transformers to the protection and control devices. The main task of the merging unit is to merge current and voltage data from the three phases. The interface between the instrument transformers and the MU is technology specific; the output is standardized according to IEC61850-9. The instrument transformers connected to the MU can be conventional CTs and VTs, non-conventional CTs and VTs or a mix of both.

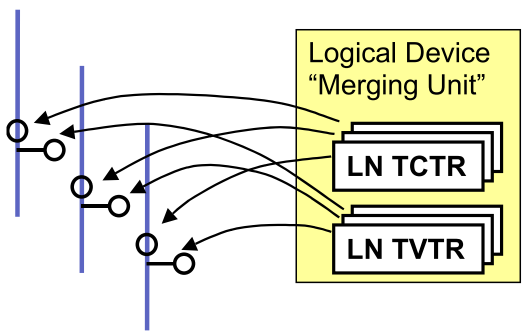

Fig. 8. Merging unit connected to single phase instrument transformers

The sampled analog values from the MU should be time coherent. This can be achieved either by synchronous sampling of all analogue values throughout the whole substation or by having each sample time tagged. In the latter case a local or global common time reference is necessary in the system.

There are different process close architectures depending on which signals of the switchgear are connected with conventional wires and which are connected via an IEC61850 network.

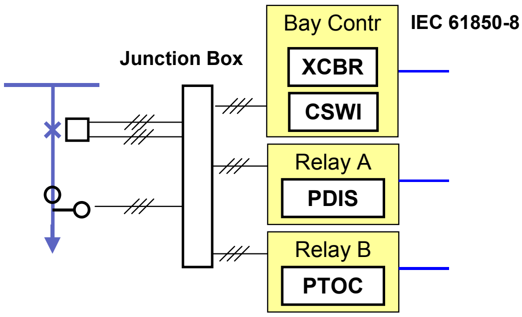

Fig. 9. Conventionally connected switchgear

Fig. 9 shows a conventional connection of all analog and binary data. On bay level, there are three devices: A bay controller, a distance protection as main protection (Relay A) and a time overcurrent protection (LN PTOC) as backup protection (Relay B). There are a large number of copper wires between the switchgear and protection and control equipment. It can be 200 to 500 wires that need individual assembling and testing according to system drawings for each bay. There is a large amount of manual work involved in this assembling and testing and also in assuring the consistency of the related drawings.

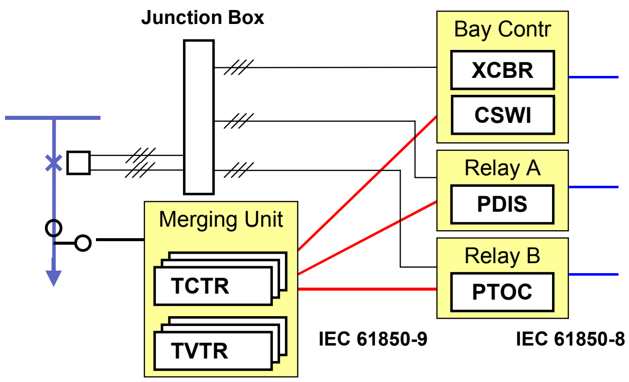

Fig. 10. Non-conventional instrument transformers

The first step, where non-conventional instrument transformers are connected to the protection and control equipment via the MU is shown in Fig. 10. The connection from sensor to MU is a proprietary serial link. The connection from MU to the protection and control equipment is standardized according to IEC61850-9. The IEC6850-9 connection can be either several point-to-point links or a network with a switch.

In a next step, in addition to the non-conventional sensor, a monitoring unit (modeled with the LN SCBR) for the monitoring of the circuit breaker drive is introduced, see Fig. 11. The monitoring unit has a proprietary connection to sensor electronics on the circuit breaker. From the monitoring unit there are conventional connections to the existing protection and control equipment for alarms and operational capability signaling and also an IEC61850-8 connection to the station level for detailed monitoring data. All trip commands and positioning signals between circuit breaker and protection and control equipment are still connected conventionally with wires.

