INTEGRATION OF DIGITAL MEASURING TECHNOLOGY IN GAS INSULATED SUBSTATIONS (GIS)

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Abstract---Globalization of the world's markets are intensifying the competition between power suppliers. As industries strive to become more competitive, greater pressure is being put on the price of electrical energy. One result of this is that many utilities are being forced to deregulate their cost management strategies. New installations are consequently being evaluated not only on the basis of the first-time costs but also on the expected total costs over their life cycle. In line with this development, manufacturers of electrical equipment are having to offer new, innovative solutions and at the same time make use of the latest technologies to ensure cost-efficient operations. A look is taken in the following at the kind of changes that are in relation to integration of modern digital measuring technology in gas-insulated substations (GIS).

IndexTerms ---GIS, Intelligent Control, Combined Sensors, Voltage Transformer, Current Transformer

I. INTRODUCTION

Gas insulated switchgear (GIS) is ideally suited for installations in limited space especially if a high availability is required. New technologies are constantly being introduced to the GIS substation sector with the aim of reducing total life cycle costs, improving reliability and minimizing environmental impact. They are based on modern integrated control and protection systems, innovative sensors. Traditionally, a substation's high-voltage apparatus and its control and protection equipment have been treated as separate systems. The interfaces between these systems are defined on the level of the hard-wired connections that link the electronics to the primary hardware. Given the technical maturity of the primary equipment and the numerical control and protection systems, it is possible today to achieve a substantial improvement in functionality as well as overall cost benefits by mutually integrating the two technologies. Due to the good availability and proven performance of numerical station control and protection systems, it can be expected that the traditionally heavy and expensive current and voltage transformers as well as the electromechanical tripping relays and contacts will be replaced by low-cost sensors and electronic actuators. As a result, the A/D conversion units and some intelligent preprocessing functions that are now located in the control cubicles will be decentralized, in some cases as far down as the process level. The hardwired connections between the process and the control equipment will be replaced by optical fiber buses [1].

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II. INTEGRATION OF SECONDARY TECHNOLOGY IN GIS

In gas-insulated substations a clear distinction is made between the primary and the secondary equipment. The GIS primary equipment consists of the high voltage apparatus that performs the primary functions of the substation, such as switching, short-circuit current interruption, measurement and isolation. The term 'secondary technology' covers all the individual components that make up the protection, control and measuring equipment. One way of obtaining a major improvement in functionality as well as cost benefits is to merge the two technologies. Three consecutive phases define the merger of the primary and secondary technologies [2].

- Conventional technology
- Modern technology
- Intelligent GIS

A. *Conventional technology*

Electromechanical relay technology has largely responsible for the conventional layout of the secondary part of a substation. In this technology a large number of different devices, each one developed for a specific application, is interconnected by copper wires in order to fulfil all of the control, protection and measuring functions. These devices are mainly built into cubicles located in a separate room next to the GIS. In the GIS bay itself there is another cubicle that contains several relay switches for simple bay interlocking and local control functions. As many as several thousand connecting wires between the GIS and the local cubicle, as well as between the local cubicle and the main control and protection cubicles, are to be planned and installed. In time, some of their protection functions are performed by static relays. Although these are not able to match the high stability and reliability of the electromechanical relays, they offer more functionality. At a later stage, the static relays are replaced by digital relays. Steady improvement of the digital electronics and the introduction of selfsupervision routines have meanwhile resulted in modern digital relays becoming even more reliable than the conventional electromechanical types. It has been this technological re-orientation that has allowed the layout of the secondary equipment of a gas-insulated substation to be considerably simplified.

B. Modern technology

As mentioned above, the progress made in the field of digital electronics allows most of the functions of the secondary equipment to be performed by means of software modules running on the same computer-based devices. These digital, multi-functional units can be used for control as well as for protection and other secondary functions. Because of this, it is possible to group and combine different functions using just software tools. In past years, this opportunity was taken advantage of to integrate the secondary bay equipment of a GIS in the local bay cubicles, which had traditionally been equipped with just the hard-wired interlocking equipment for the bays. The communication between the bays themselves and between the bays and the substation control computer is established by a small number of serial fiber optic buses that replace the traditional hard-wired single signal connections.

