Future-oriented concepts for substation protection and control

Modern substations feature both a higher level of automation and a higher reliability than their predecessors. Sensors, digital switchgear controls, and advanced process control software, have come onto the market in recent years which are creating a new platform for substation secondary technology and providing many benefits for users. Use of digital switchbay control and protection equipment in medium-voltage and simple high-voltage substations has further increased the high functionality and reliability of the primary systems.

PYRAMID is a digital control system [1], developed by ABB for substations operating at every voltage level. Tasks it performs include local and remote control, signalling, measurement, interlocking and protection. The system, which has a simple, logical structure, is based on programmable microprocessors, fiber optics and serial data communication. PYRAMID's configuration for medium-voltage and simple high-voltage substations is shown in 1.

At the station level, its MicroSCADA video control and display system provides operators with an up-to-date overview of events and equipment statuses in the substation which is difficult to obtain with conventional technologies. Menus guide the operator through the system. At the switchbay/switchpanel level, there are control units for all the protection, control, measurement, monitoring and communication tasks.

Hardware which can be tailored to suit the substation

The SCUs (switchbay control units) 2 are microprocessor-based. This technology and the benefits that come from software-driven process control give the units the capability to perform a wide range of functions. The SCUs can be economically adapted to practically every substation requirement through parameterization, based on the customer's specific needs and actual switchpanel conditions. 3 shows a medium-voltage substation in which the SCUs perform the control and protection functions for the individual switchpanels. The panels are also equipped with the usual current and voltage sensors 4, plus inductive proximity switches [2].

In order to meet the full range of requirements of substation operators, the SCU development engineers designed this unit with a hardware platform that divides the full range of functions among several microprocessors. 5 shows the basic structure of the hardware as well as how the functions are distributed.

Dr. Volker Biewendt
Dr. Werner Ebbinghaus
Rudolf Wiegand
ABB Calor Emag Schaltanlagen AG

New sensor technology for process interfacing

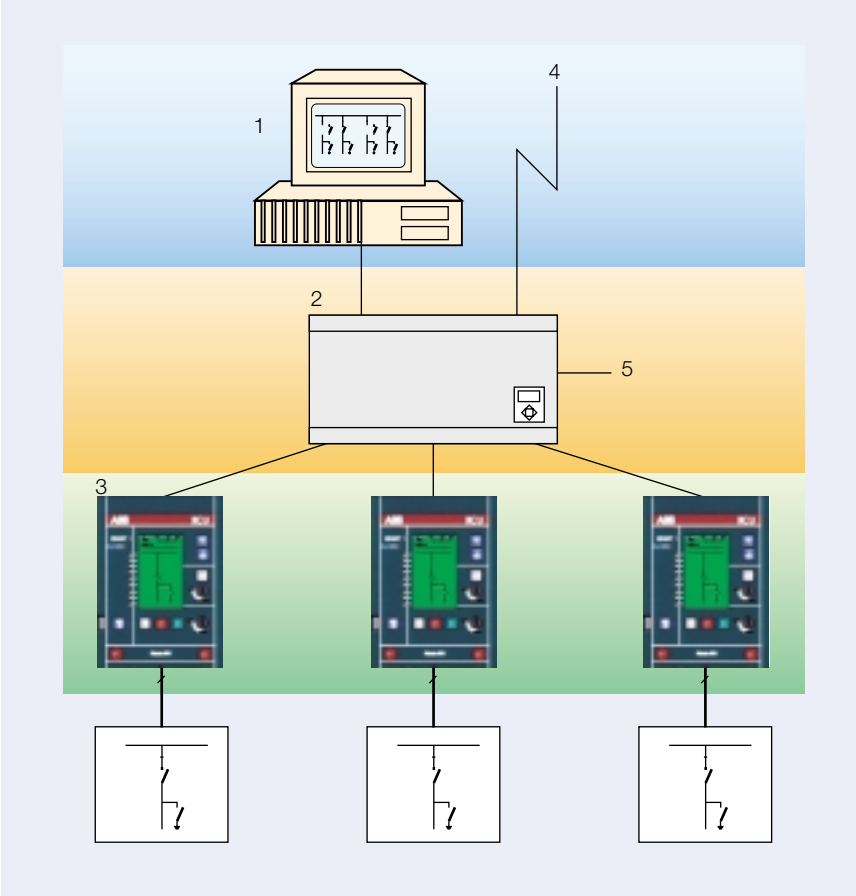
The SCUs are interfaced with the medium-voltage switchpanels through electrically isolated input/output units. Messages and control signals are exchanged via these I/Os.