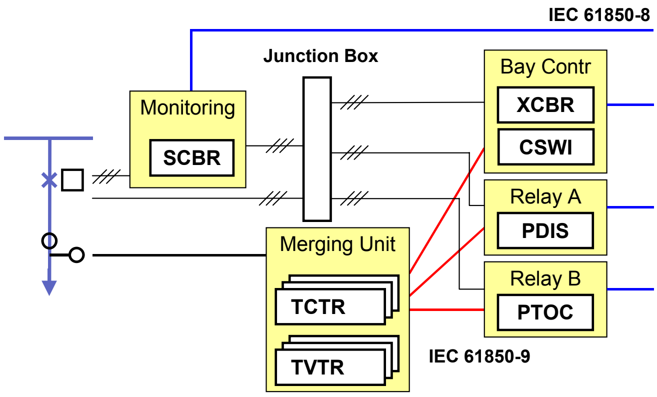

Fig. 11. Non-conventional instrument transformers and CB monitoring

The fully intelligent switchgear in Fig. 12 has non-conventional instrument transformers and a breaker including the breaker monitoring LN SCBR. The monitoring device and the merging unit are connected to the protection and control equipment with a process bus using both IEC61850-8 and IEC61850-9. The process bus is used for the complete information exchange between process level and bay level. There are no conventional wire connections between the switchgear and equipment on bay level anymore.

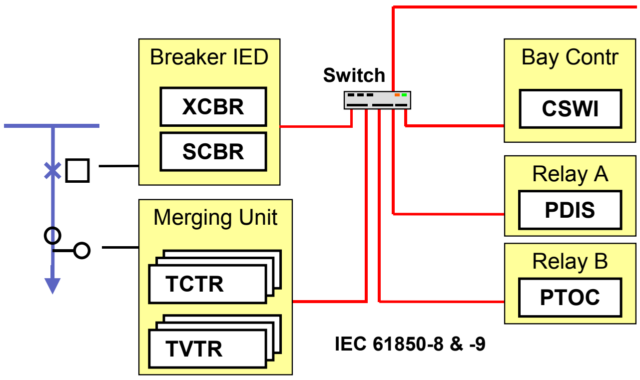

Fig. 12. Non-conventional instrument transformers and intelligent CB drive (IED: Intelligent Electronic Device)

C. Function Integration

Function integration is a way to reduce the number of physical devices required in a system. This reduction of devices can also contribute to increase the system reliability.

The traditional function allocation today is that all protection, control and monitoring functionality is allocated to the bay and/or station levels. At the bay level protection, control and sometimes monitoring functions are implemented in separate physical devices.

Some functionality has been integrated and reduced the number of physical devices required on the bay level already today. One example is the disturbance recorder integrated in the protection device, another is the protection and control integrated in one physical device.

With the introduction of the non-conventional sensors and actuators, electronic devices are introduced also below the bay level. In a first step this increases the total number of electronic devices. However, it offers an additional opportunity of function integration. Fig. 13 gives an example of function integration. It is the same functional setup as in Fig. 12 but the protection functions are integrated in the merging unit and in the bay controller.

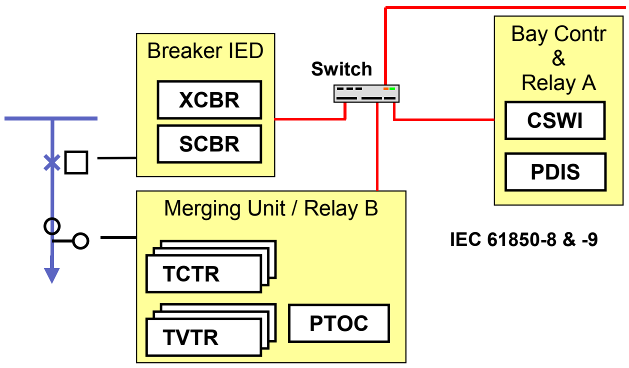

Fig. 13. Example for function integration at process and bay level

IV. Reliability and Availability

A. Introduction

For the following discussion, the terms reliability and availability are used as follows:

- Reliability is the ability of the equipment or the system to perform a required function for a given time interval. Reliability is directly related to the mean time to failure (MTTF).
- Availability is the ability of the equipment or the system to perform a required function at a given instant of time. Availability is related to the MTTF and the mean time to repair (MTTR). The MTTR itself depends, among other things, on the error detection rate. Self-diagnosis of the equipment will therefore improve the availability.

