SYNCHRO-CHECK IN DIGITAL SWITCHGEAR

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ABSTRACT

Modern communication standards and techniques are the way forward in the simplification and improvements of today's protection application. Different communication services in IEC 61850 standard Ethernet based bus enable new type of applications and possibility to simplify the design of the medium voltage switchgear. This paper describes how IEC 61850-9-2 together with non-conventional measuring devices can be used in synchro-check application to improve the overall performance and functionality of the protection and control system in digital medium voltage switchgear.

INTRODUCTION

With the usage 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 (Intelligent Electronic Device) of different manufacturers to "talk with each other" and thus communicate in interoperable way.

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 standard part 8-1 for real-time communication and fast event based data exchange between the peer IEDs. Additionally, the standard includes in the standard part 9-2 a standardized way for devices to publish and subscribe sampled measurement value streams. These services enable designing of the substation application for medium voltage (MV) digital 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.

Digital switchgear is based on the combination of smart technologies: current and voltage non-conventional measuring devices (sensors) and IEC 61850 communication incorporated in modern numerical protection relays (IEDs). It removes the last electrical connection between the medium voltage primary equipment and the protection and control panels, creating a safer work environment, whilst reducing the costs for transportation, building, engineering, commissioning, operation and maintenance of the system. As a key component towards smarter grids, where utilities continue to integrate increasing amounts of intermittent renewable energy sources. Digital switchgear also improves safety because it enables faster operation times in case of an emergency, as data exchange is faster in communication bus comparing to conventionally hard-wired signals.

USING IEC 61850-8-1 AND 9-2

IEC 61850-8-1 GOOSE service and 9-2 (process bus) offers several advantages, for example functional flexibility and improved performance. These are achieved by moving the traditional signal wiring to Ethernet. When Ethernet is used for protection and control application the signals between switchgear panels are exchanged using the available station bus omitting the need of conventional bus wires. Also, in digital communication the signals are constantly supervised which is not the case generally with conventionally wired signals.

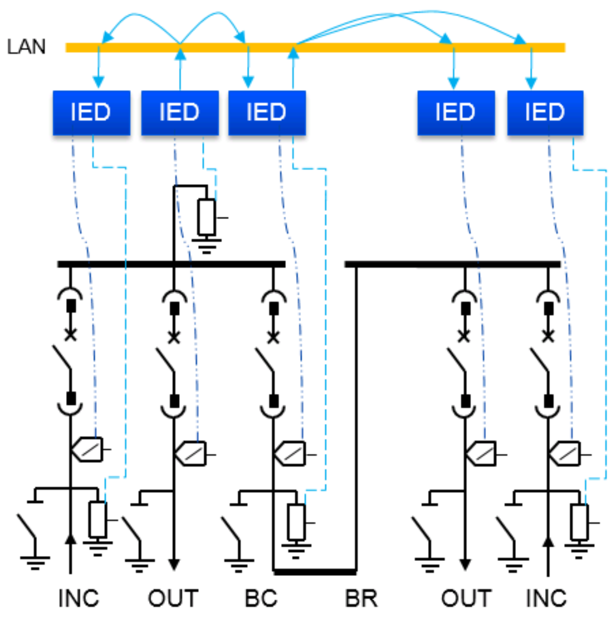

Figure 1. Combined station and process bus

IEC 61850 offers different possibilities for usage of Ethernet. In case of high voltage substation it is possible to build a separate process bus where primary equipment in switchyard is connected over own communication network to protection and control relays. Station bus is used then to connect protection relays to upper level system, e.g. SCADA. On the other side, in case of medium voltage switchgear, primary equipment is close to the protection and control relays. In this type of installation it is possible to combine the station and process bus to common Ethernet network simplifying the overall system.

Figure 1 shows a single busbar switchgear example with two sections and incomers (INC) on both sections. Local area network (LAN) is used fully to exchange signals between feeders in switchgear. E.g. binary interlocking and blocking signals are sent using GOOSE service and busbar voltage is shared by one protection relay per busbar section to other relays in section using 9-2 (process bus) service.

ETHERNET REDUNDANCY

In IEC 61850 based system where Ethernet is used for protection related signals it is important to keep the availability of the network high. Redundant Ethernet is needed to avoid single point of failures in communication network when it is used for protection applications. IEC 61850 specifies a network redundancy that improves the availability for substation automation.

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. Both are able to overcome the failure of a link or switch with zero-switchover time. With this feature these protocols are especially suitable for IEC 61850 protection applications where fast and ensured operation of the network is require.

In both protocols, each node has two identical Ethernet ports for one network connection. They rely on the duplication of all transmitted information and provide zero-switchover time if links or switches fail, thus fulfilling all the stringent real-time requirements of substation automation and especially protection related applications.

