SWITCHGEAR OPTIMIZATION USING IEC 61850-9-2

Janne STARCK
ABB Oy, Distribution Automation
janne.starck@fi.abb.com

Dr. Wolfgang WIMMER
ABB Schweiz AG, Substation Automation
wolfgang.wimmer@ch.abb.com

Karol MAJER
ABB Oy, Distribution Automation
karol.majer@fi.abb.com

ABSTRACT

This document describes the utilization of the non-conventional measurements and advanced features of IEC 61850 standard for substation automation systems, especially how sampled value sending according standard part 9-2 can be used between IEDs in medium-voltage substation to improve the reliability and functionality of the system. Calculated results indicate improvements on availability, performance and reliability with the selected application example, busbar voltage sharing.

INTRODUCTION

With the introduction of the IEC 61850 standard, substations have been moving into a new era of communication. All manufacturers can adapt their products to the same communication model and protocol, enabling the IEDs of different manufacturers to "talk with each other" and thus operate with each other.

The IEC 61850 standard defines the Ethernet technology for substation automation communication. It also includes the related system requirements and the data model of the protection and control functions. The standardized data modeling of substation functions including the communication interfaces pave the way to openness and interoperability of devices. The IEC 61850 standard includes self-describing intelligent electronic devices (IEDs) and XML-based Substation Configuration Language (SCL) which allows system engineering of a multi-vendor system.

The IEC 61850 standard includes the GOOSE service in the 8-1 profile for real-time communication between the IEDs. Additionally, the standard includes in the 9-2 profile the communication between measurement apparatus and IEDs. These profiles enable designing substation communication for medium-voltage switchgear in a novel and flexible way to make the IED process data available to all other IEDs in the local network in a real-time manner.

USING IEC 61850-8-1 AND 9-2

The principle architecture of the IEC 61850 substation automation is divided into three levels as in the following figure. SCADA system interface and substation controller reside in the station level. In this level, the operator monitors the system and operates the power network.

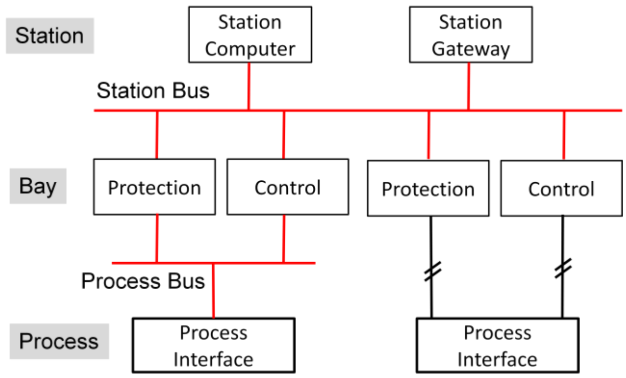

Figure 1 Basic structure of communication levels

Protection and control IEDs are on the bay level. As bay level IEDs use the same IEC 61850 station bus, it is possible to replace the traditional bay-to-bay signal wires with station bus using horizontal communication. Today, IEC 61850 GOOSE is used increasingly in substations e.g. for tripping, interlocking or blocking type of signals. The GOOSE service offers several advantages, for example reduced costs in the switchgear design, functional flexibility and improved performance [1].

Process interfaces to high-voltage apparatus are on the process level. Besides the conventional signal wiring between the process interface and IEDs, IEC 61850 introduces a concept where process signals can be exchanged in process bus using local area network (LAN). This reduces the wiring between process interface and IEDs by using simple Ethernet cable instead of a set of galvanic wires. It also gives flexibility to application and installation as the signals can be shared over LAN between all the devices connected to the same bus. Changes in application do not necessarily require physical re-wiring which increases operational safety and decreases modification time.

This paper introduces a method with example and availability analysis how to combine station and process buses together to common bus. This has benefits especially in medium-voltage switchgear where primary equipment is close to protection and control IEDs [2].

MEDIUM-VOLTAGE APPLICATION

The power system networks today are becoming more interconnected to each other, from simple radial network type to meshed networks. This also affects the applied protection and selectivity schemes, which are moving from simpler non-directional functions towards directional functions with a higher selectivity. Protection functions used in application focus on protection requiring voltage measurements as basic voltage protection and in the directional overcurrent protection and earthfault protection, plus within incoming feeders synchrocheck for synchronization of the voltages.

The selected application is applied to medium-voltage switchgear, e.g. type ABB's UniGear ZS1, in single-busbar arrangement. The switchgear has 20 feeders divided into 2 sections with a bus coupler (BC) and a bus riser (BR). There are one incoming feeder (INC) and eight outgoing feeders (OUT) per section. As measuring devices for currents and voltages we will consider both conventional instrument transformers (IT) and non-conventional instrument transformers (NCIT).