For the protection function, an incorrect operation is either a failure to operate (i.e. the protection did not operate while it should have operated) or an unwanted operation (i.e. the protection was operating when it should not have operated). In this context the term availability (better: unavailability) will be used as a measure for a failure to operate and the term security (better: unsecurity) will be used as a measure for an unwanted operation. Redundancy will increase the availability of the function but may decrease its security.

The introduction of communication networks connecting all intelligent devices in the substation combined with the use of intelligent primary process equipment will reduce the number of non-supervised functions and components to almost zero. The time until an error will be detected is therefore reduced and the availability of the system will increase.

In conventional systems, there is no true redundancy available. The individual application functions (local control, transmission line protection, remote control, busbar protection, disturbance recording, revenue metering, etc) separately acquire their respective process signals, but just once. The new technologies used in substation automation systems make it possible, for the first time, to offer clearly scalable redundancies for all secondary functions.

B. Reliability of the Protection Function

When introducing new process close technologies, the main challenge is to make the process close equipment reliable enough to fulfil the requirement on availability of the system as we have today. Basically, new electronic equipment is added with high requirements with regard to reliability. But as it was discussed above, there is an additional degree of freedom in the design with the free allocation of functions that allow for new architectures. The design of the architecture can be optimized for reliability. Mainly by reducing the number of electronic devices and allocate functionality optimally with respect to the design of the process close equipment.

A first possibility how to connect the non-conventional instrument transformers to the protection relay in a one and a half circuit breaker arrangement is shown in Fig. 14. A physical device implements one logical device "merging unit". Two of these IEDs are required to collect the information from the instrument transformers. The MUs and the protection relay are connected via a switch. The protection needs data from both MUs.

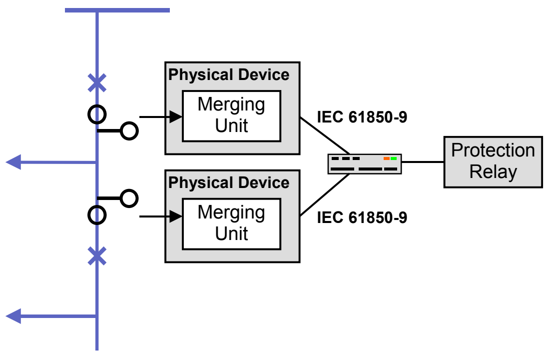

Fig. 14. Individual merging unit for each measuring point

A second possibility is shown in Fig. 15 where the physical device implements two logical devices "merging unit". No switch is required in this case. The number of individual electronic devices is reduced by 50%. This simple example shows that a careful design of the system architecture needs to consider reliability aspects.

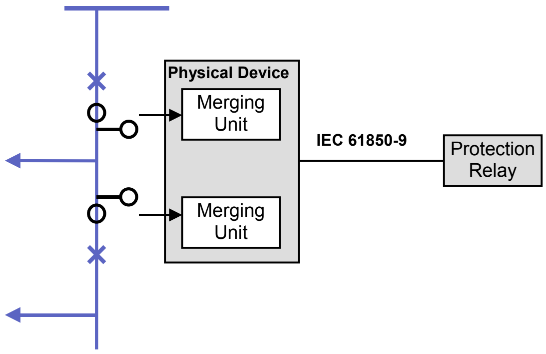

Fig. 15. One physical device implementing two merging units

For protection functions in high voltage transmission systems redundancy is used to increase the availability of the protection function. While with conventional instrument transformers, no true redundancy is available, the non conventional instrument transformers offer a true redundancy from the sensor to the protection function. This is achieved by fully duplicating the protection system with instrument transformers, merging unit, communication link and protection relay.

C. Further Substation Functions

With the new instrument transformers, the voltage and current data may be distributed from the merging unit not only to the protection function, but also to other functions like disturbance recording or control. Therefore, also these functions may benefit from a redundant data acquisition used for the protection functions. Increased availability due to redundancy may therefore be extended to all functions of the substation.