Sensors link the binary inputs to the operating equipment [2]. The switchgear statuses are identified by inductive proximity switches. Due to their small size, the sensors can be positioned for direct, precise detection, thus allowing more reliable status signalling. Also, being contactless, they feature long service lives and high dependability.

The SCUs can also be interfaced with freely selectable external signals for the process control.

Power semiconductors are used for the control and signal outputs, enabling the switchgear to be operated without extra contactors. A large part of the wiring that was necessary in the past for the secondary systems has therefore been eliminated. The SCUs control and monitor the switchgear installed in the switchpanels (eg, vacuum circuit-breakers, disconnectors and grounding switches) as well as the switching apparatus at lower levels (eg, in an LV substation). The switchgear statuses are also displayed.

Current sensors (Rogowski coils) and voltage sensors (potentiometer-type resistors) measure the current and voltage signals 4. These high-precision



Basic configuration of the PYRAMID digital control system for medium-voltage and simple high-voltage substations **1**

Blue *Station level*
Yellow *Communication level*
Green *Bay/panel control level*

1 *Local control*
2 *Modular station unit*
3 *Switchbay control and protection unit (SCU)*
4 *Link to load dispatching centers*
5 *Ancillaries, busbar protection*

sensors are mounted in the switchpanels as combined instrument transformers, and feature a linear response and wide dynamic range. The signals provide the information needed for the calculation of the frequency, mean and maximum current values, apparent and active power as well as energy values.

Local operator's panel with graphic display

Each of the SCUs has a standardized operator interface with liquid crystal display. A freely programmable mimic diagram of the switchpanel configuration **6**, with integrated dual-colour LEDs and showing related, freely programmable plain-text messages and alarms, etc, provides the user with direct information about the current status of the panel **7**.

Control is via this mimic diagram and the selector and on/off buttons. Local or remote control can be authorized by means of key-operated switches. In the 'input' mode, the operator can vary the parameters of activated protection functions on the panel, activate or deactivate reclosure functions, store maximum values, and reset energy values and circuit-breaker data.

Bargraphs and numerical displays of the measured currents and voltages, calculated reactive power, active power and energy values, are other items of information available to the operators.

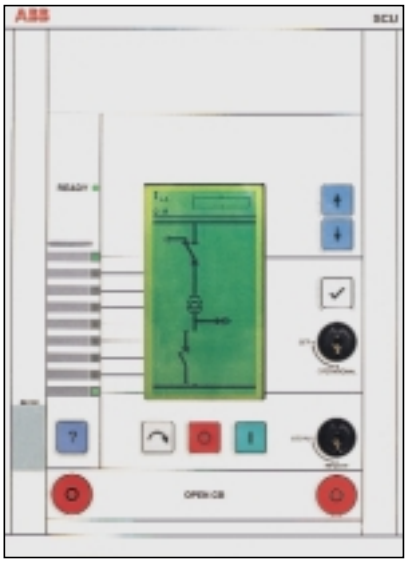
The functions offered by the local operator's panel on the SCU can be tailored exactly to the substation requirements with the help of application-specific software.