Advantages of the modern technology are:

• A substantial reduction in the number of components used to perform the same functions.

• The hardware required for the bay oriented control, protection and measuring functions can be built into the local control cubicle. An additional room for the secondary equipment is no longer needed.

• Reduction or elimination of parallel wiring between the bay and the station level due to the use of fiber optic communication buses. As a result, project engineering can be simplified and EMC problems are less severe.

• Increased availability through self supervision and self-checking of the electronics for the remaining hardwired connections between the control cubicle and the primary hardware as well as checking of the function of the tripping circuits [1].

C. Intelligent GIS

A drawback of modern integrated secondary technology is the continued presence of hard-wired connections between the bay cubicle and the primary components of GIS. Therefore a serial optical bus system is used to replace these connections. The introduction of a serial fiber optic connection between the local control cubicle and the GIS primary equipment (process bus) has caused a shift in the traditional borderline between the primary and the secondary part of substations.

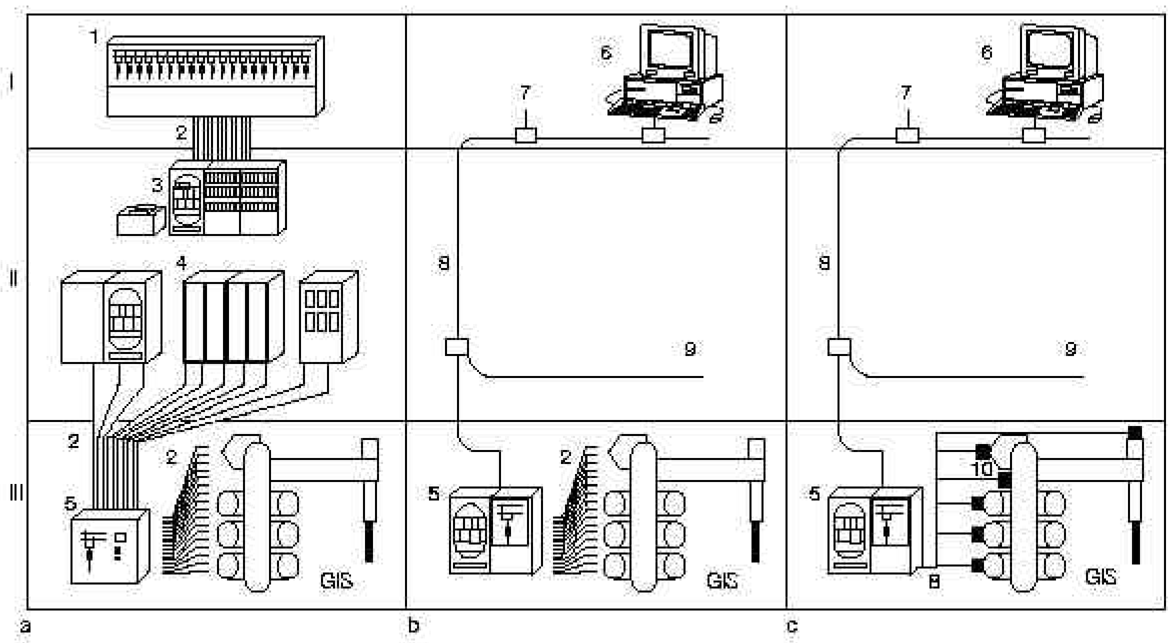

Figure 1. Phases in the development of secondary equipment in gas-insulated substations

a Conventional technology
b Modern technology
c Intelligent GIS

I Operating room
II Relay and ancillaries room
III Switchyard

1 Control board
2 Hard-wired connections
3 Event recorder and protection
4 SCADA: distribution and metering
5 Bay cubicle
6 Man-machine interface
7 Gateway