V. Conclusions

The new process close technology and the new standard IEC61850 offer several benefits for the design of a substation. The number of copper wires will be significantly reduced. This will also reduce the amount of manual work involved in assembling and testing these wires.

The number of non-supervised functions will be reduced to almost zero. This reduces the time until an error will be detected and increases the availability of the system. With the introduction of the new technology, a true redundancy is possible at reasonable cost for all functions of the substation.

Initially, on the path towards the intelligent switchgear, more physical devices are introduced in the system and may affect the overall system reliability. However, with each step of function integration, there is a reduction of the number of physical devices that consequently will improve the overall system reliability.

VI. References

Papers Presented at Conferences:

[1] Christoph Brunner, "How the IEC61850 support the migration phase", CIGRE 2002.

[2] Lars Andersson, "Discussion on cost differences between conventional and intelligent sensors as well as the different process connections for intelligent sensors", CIGRE 2002

Papers from Conference Proceedings (Published):

[3] Ch. Brunner, G Schimmel, H. Schubert, "Standardisation of serial links replacing parallel wiring to transfer process data- Approach, state and practical experience", CIGRE 2002 Paris.

[4] Lars Andersson, Klaus-Peter Brand, Wolfgang Wimmer, "The Impact of the coming Standard IEC61850 on the Life-cycle of Open Communication Systems in Substations", Distribution 2001, Transmission & Distribution, Brisbane 2001

[5] Lars Andersson, Klaus-Peter Brand, Wolfgang Wimmer. "The communication standard IEC61850 supports flexible and optimised substation automation architectures", 2nd International conference on Protection and Control in NEW DELHI 2001.

[6] C. Brunner, A. Ostermeier, "Serial Communication Between Process And Bay Level - Standards And Practical Experience –", CIGRE 2000

[7] M. Saitoh, T. Kimura, Y. Minami, N. Yamanka, S. Maruyama, T. Nakajima, M. Koskada, "Electronic Instrument Transformers for Integrated Substation Systems", IEEE/PES T&D Conference and Exhibition 2002: Asia Pacific

[8] Masayuki Kosakada, Hiroshi Watanabe, Tokuo Ito, Yoshito Sameda, Yuji Minami, Minoru Saito, Shiro Maruyama, "Integrated substation systems – harmonizing primary equipment with control and protection systems", IEEE/PES T&D Conference and Exhibition 2002: Asia Pacific

Standards:

[9] *IEC 61850 Communication Networks and systems in substations*, IEC standard in ten main parts, first parts published in 2002.

VII. Biographies

Lars Andersson, M.S.C.S., graduated from the Institute of Technology in Lund where he received Master of Science degrees in Computer Science in 1987. His employment experience included Swedish Royal Navy, the Institute of Technology Lund and ABB. His work with ABB has been focused on the application of communication in the substation domain and related architecture aspects. Andersson worked during 1994 and 1995 with the IEC 60870-5-103 as external expert to TC57 and been a member of the IEC TC57 since 1995, active in WG12 with the new communication standard IEC61850. Andersson is presently working with architecture and communication by ABB Switzerland Ltd, business area Power Technology Products.

Christoph Brunner, M.Sc.E.E., graduated from the Swiss Federal Institute of Technology in 1983. He is member of IEEE-PES and IEEE-SA. Brunner started his career as a HW development engineer. Later he was project manager and development manager for telecontrol systems and RTU's used for utility automation. He now works as a project manager at ABB Switzerland Ltd in the business area Power Technology Products in Zurich / Switzerland where he is responsible for the communication architecture of the substation automation system. He is convenor of the WG 12 of the IEC TC57. This working group, in cooperation with WG10 and WG11, has the task to develop IEC 61850.

Fred Engler, M.Sc.E.E., graduated from the Swiss Federal Institute of Technology in 1980. He started his career as a HW and SW development engineer in the area of process control systems. From 1988 he was leading the R&D of protection relays and substation control systems of ABB in Switzerland. In 1993 he started the new R&D project team for developing the new smart GIS switchgear system with non-conventional sensors, actuators and a dedicated process bus system. From 1994 he was in addition responsible for the AIS and GIS substation automation engineering activities at ABB in Switzerland. He now works as substation automation R&D responsible within ABBs business area Power Technology Products.