Protection functions

The implemented protection functions are based on the current and voltage signals received from the sensors. The range of functions covers the protection usually provided in medium-voltage and smaller high-voltage substations, for example overcurrent and earth fault protection (directional and non-directional in each case), overvoltage and undervoltage protection, plus distance protection. The individual functions can be combined as required to give the switchpanel the protection capability it needs to meet the substation's specific requirements.

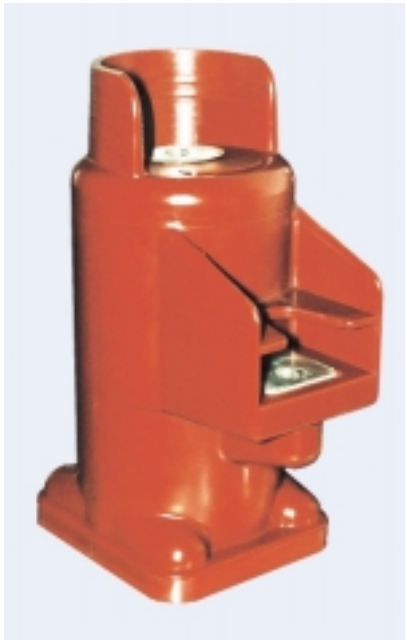
All the protection functions can be implemented in such a way that the circuit-breaker opens when they re-

The SCU offers a high level of functionality and reliability **2**



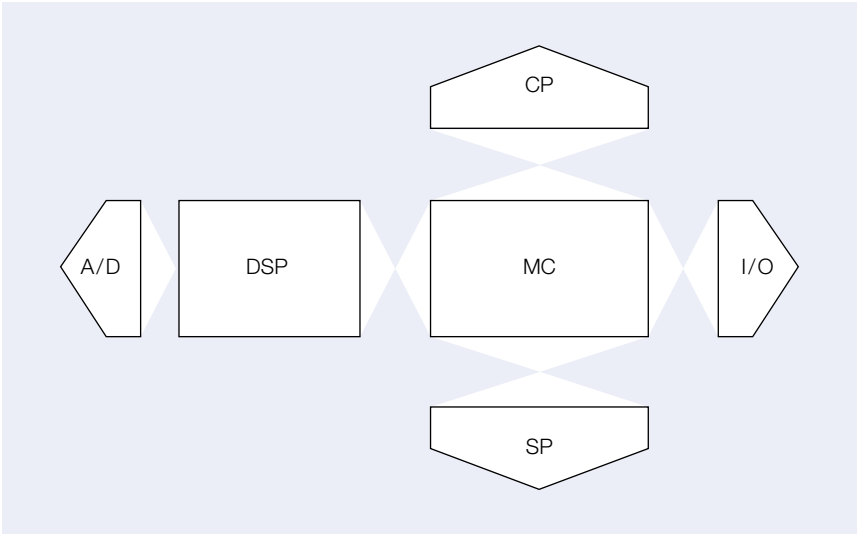
Medium-voltage substation with SCUs **3**

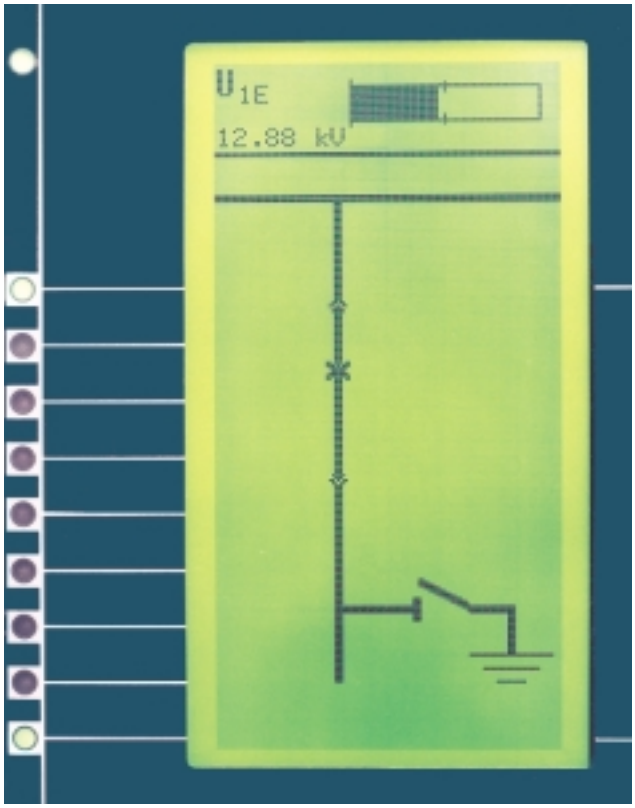
Combined current and voltage sensor **4**