8 Serial data link
9 To other bays
10 Sensors and actuators

Allowing simple replacement of the hard-wired connections to the primary equipment – a simplification which translates into reduced costs – this significant innovation is needed to respond to increasing demand for monitoring, diagnostics and automatic maintenance scheduling functions. Also, modern sensor technology can be used for the primary apparatus, such as drives, auxiliary position indicators, current and voltage transformers, etc. The serial process bus concept with distributed electronic process interfaces integrated in the primary hardware allows a well-structured and modular approach to the merging of the primary and secondary equipment in a substation. Besides, the standardization of the process bus communication is intended to allow equipment from different vendors to be interconnected, thus enabling utilities to make savings on their capital investments.

III. SENSORS REPLACE CURRENT AND VOLTAGE TRANSFORMERS

A. Difficulties with conventional instrument transformers

Conventional current and voltage measurement transformers have the following drawbacks:

• Their design is based on the requirements of electromechanical relays. The high input power requirements of these protection devices (up to 60 VA and 5 A) have led to large physical sizes for the measurement transformers and, as a result, high costs.

• To meet the accuracy class and stability requirements of the measurement system, special attention has to be paid to the connecting leads between the measurement transformers and the relays.

• The saturation of the transformer cores limits the dynamic range of conventional instrument transformers. Therefore, different Current Transformer (CT) cores and Voltage Transformer (VT) taps have to be provided for the different applications in the secondary systems.

• The saturation of the current transformer cores that takes place at high short-circuit current levels distorts the measured current signal.

• High overvoltages due to ferro-resonances excited by the non-linearity of measurement transformers have repeatedly caused damage to nearby station equipment.

• Because of their complex dielectric structure, voltage transformers represent a weak point in the dielectric insulation of the transmission system.

The replacement of conventional current and voltage transformers by sensors is among the most obvious advantages of intelligent GIS. As a result, high-power input signals are not needed for numerical control and protection equipment. Low-voltage signals with small current values are sufficient, so that heavy and expensive instrument transformers can be replaced by low-power, compact sensing devices. Many significant difficulties with the traditional measuring systems can then be eliminated direct.

B. Combined current-voltage sensor

A combined current and voltage sensor is used to replace the conventional current and voltage transformers in GIS. The current sensor is based on a Rogowski coil (a coreless inductive current transformer). The voltage sensor is based on a capacitive electrical field sensor. Since the Rogowski coil has a linear characteristic, saturation does not have to be taken into account for the protection algorithms [2,3,4].

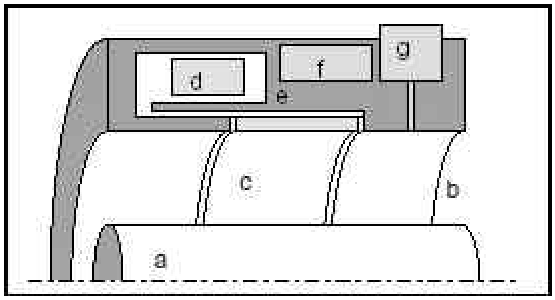

Figure 2. Main primary elements of GIS with combined current and voltage sensor:
a - high voltage conductor, b - insulating gas,
c - voltage measurement electrode, d - current sensor (s) (Rogowski coil), e - encapsulation, f - memory (PROM) of sensor data, g - density sensor (s)

The capacitive ring, which acts as a voltage sensor, also has a linear characteristic and is very simple in terms of the insulation. This solution, including the integrated electronic interface (PISA)

