# PASS for retrofitting, extending and constructing new high-voltage substations

**The improved reliability and availability of substation equipment, new approaches to voltage and current measurement, and the introduction of modern control, protection and monitoring concepts, have opened the door to new possibilities in substation design. PASS, for Plug And Switch System, is a highly innovative hybrid switchbay system for high-voltage substations. It is based on state-of-the art technology and is suitable for retrofit and expansion projects as well as new substations.**

Innovation in high-voltage substation products has been relatively limited in recent decades. Some key components have undergone major technological changes, eg circuit-breakers (airblast and minimum oil to $SF_6$ gas), arresters (gap to gapless) and current and voltage transformers (oil to $SF_6$ gas), but this has happened without substantial changes to their external dimensions. Consequently, the changes have not allowed any major modifications to the layout of the substations.

In the late 1960s and 1970s GIS technology brought a major advance in terms of in-service conditions and space requirements. Today, there are several countries using almost only GIS technology, especially in the lower high-voltage range.

Many of the existing substations have now outlived their useful operational life. An increasing number of users are considering a one to one replacement of components such as circuit-breakers, disconnectors, etc, or whether to replace them with completely new primary and secondary technologies in order to upgrade and increase the availability of the substations at the same time.

It has been usual in the past not to replace the switchgear, control and protection equipment, etc, at the same time. This approach led to a relatively low innovation rate for retrofit projects, as it did not allow new concepts to be easily adapted to the existing substation designs. There were many 'interface problems' between the suppliers of the high-voltage equipment and the engineers responsible for the substation design.

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This prompted the development of innovative substation concepts for both AIS and GIS applications.

## Trends

The following development trends in component technologies are contributing to the introduction of a new substation concept.

### Circuit-breakers

The number of interrupters required is steadily decreasing. A single interrupter for ratings of up to 300 kV and two interrupters for ratings of up to 550 kV are today the state of the art. Increasing use of the self-blast principle means that less operating energy is required. Consequently, the mechanical reliability of the circuit-breaker is increasing, which reduces the need for maintenance. Controlled switching is another innovation that has simplified the breakers, since they no longer require closing resistors. In a few years time, all breakers across the whole voltage range can be expected to have only one interrupter and to require only very little drive energy. Porcelain insulators are being replaced by composite types, making the circuit-breakers simpler and lighter in weight.

### Disconnectors and earthing switches

Since the breakers are becoming simpler and smaller, the function of the disconnector can be integrated in the circuit-breaker itself. In addition, disconnecting and earthing functions can be combined.

The reduction in maintenance and the higher reliability also mean that fewer disconnectors and earthing switches are needed in the first place.

### Current and voltage sensors

Substation designers can choose between a wide variety of current and voltage sensors based on optical or electrical working principles. Most of them can be integrated either in the breaker or the bushing insulator. Control equipment designed to communicate

***Smart GIS – the new generation of gas-insulated substations*** **1**

a *Smart GIS for 123 kV*

b *Smart GIS for 550 kV*

with these sensors is also available. Protection equipment, which needs only low-energy analogue signals, is already on the market. Equipment capable of working directly with digital signals is also being developed.

### Control systems, maintenance, diagnostics, intelligent switching

Lately, traditional switchgear control has been complemented by systems for recording and analyzing gas density trends, breaker timing and speed, and contact wear in breakers and other components, etc. These measurements provide information about necessary maintenance or repair at an early stage. Devices for controlled switching are used to reduce stress in the breakers and the connected high-voltage components.

The trend today is towards all standard and optional functions being handled by just one or two processing units. Data transfer will be digital, via fiber optics, thereby saving a great deal of copper hard-wiring and project engineering work.

### Insulators

Due to the good experience with composite insulators on transmission lines and, increasingly, in substation applications, this type of insulator will be used in ever-larger numbers in substations in the future. Besides reducing the weight, this also eliminates the cleaning and greasing of insulators that was necessary in the past.

Future AIS substations will therefore look quite different from their present-day designs. The described advantages will benefit mainly retrofit projects and new substations. A one to one replacement of individual AIS components is not the optimum solution for retrofitting substations.

## Innovations already implemented in substation and switchgear design

Several of the described development trends have already found their way to the marketplace in the form of new products.

For example, optical current and voltage sensors for outdoor applications as well as equipment with integrated monitoring functions are available.