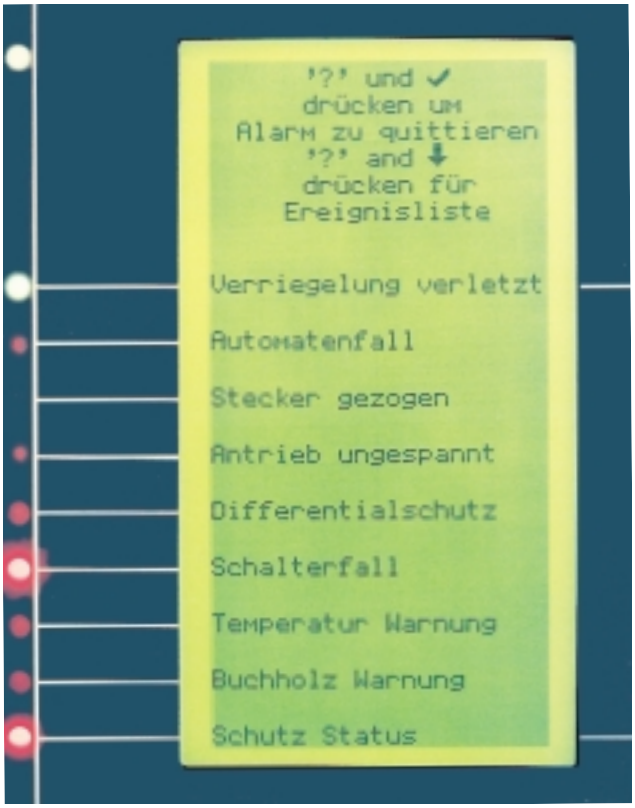
SCU processors, with functions **5**

CP	*Communication processor*
A/D	*Analogue/digital converter*
DSP	*Signal processor for protection and measurement*
MC	*Main processor for control and signalling*
SP	*Sensor processor*
I/O	*Interface*





Mimic panel showing the configuration for a single-busbar bay 6



Messages in plain text provide operators with details of a bay's operating status, including information about interlock violations, breaker tripping and protection conditions. 7

spond. Also possible is their use as signalling or alarm functions, as are combinations of these two options (ie, with and without operation of the circuit-breaker).

Switchpanel and substation interlocking

To avoid operational disturbances due to erroneous switching, it is necessary to interlock the switchgear within each switchpanel and from panel to panel. Within the panels, for example, it is important to interlock the disconnector, circuit-breaker and earthing switch. Substation-wide, interlocking has to include the bus-section ties and the bus couplers.

Considering the above, it is clear that the interlocking conditions can vary widely from substation to substation. In conventional secondary systems, the interlocks may be run over collector wires, wires in the switchpanel, and contactors. The extensive wiring that is needed is not only a considerable cost item but also a major source of potential disturbance.

With the SCU, all the interlocking functions can be implemented in the panel via the software. The interlocks that extend beyond individual switchpanels are led over a bus or over collector wires, and are tied into the appropriate units via the software.

This type of switchgear interlocking has the advantage that the equipment can be completely tested with the help of simulators before commissioning begins. The time for on-site commissioning of the substation is shorter as a result.