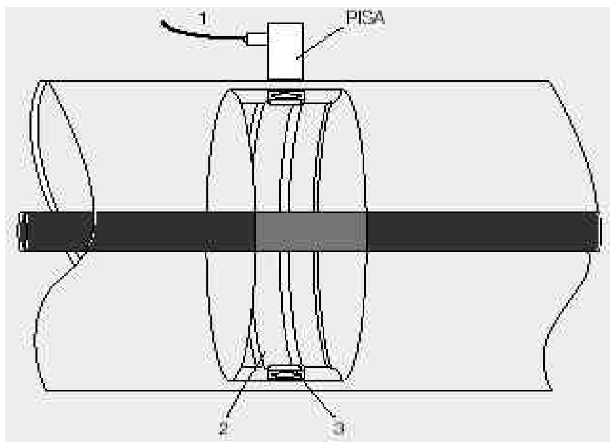

Figure 3. Combined Voltage-Current (UI) sensor for GIS with Process Interface for Sensors and Actuators (PISA)
1 Serial optical fiber link, 2 Voltage sensor,
3 Rogowski coil

C. Functions of PISA

PISA is an abbreviation for **P**rocess **I**nterface for **S**ensors and **A**ctuators. It is an electronic device for data acquisition, formatting and transmitting the measured data over a process bus. Two PISAs can be connected to one combined sensor if the redundancy is required.

1) Main Tasks of the PISA interface:

The PISA interface is responsible for the analogue filtering, the analogue to digital conversion, the digital filtering and the preprocessing of the measured sensor signals . The output signals of the Rogowski coil and the capacitive voltage sensor are the derivatives of the current and voltage to be measured, and are digitally integrated in the PISA interface. PISA sends the measured signals as serial protocols to the connected control and protection equipment via an optical bus connection (process bus).
Further duties may be the local storage of data for the fault recording function of the Station Control System (SCS), some device-specific monitoring and diagnostic functions and intelligent switching functions, such as point on wave switching for circuit breakers.

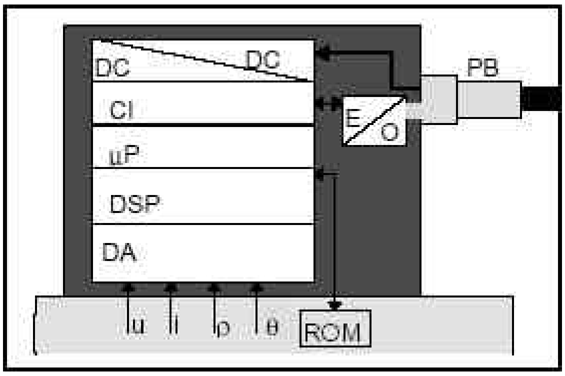

Figure 4. PISA - Block diagram:
PB - system cable consisting of optical process bus and power supply, E/O - data converter (electric optic), DC-DC - power supply, CI - communication interface, mP - microprocessor, DSP - digital signal processing, DA - data Acquisition, ROM - memory element, inputs: u, i, ñ, è - voltage, current, density and temperature.

IV. THE CURRENT AND VOLTAGE SENSORS

Sensors form an important part of the intelligent GIS concept. The cost-saving potential of sensors is a result of the simplification of the insulation system. One solution has been to put the electronic interface close to the current sensor located at HV potential and to transmit the measured signals from the high potential to ground potential by means of an optical digital signal. The power for the electronics located at high potential is supplied either by magnetic or capacitive stray fields or optically by means of laser light through an optical fiber coming from a laser diode at ground potential [2,3].
Given the drawbacks of conventional instrument transformers and the maturity of the numerical protection and control equipment, alternative measurement devices featuring sensors are developed and tested in long-time field trials. The novel sensors are based on various physical principles. There are two basic categories the first category (semi-conventional) is based on conventional electromag- netic measurement techniques but with a strongly reduced power output compared with today's current and voltage transformers; the second category is based on other kinds of physical effects, usually of an optical nature [4,5,6,7].