### Smart GIS

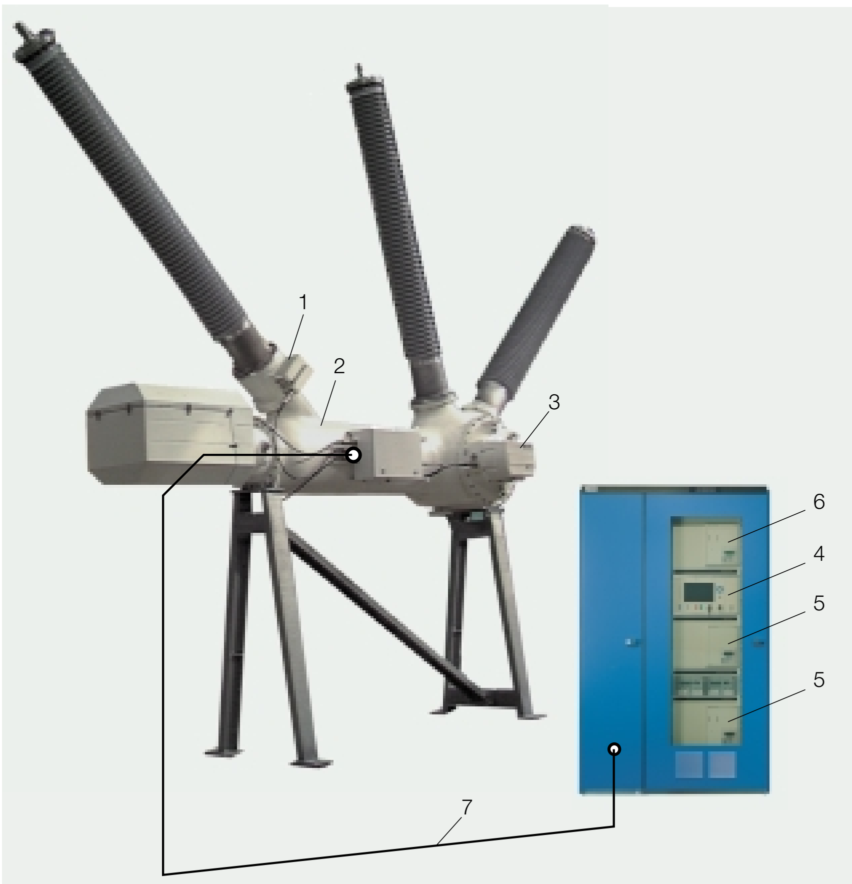
In the new generation of GIS substations rated at 123 to 550 kV **1**, the inductive voltage and current transformers, which are heavy and large, have been replaced by optical or electrical sensors. The drive motors for the disconnectors and earthing switches are controlled electronically, and the function of the auxiliary switch is performed by a sensor mounted directly on the operating rod.

The control and protection signals are

***Substation extension with PASS (coupler bay)*** **2**

***PASS – single-pole switching module with control and protection cubicle*** **3**

1 *Combined current/voltage sensor*
2 *Circuit-breaker*
3 *Combined disconnector/earthing switch*
4 *Bay control unit*
5 *Main protection*
6 *Back-up protection*
7 *Optical bus (signal transmission)*




transmitted in digital form over fiber optic links.

Smart substation technology of this kind is certain to achieve a market breakthrough within a very short time.

### PASS

Another, unique substation technology based on new approaches to high-voltage component design is PASS, for Plug And Switch System **2**. PASS has been designed primarily to meet growing retrofit requirements in the high-voltage substation market, but is equally well suited for extensions and new substations. PASS considerably reduces the planning and project engineering work for substations. The higher availability with PASS in comparison with conventional AIS substations reduces lifetime costs by a significant amount.

## PASS concept

### Design

PASS is a metal-enclosed, gas-insulated combination of circuit-breaker, disconnectors, earthing switch, current and voltage sensors, and bushings located in a common gas compartment **3**.

The high-voltage switchgear is limited to the minimum amount of equipment really necessary to guarantee the functionality of the bay or the substation for all typical configurations. Each unit is completely assembled and routinely tested in the factory. PASS is shipped preassembled except for the bushings.

The circuit-breaker and the disconnectors and earthing switch used in PASS are all based on proven GIS technology. The bushings consist mainly of an insulator made of composite material. An epoxy resin-impregnated glass fiber tube ensures the required mechanical properties, while the moulded silicon rubber housing provides the necessary creepage distance and protects against the environment. Effective voltage control is provided by an extended grounded electrode.