Switchpanel monitoring

The SCU offers a wide range of monitoring functions:

- The trip circuits of the circuit-breaker are permanently supervised. The SCU immediately detects any defect in the circuits and signals the disturbance before a malfunction can occur.
- The breaker switching cycles and switched currents are recorded to allow the contact erosion to be estimated. This information can be accessed by the control room staff and processed as required. Substation operators can therefore schedule maintenance work for a switchpanel as and when it becomes necessary rather than at regular intervals.
- The running time of the make/break units and the recharge time required by the energy storage mechanism are

recorded and compared with the set-points. In the event of deviations, the SCU signals an alarm or displays an appropriate message.

- Permanent self-monitoring of the SCU hardware and software guarantees immediate detection of a failure or fault. The supervisory module trips a local alarm or activates the implemented watchdog function. It is therefore possible to replace the defective equipment before malfunctioning (eg, the protection not tripping in the event of a fault) can cause damage. Permanent self-monitoring also does away with many of the tests that otherwise have to be carried out on the equipment at specific intervals.

Applications in conventional medium-voltage switchboards

The SCU has been designed to accept an add-on instrument transformer package. It allows the SCU to be used in switchboards with conventional current and voltage transformers or with contacts for signalling the switching statuses of the switchgear. The package is equally well-suited for new installations and retrofit projects.

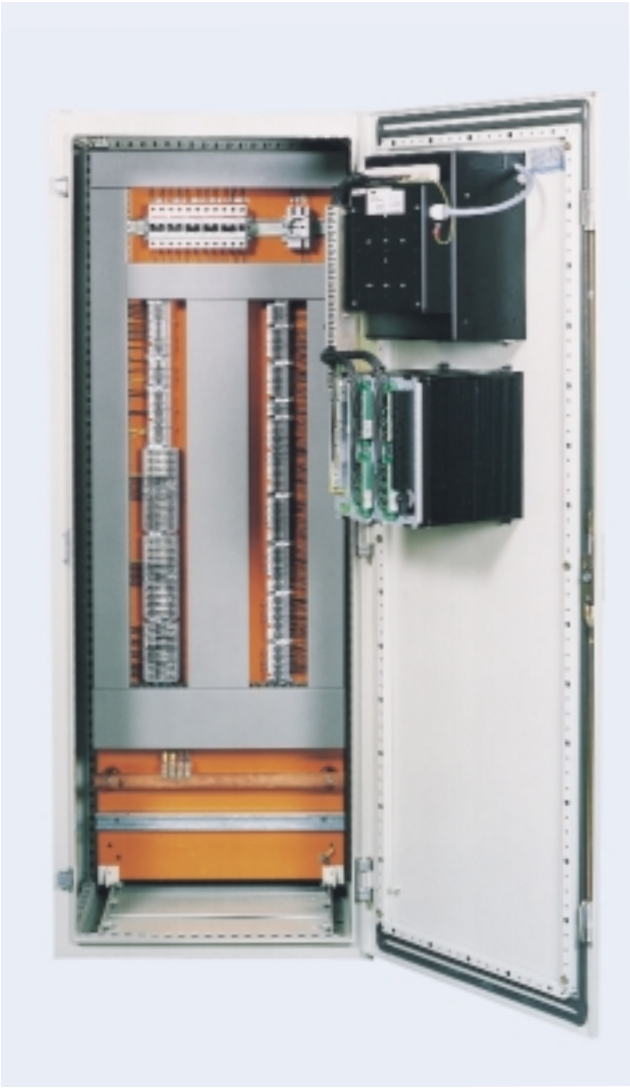
This option also offers special benefits for substation operators: compactness, easy mounting in the switchpanel, a high level of functionality and user-friendliness, plus a choice of information indicating the panel's condition. A very wide range of application exists for this option.