When using ITs, voltage instrument transformer (VT) is located in the incoming feeders on the cable side and the busbar voltage is measured in any of the outgoing feeders. The sharing of the voltage in the switchgear is done by wiring signal from busbar to outgoing feeders.

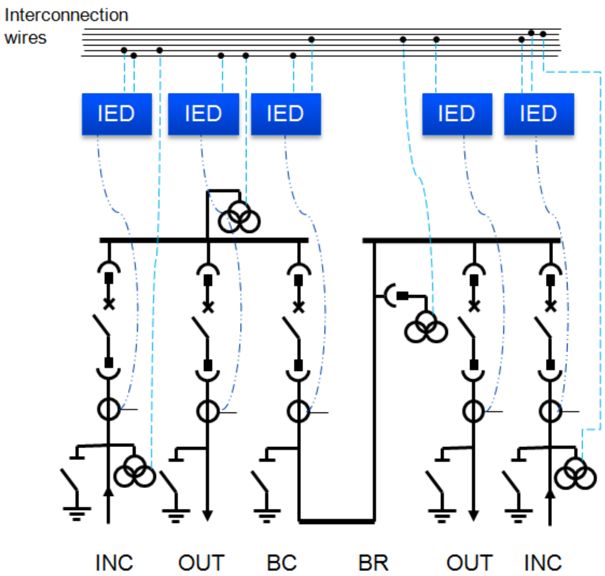

Figure 2 Switchgear with conventional measurement

When considering the usage of NCITs (also called as sensors) with IEC 61850-9-2 in the same switchgear arrangement, the design of switchgear is improved. Sensors are safer, simpler, lighter and easily connectable to the IED. This has a significant effect on the design of the switchgear, e.g. the measuring cubicle is not required any more. The signal from the sensor is routed to one IED, and sharing of the voltages can be done easily via LAN. In this way, different IEDs connected to the network can easily access available voltage measurement information if they require it. The interconnection wiring in switchgear becomes simplified as less regular galvanic wires are needed.

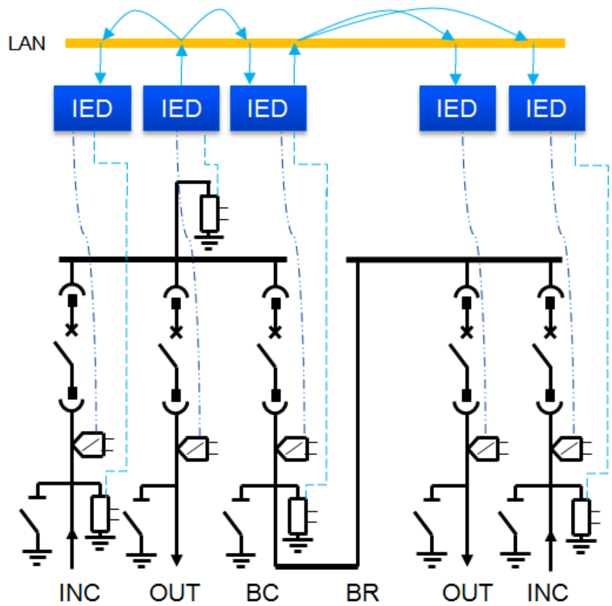

Figure 3 Switchgear with NCIT measurement

Voltage measurements shared via LAN are used in IEDs for protection purposes. With the usage of NCITs and 9-2, IED hardware can be simplified as IEDs do not require so many analog inputs. It is also possible to have several voltage signal sources from different places in the switchgear for high-availability back-up schemes. These are not easily doable with conventional VTs, where more physical sets of VTs and additional auxiliary equipment (e.g. terminal blocks, auxiliary relays etc) are needed. The example application can have two 9-2 sources per section for redundancy: one from busbar side and the other, backup from incoming feeder side. By using NCITs, the protection schemes remain the same, but digitalization brings benefits while utilizing same signals in different places of switchgear over LAN.

ETHERNET REDUNDANCY

IEC 61850 specifies a network redundancy scheme that improves the system availability for substation communication. It is based on two complementary protocols defined in the IEC 62439-3 standard: parallel redundancy protocol (PRP) and high availability seamless redundancy (HSR) protocol. They rely both on the duplication of all transmitted information via two Ethernet ports for one logical network connection. Therefore, both are able to overcome the failure of a link or switch with zero-switchover time, thus fulfilling all the stringent real-time requirements of substation automation.

In PRP, each node is attached to two independent networks operated in parallel. The networks are completely separated to ensure failure independence and can have different topologies. Both networks operate in parallel, thus providing zero-time recovery and the continuous checking of redundancy to avoid failures.