In PRP, each node is attached to two independent networks operated in parallel (Figure 2). 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.

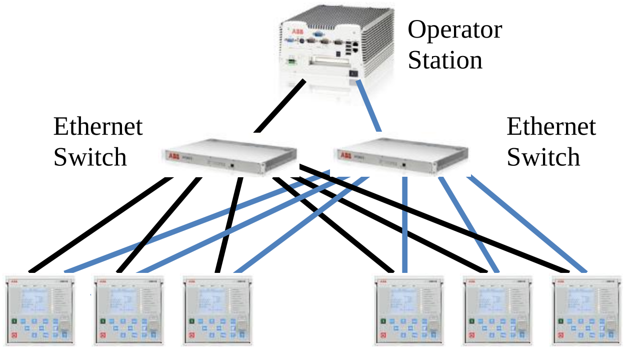

Figure 2. Redundant PRP network.

HSR applies the PRP principle of parallel operation to a single ring (Figure 3). 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.

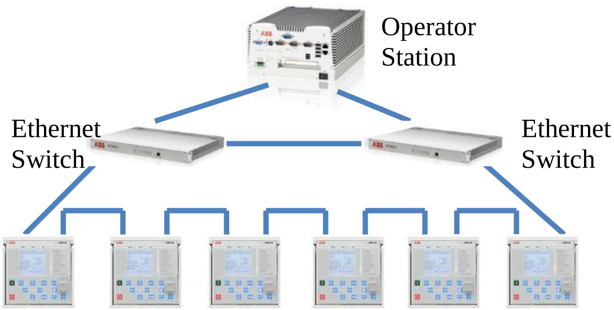

Figure 3. Redundant HSR network

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

SYNCHRO-CHECK

The main purpose of the synchro-check function is to control the closing of a circuit breaker in the power network, to avoid closing where the conditions for synchronism are not met. Synchro-check prevents reconnection of two parts of the network until the voltages on both sides of the circuit breaker have been perfectly synchronized. The same is true when part of the network has been islanded from the grid. The energizing check ensures that at least one side of the bus is dead to allow safe reclosing.

The synchro-check function monitors the voltage and phase angle difference and system frequency over the circuit breaker and gives the permission to close the breaker when set conditions are fulfilled. If the breaker is closed against dead bus or line, closing can be done without any synchronism checks [3].

Figure 2 shows the phasor diagram of the synchro-check application. Frequency difference between the bus voltage and the line voltage change the phase difference between the bus and the line voltage. Once the phase difference is within the closing parameters, breaker is closed. The timing of the close command is estimated from frequency difference and from the closing delay time of the breaker (Figure 3).

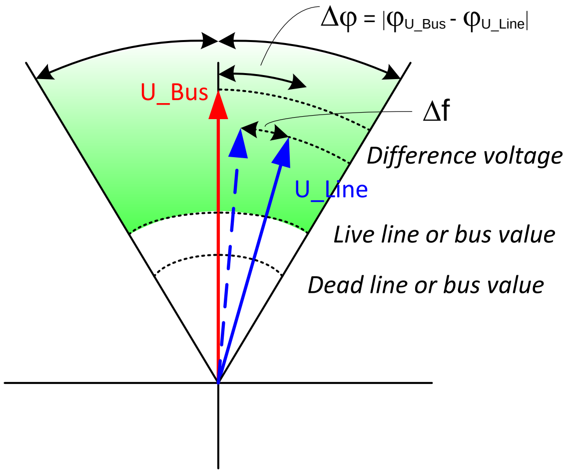

Figure 2. Conditions to be fulfilled when detecting synchronism between systems (phasor diagram)

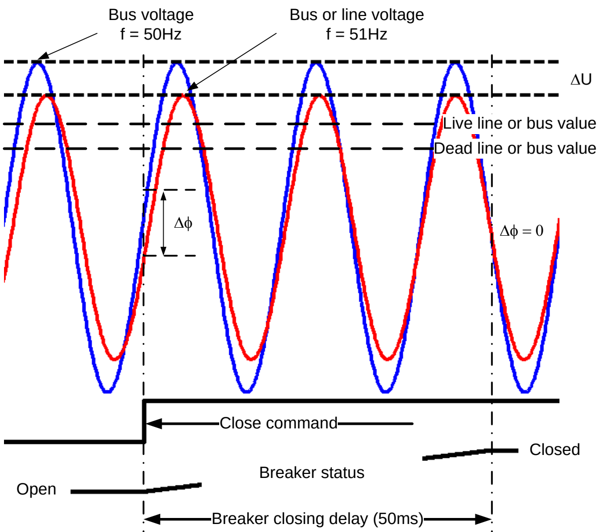

Figure 3. Conditions to be fulfilled when detecting synchronism between systems (time domain)

In a synchro-check application utilizing 9-2 the relay measures the local voltages from one side of the circuit breaker and the voltages from the other side are received from the process bus via 9-2. The measurements from the process bus are then configured in the relay to the synchro-check function. Figure 4 shows a simplified setup where 9-2 is used to share bus voltage between switchgear sections for synchro-check. System is simplified as whole signal exchange is moved to Ethernet communication.