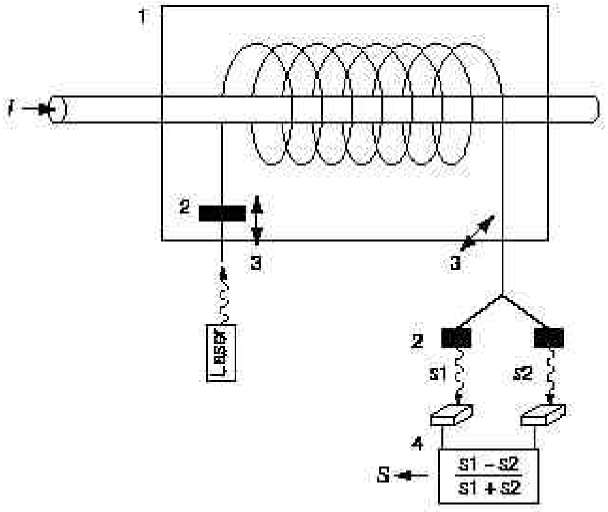

Figure 5. Principle of operation of an optical current measurement sensor:
1 Optical fiber sensor I Current, 2 Polarizer S Light intensity, 3 Angle of polarization, 4 Photodiodes

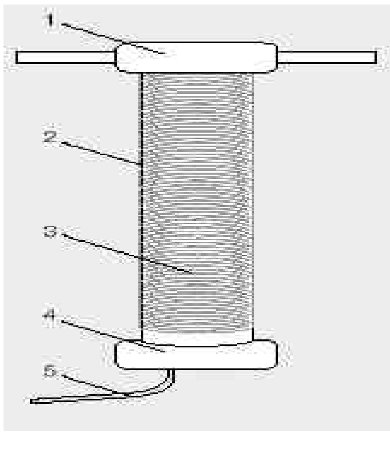

Figure 6. Optical voltage sensor
1 High potential shield
2 Quartz
3 Optical fiber wound around quartz crystal
4 Ground potential shield
5 Optical fiber in/out

V. CONCEPT OF INTELLIGENT GIS

The concept of intelligent GIS is shown in Fig.7 .

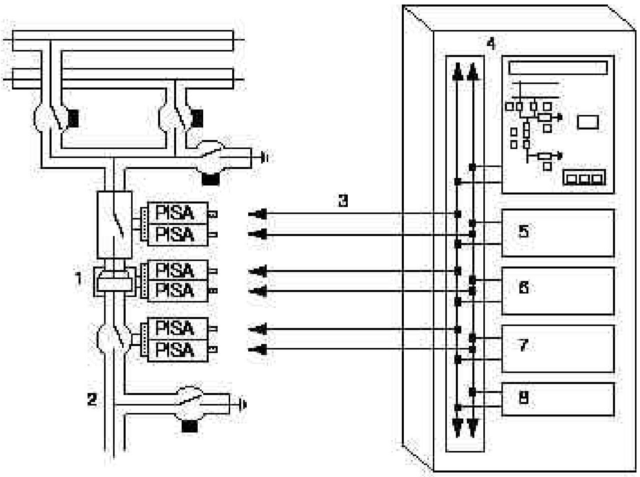

Figure 7. The intelligent GIS bay
1 UI sensor, 2 GIS primary hardware, 3 Redundant serial optical process bus, 4 Local control and protection cubicle, 5 Control back-up protection, 6 Main protection, 7 Metering, 8 Interface to other systems