Small high-voltage substations

The SCU also has many advantages for operators of simple types of high-voltage substation, in which its protection func-

Compact control panel with SCU for a simple HV switchbay. Capabilities include back-up protection and additional main protection. **8**

The same control cubicle with opened door **9**



tions can be used to provide back-up protection. Operation of the switchboards and switchbays is identical in high- and medium-voltage substations – another plus for utilities working towards standardized operations control.

8 shows a compact switchbay control panel for a simpler type of high-voltage substation, and 9 the same panel with the door opened. The chosen panel size demonstrates that this new concept, with the SCU as control and back-up protection unit, plus additional main protection, also allows simpler, more transparent and economic solutions for secondary systems at the high-voltage level.

Integrating switchbays with SCUs at the station level

Bays with SCU in otherwise conventional substations

At the bay level, the SCU performs the secondary system functions that relay systems perform in conventional stations. At the lowest level, ie, with the simplest SCU configurations, the individual bays can be interconnected and linked to the station-level systems in the conventional way, using wires. In such cases, the advantages of the digital modules only come to the fore at the bay level.

Bays with SCUs embedded PYRAMID

The SCU is equipped with a high-performance serial interface for simple coupling to the station level via fiber optic cables. Serial coupling of this kind not only allows a considerable saving in wiring and attendant costs but also permits transmission to the station level of all the measured and calculated analog values (U, I, P, Q, cos φ, frequency, switching cycles, switched currents, etc), all the binary values (eg, events, position statuses, alarms, plus time tags), and the parameters for the protection settings. In addition, it allows the transmission of fault data to the relevant evaluation system.

In this more advanced configuration, the SCU is embedded in the PYRAMID digital control system. Integrating the SCU in this way allows all of the digitized functions to be used to special advantage.

Transparent and user-friendly

At the station level, PYRAMID offers users the video control and display system MicroSCADA. This can be used for local control with a graphic 3D windows user interface (OSF Motif) run on a personal computer. Multiple video control and display workstations can be installed to suit the specific project size and requirements. Communication between the workstations within the distributed system is via Ethernet. Process data as well as complete graphics can be exchanged.

Substation-specific tasks, such as the generation of collective messages, integration of secondary installations, higher-order control of transformers, etc, are also performed at the station level.

Modular station unit as connecting link

The serial links connecting the individual bays, panels and station level are brought together in a modular station unit equipped with, among other things, interfaces for coupling the bay level and the station control system to one or more load dispatching centers or any required process control system (eg, in a power plant or industrial facility). The data for synchronizing the system components are also transmitted over this unit.

Versatile, yet standardized

The SCU offers numerous measurement, control, protection and monitoring functions in a single, compact unit. This makes it much easier to tailor the switchbay or panel to a specific process. By using advanced sensors to measure the current and voltage and to identify switchgear statuses, a substantial improvement is also achieved in the accuracy and availability of the input signals.

The combination of different functions in a single unit offers operators a standardized, user-friendly environment extending from the medium-voltage level to simpler high-voltage bays, providing benefits even for conventional substations.

The integration of the switchpanel control in the higher-order PYRAMID substation control system enables the advantages of the SCUs to be utilized more comprehensively at the station level. Also, this control technology allows very easy link-up of substations to load dispatching centers or process control centers.

References

[1] General description: PYRAMID – the total switchgear protection and control concept. ABB Calor Emag Schaltanlagen AG. Publ. no.: DEACE 1024 95E.

[2] E. Dullni, H. Fink, G. Hörner: Steuerung moderner Leistungsschalter. etz (1995) 11, 8–14.

Authors' addresses

Dr. Volker Biewendt
Dr. Werner Ebbinghaus
ABB Calor Emag Schaltanlagen AG
Bahnhofstrasse 39–47
D-40878 Ratingen
Germany
Telefax: +49 2102 12 1713

Rudolf Wiegand
ABB Calor Emag Schaltanlagen AG
Käfertaler Strasse 250
D-68167 Mannheim
Germany
Telefax: +49 621 386 2815