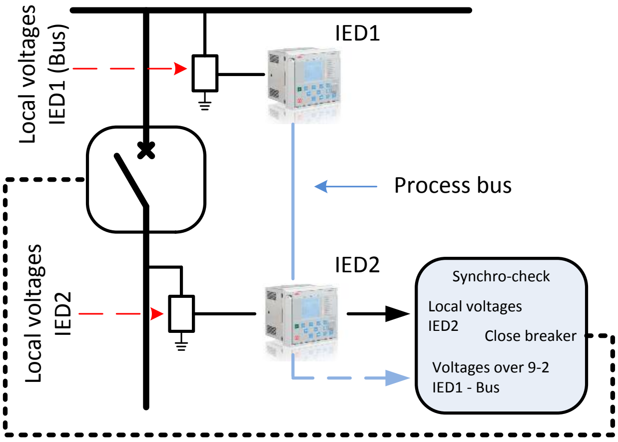

Figure 4. Synchro-check function configuration

DIGITAL MV SWITCHGEAR

Digital Switchgear for medium voltage primary substations is based on the combination of modern technologies: current and voltage non-conventional measuring devices (sensors) and IEC 61850 communication incorporated in modern numerical protection relays (IEDs) including GOOSE and 9-2 (process bus) [2].

Non-conventional measuring devices (sensors) are based on advanced measurement principles that achieve significant benefits over conventional instrument transformers. Figure 5 shows a cross-section of a medium voltage switchgear panel with conventional measuring devices. Figure 6 shows a cross-section of a Digital Switchgear panel with non-conventional measuring devices, such as current and voltage sensors.

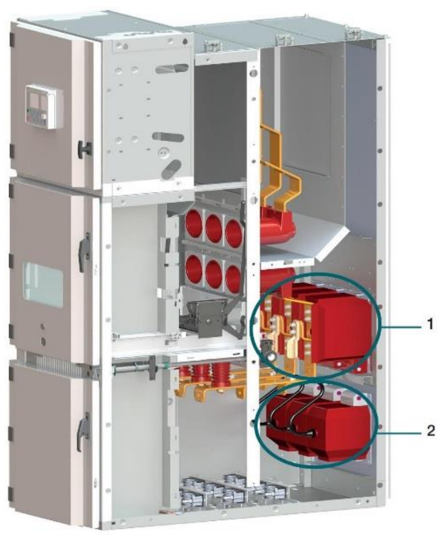

Figure 5. Cross section of a traditional medium voltage switchgear panel (1 – current transformer, 2 – voltage transformer)

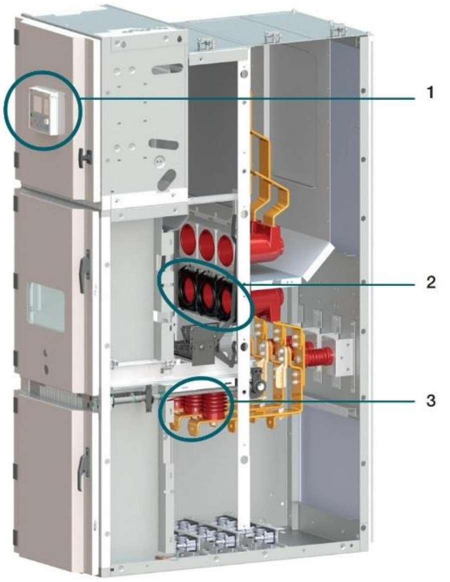

Figure 6. Cross section of a Digital medium voltage switchgear panel (1 – protection relay with IEC 61850, 2 – current sensor, 3 – voltage sensor)

In Digital Switchgear non-conventional instrument transformers can be optimally designed to better fit into the switchgear, while reducing the overall panel weight. Moreover non-conventional measuring devices based on Rogowski coils and resistive dividers increase the safety level for operators and maintenance personnel, thanks to low level output signals. Additionally, current sensors based on Rogowski coil do offer linear characteristics which results in higher flexibility and standardization level. All these benefits positively affect the design of medium voltage switchgear and makes them more flexible in customer applications.

Modern microprocessor based protection relays offer wide range of functions in “one box” which results in a multi-terminal protection and control IEDs. Full potential of relays can be obtained when these are supporting all services provided by IEC 61850 standard, including GOOSE and 9-2 based process bus. IEC 61850 9-2 can be used for distributing the bus voltages, currents, over the whole substation for different measurement, protection and control purposes, for example for synchro-check function.