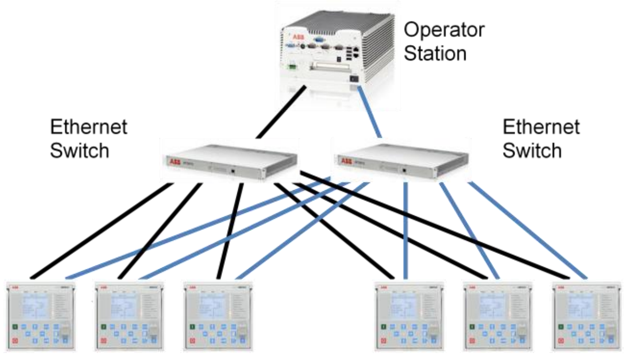

Figure 4 Figure PRP

HSR applies the PRP principle of parallel operation to a single ring. For each message sent, a node sends two frames, one over each port. Both frames circulate in opposite directions over the ring and every node forwards the frames it receives from one port to the other. When the originating node receives a frame it sent, it discards the frame to avoid loops.

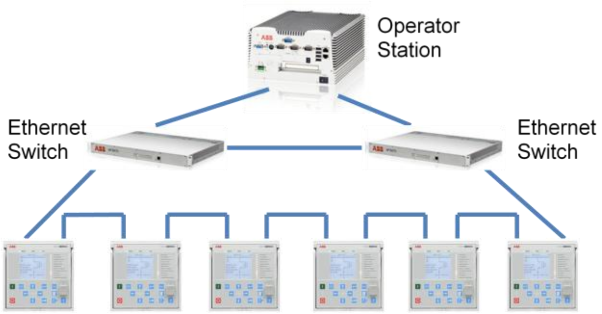

Figure 5 Figure HSR

The choice between these two protocols depends on the required functionality, cost and complexity [3].

AUTOMATED ENGINEERING

Any IEC 61850 system must be described with an SCD (System Configuration Description) file. This contains the IED addresses, data model, the logical data flow between the IEDs and the relation between the substation primary equipment at the single line level and the logical nodes (LN) on the IEDs. This feature together with the defined semantics of the logical nodes in terms of LN classes allows automating the data flow engineering and also the data input to the logical nodes representing the functions. This is done by providing the input data reference to them either in an SCD input section to the receiving logical nodes or appropriate input reference data objects (Inref objects) of the LNs which make the input data visible in the communication.

The algorithm of automated engineering is illustrated in Figure 6 with the example of voltage sample data flow engineering for the directional overcurrent function (LN PTOC) with voltage samples provided by the LN TVTR.

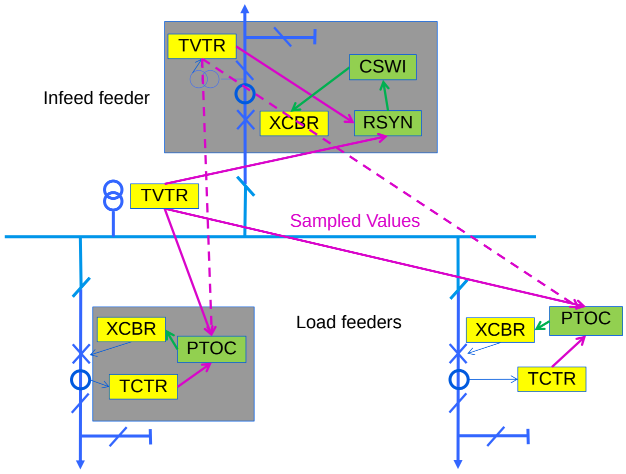

Figure 6 Voltage data flow for directional earth fault

The engineering wizard for the PTOC 'knows' that it needs the voltages related to the XCBR of the load feeder. It traverses the single line to find an appropriate VT with TVTR, first inside the feeder itself, next from the busbar. It establishes a Sampled Value Control block (SVCB) with a data set containing the voltage samples at the IED hosting this TVTR, and then inserts the IED hosting the PTOC as destination IED for this message. Furthermore, it defines the found TVTR.Vol data objects into an input section of the considered PTOC LN. This algorithm is repeated for all the PTOCs allocated to load bays. Similarly, based on the knowledge about the needed input data, all other data flow between IEDs can be generated.

In case of redundant inputs, the algorithm can continue searching from the busbar part to an incoming feeder containing a TVTR, and establish this as the second, redundant input source for the PTOC. During this traversal, it also finds that this source only needs to be considered active, if the circuit breaker and the truck / disconnectors of this feeder are closed, and configure the data flow of this data to the destination IEDs.

AVAILABILITY CONSIDERATIONS

The functionality described in Figure 6 can be implemented with NCITs providing a sampled value stream either from a merging unit IED, typically for the busbar VT, or from the protection and control IED to which the sensor is locally connected, typically the sample stream from the incoming feeder. As indicated above, for the directional earth fault these streams can be considered redundant to each other. As they shall be used in each feeder, also communication redundancy is necessary. This can be supplied either by a PRP network or by an HSR ring connecting all 20 MV IEDs to the station level. For both variants, the availability of the directional earth fault function in one load bay is calculated in the following. It is compared to the availability of this function with a conventional VT, either located in each bay, which is quite costly, or with some wiring from the busbar VT, which is dangerous and needing more work. From the availability point of view, both are identical if the wiring is neglected.