Its characteristic features are:
• All the primary components are connected to the bay cubicle by means of a serial optical fiber bus. Conventional hard-wired connections are eliminated.
• Each primary device (sensor and actuator) is equipped with an electronic interface dubbed PISA (for Process Interface for Sensors and Actuators).
• As in a modern SCS , the control and protection devices of the intelligent bay are located in the local control cubicle. Certain device-specific monitoring and diagnostic functions can be distributed at the process level or are assigned to the PISA interface. The control and protection devices in the bay cubicle receive the sensor signals via an optical fiber bus (process bus) instead of hard-wired connections.
• The signals from the sensors and actuators are transmitted to the bus once only and are available to all the devices and for every function needing the information. This is one of the most important differences between intelligent GIS and the conventional technology.
• Today, most of the control, protection, measurement and metering devices are connected via separate measurement lines to specific transformer windings or taps. This is mainly due to the fact that these devices need function-specific input power and operate on different signal levels. The saturation of the transformer cores limits the dynamic range. Since it is coreless, the new sensor substantially increases the dynamic range of the measurement. Thus, one sensor is sufficient for all types of measurement.
• The process bus between the PISA interface and the bay units performs in true real time. This is of great importance, as the tripping and current/voltage signals which are transmitted on the bus are required for protection and interlocking functions. A prerequisite for this is that the time scatter between the devices in the bay and the PISA interface is sufficiently small.
• Devices which are not compatible with the standard process bus can be connected to the system by means of an interface.
• In the case of GIS, the power for the PISA interfaces is supplied over copper leads located in the same cable as the optical fibers of the bus.
• To obtain true redundancy the PISA interfaces and the bus connections between the interface and the local control cubicle can be duplicated. Therefore, each critical item of apparatus can be equipped with two identical interfaces and bus connections, each of which supervises the other. In the event of a failure in one of the devices, the other assumes full functionality. An alarm is generated and the defect can be repaired or the circuits replaced easily without interrupting operation in any way.
• Communication between the individual bays and between the bays and the station computer is also via a bus . Ideally, this bus will be of the same type as the process bus. In this way, the real-time communication between the bays – for example, for the inter-bay interlocking – can also take place over the optical serial bus [1,8,9,10,11].

Modern microcomputer, digital signal processor, analog-to-digital converter, optical transducer and fibre optic communication technologies provide an opportunity to acquire and process electrical power system information in a new, and effective way [12].

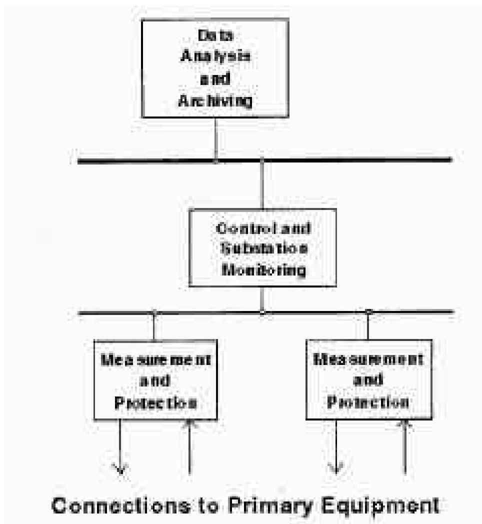

Figure 8. Integrated Protection and Control System Architecture

VI. CONCLUSIONS

The system concept of the intelligent GIS is a prerequisite for the economical introduction of sensors and of monitoring and diagnostic functions into station control systems.

Since all of the switching and measuring devices of the primary equipment are equipped with a process interface (PISA) and the computing power is available directly at the process, monitoring and device-specific supervision functions are possible which were previously either not feasible or were very expensive to realize. The effectiveness of controlled switching in terms of overvoltage reduction has been proved by field tests. Alongside synchronized closing, there is a trend towards synchronized opening, ie, opening with an optimum arcing time. With intelligent GIS, the software algorithms that run today on separate, standalone computers will be implemented in the system at the level of the PISA interface for the circuit-breaker.

Basically, the GIS maintenance and service procedures are supported by computer-aided monitoring and diagnostic functions. The trend is towards replacement of the regular maintenance work by automatic equipment status checks as well as towards increasing equipment lifetime with the help of device-specific diagnostics running as software modules loaded in the PISA interface. The electronics are fully selfsupervised and signal an alarm in the event of a defect. The described redundancy concept enables electronic components to be replaced without having to interrupt operation of the primary device. Control and protection equipment in general is increasingly being built with standardized computer boards. Long-term contracts, standards and the correct selection of electronic components will ensure adequate availability of spare parts during the lifetime of a GIS. Given the rapid pace of development in the electronics sector, electronic components will continue to be replaced on a functional basis.

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