In a single busbar arrangement with two sections the synchro-check application is typically needed in the bus coupler and in the two incoming supply feeders. The voltages for the bus coupler synchro-check application can be measured from the bus coupler control relay (bus riser side) and the bus voltage from any of the outgoing feeder protection relays. The bus voltages are then distributed via 9-2 process bus to the bus coupler control relay and to the incoming feeders (supply). The same bus voltages can be distributed to the other protection relays in the bus section as well for any measurement, control and protection application purposes. Same applies for the voltages measured by the bus coupler control relay (Figure 7).

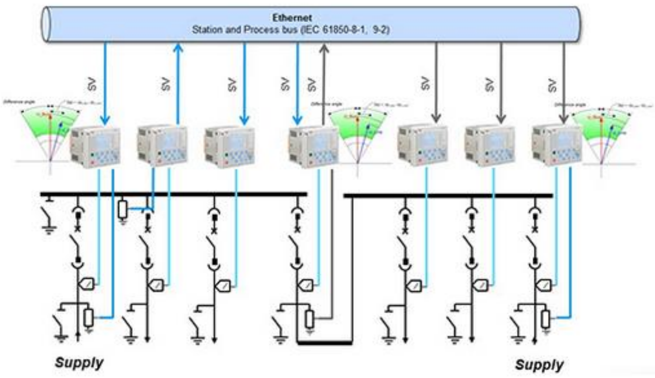

Figure 7. Synchro-check application in switchgear with single busbar arrangement in two bus section arrangement

Discussion

Medium voltage switchgear used for the distribution of electrical energy is a important element of electrical networks the function of which is to ensure uninterrupted power supply to the whole distribution network. With the new requirements and challenges the distribution networks have to face the MV switchgear assumes an increasingly important role as a part of the grid than ever before. Evolution in distribution networks asks for a medium voltage switchgear that is more efficient, safe, smart, reliable, environmentally friendly, and easy to engineer, install and operate. Digital Switchgear addresses key elements for improving project execution and switchgear operation – flexibility towards last minute changes and quicker delivery time while increasing reliability and safety (Figure 8).

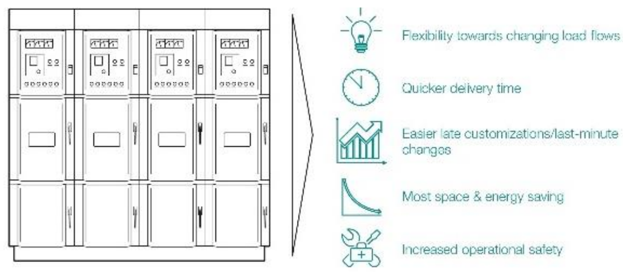

Figure 8. Digital switchgear benefits

Non-conventional instrument transformers can be optimally designed for MV switchgear which results is significant weight reduction and space saving in switchgear room. Moreover, the linear characteristic of current sensors allows the reliable operation in a wide range of primary current which results in a flexibility towards changing load flows. Voltage sensors with resistive dividers are immune against grid disturbances, such as Ferro-resonance phenomena. And thanks to their compact design they help reduce space in switchgear room by omitting a dedicated metering cubicles with busbar voltage measurement transformers. Further, traditional CTs and VTs are sensitive to incorrect handling, e.g. during testing or maintenance. Sensors eliminate this risk of failure and the related costly downtime, they increase safety and maximize system uptime [4].

Modern protection relays with wide support of IEC 61850 services saves time and costs during engineering, testing, installation and commissioning. GOOSE is used for fast reliable horizontal communication between the relays which enables significant time and cost savings by reducing hard-wiring between the relays. Moreover digital communication is still flexible towards last minute changes through easy re-programming. Process bus concept extends the application capabilities by sharing of analog measurements between relays. Both, GOOSE and process bus, are continuously self and cross supervised which increases the level of reliability and system performance.

CONCLUSION

In this paper we have introduced how synchro-check control application can be used in an efficient way in Digital Switchgear for medium voltage primary substations with modern technologies. Digital Switchgear takes advantage from IEC 61850 by fully using all services and thus moving as much as possible data exchanges to digital communication bus.

Additionally non-conventional instrument transformers are more flexible in terms of nominal currents. Their compact design enables better fit into the switchgear application and decreases overall panel weight and engineering efforts. Furthermore, they are safe for operators and maintenance personnel. This combination of products in Digital Switchgears brings new benefits for end users of the equipment.

The IEC 61850-9-2 adds flexibility to the synchro-check control application and it also reduces signal hardwiring inside the substation. The monitoring and supervision features of the IEC 61850 9-2 can also be used to enhance further the security of the synchro-check application.

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