The availability investigation is based on the used switchgear application. Note that the used MTTF figures are no absolute values; they only show the order and expected differences between different kinds of IEDs.

IED type	MTTF(y)	Remarks
VT	80	Conventional VT
NCIT VT	300	Non-conventional VT
MU	200	Merging Unit
IED	100	Protection / Control IED
Switch	50	Ethernet Switch

Table 1 Used MTTF figures

Availability calculation

The availability calculation is performed using availability diagrams, showing all components needed simultaneously as serial connected and components redundant to each other as parallel connected. This leads to the following availability diagrams.

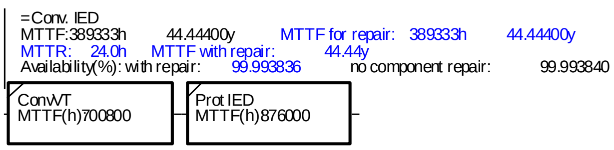

Figure 7 Protection with conventional VT

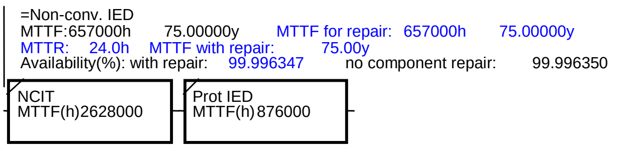

Figure 8 Protection with non-conventional VT

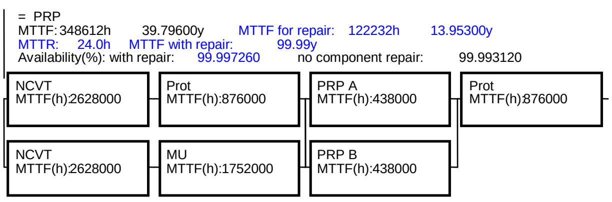

Figure 9 Using busbar / incomer VT with PRP

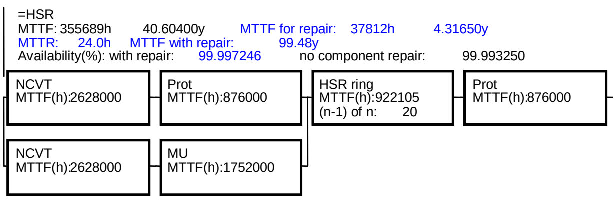

Figure 10 Using busbar / incomer VT with HSR

Availability result overview

The following table summarizes the availability figures and MTTF with repair, i.e. the resulting MTTF if repair of failed parts is done within 24 h.

Type	Avail.(%)	MTTF(y)	Remark
Conv. IED	99.993	44	More wiring
Non-conv. IED	99.996	75	NCIT in each feeder
NCVT, PRP	99.997	100	Needs more switches
NCVT, HSR	99.997	99	20 IEDs add 2 ms time delay

Table 2 Used MTTF figures

As can be seen, all solutions with a non-conventional VT have a better availability than with a conventional VT. This is expected due to their different MTTF values assumed. Due to the redundancy at VT selection (busbar VT and incomer VT), the system solutions transferring samples to all load bays have a higher availability as the solution with one VT per (load) feeder and are even less costly. Furthermore, PRP and HSR solutions with high availability have almost the same system MTTF value.

An option is to always to use a separate 9-2 merging unit (MU) with the VT providing the voltage values. This increases the number of devices in the system, and thus decreases the availability of the protection at the incoming feeder. From the availability point of view for the load feeders this changes nearly nothing, as the most determining factor is the MTTF of the protection IED itself. The high availability of the PRP and HSR solutions with the same system MTTF as the IED itself illustrates this: the voltage value is practically 100% available.

CONCLUSIONS

Usage of non-conventional instrument transformers together with IEC 61850 real time communication enables cost-efficient solutions with higher availability compared to traditional instrument transformer usage. Utilizing a concept of redundant voltage measurements together with today's usage of GOOSE paves the way for future digital MV substation.

REFERENCES

[1] A. Hakala-Ranta, O. Rintamäki, J. Starck, 2009, *"Utilizing Possibilities of IEC 61850 and GOOSE"*, CIRED, Prague.

[2] J. Starck, A. Hakala-Ranta, M. Stefanka, 2012, *"Switchgear Optimization Using IEC 61850-9-2 and Non-Conventional Measurements"*, PAC World Conference, Budapest.

[3] H. Kirrmann, 2010, *"Seamless Redundancy"*, ABB Review, Special Report IEC 61850, 57-61.