### Current and voltage measurement

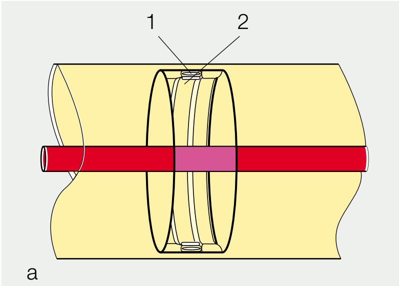
The function of the traditional high-voltage current and voltage instrument transformers is performed by an advanced generation of current and voltage sensors combining both the functions in a single component **4**. For the current measurement a Rogowski coil (an air-core ring coil) is used. This measures the current with the highest precision and without saturation across the entire operating range. The voltage is measured by means of a metal-enclosed, capacitor voltage divider. This avoids any ferromagnetic resonance.

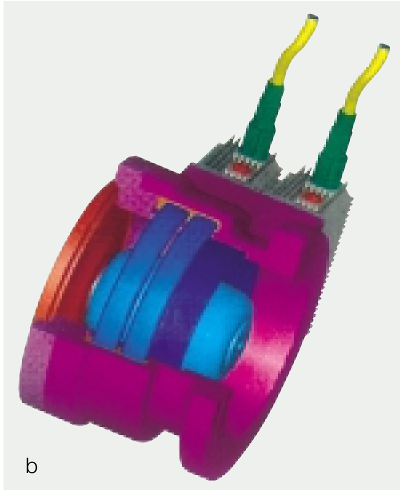
The measured signals are processed by PASS itself after being digitized by a Process Interface for Sensors and Actuators (PISA) and then sent, in serial form, via the optical process bus (IEC 1375) to the bay protection and control level. The sensors are normally located in the outgoing circuit of the breaker and meet all the demands made on control and measurement as well as on state-of-the-art protection and revenue metering. Approval of this system by the authorities is expected shortly. The concept also allows additional sensors to be fitted on the busbar side of the circuit-breaker if this should be necessary for protection or any other reasons (eg, synchronized switching).

### Control, protection and monitoring

The drive control, the density measurement and various measurements for monitoring are also realized with modern sensor technology. The Process Interface for Sensors and Actuators (PISA) integrated in PASS digitizes the measured analogue signals before transmitting them serially over the optical process bus to the bay level.

For this connection to the control and protection system (control cabinet) there is a plug-ended cable which incorporates the fiber optic (bus) cable for analogue and binary signal exchange as well as the auxiliary power supply for the drive mechanisms. This version of PASS can be connected to numerical/digital protection systems. Conventional toroidal-core current or voltage transformers are required for the electromechanical and solid-state protection relays.




***Schematic (a) and model (b) of the current and voltage sensors for PASS and GIS*** **4**

1 *Current sensor (Rogowski coil)*
2 *Voltage sensor (capacitive ring)*

The wide use of sensors make it possible to implement a large range of monitoring features, such as self-checking, trend analysis of the gas density and circuit-breaker conditions (pump running time, operations, energy needs, contact displacement curve, remaining lifetime, etc).

### Installation and commissioning

PASS needs only one foundation per pole. The wiring and inspection of the bay control cabinet is carried out in the factory. Only a few hours are needed to install and commission a PASS bay, since the plug-in connecting cables contain the serial optical bus as well as the power supply.

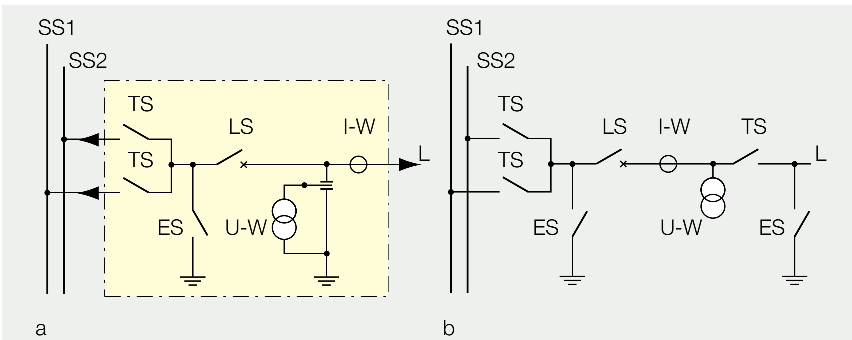
### Availability and single-line diagram

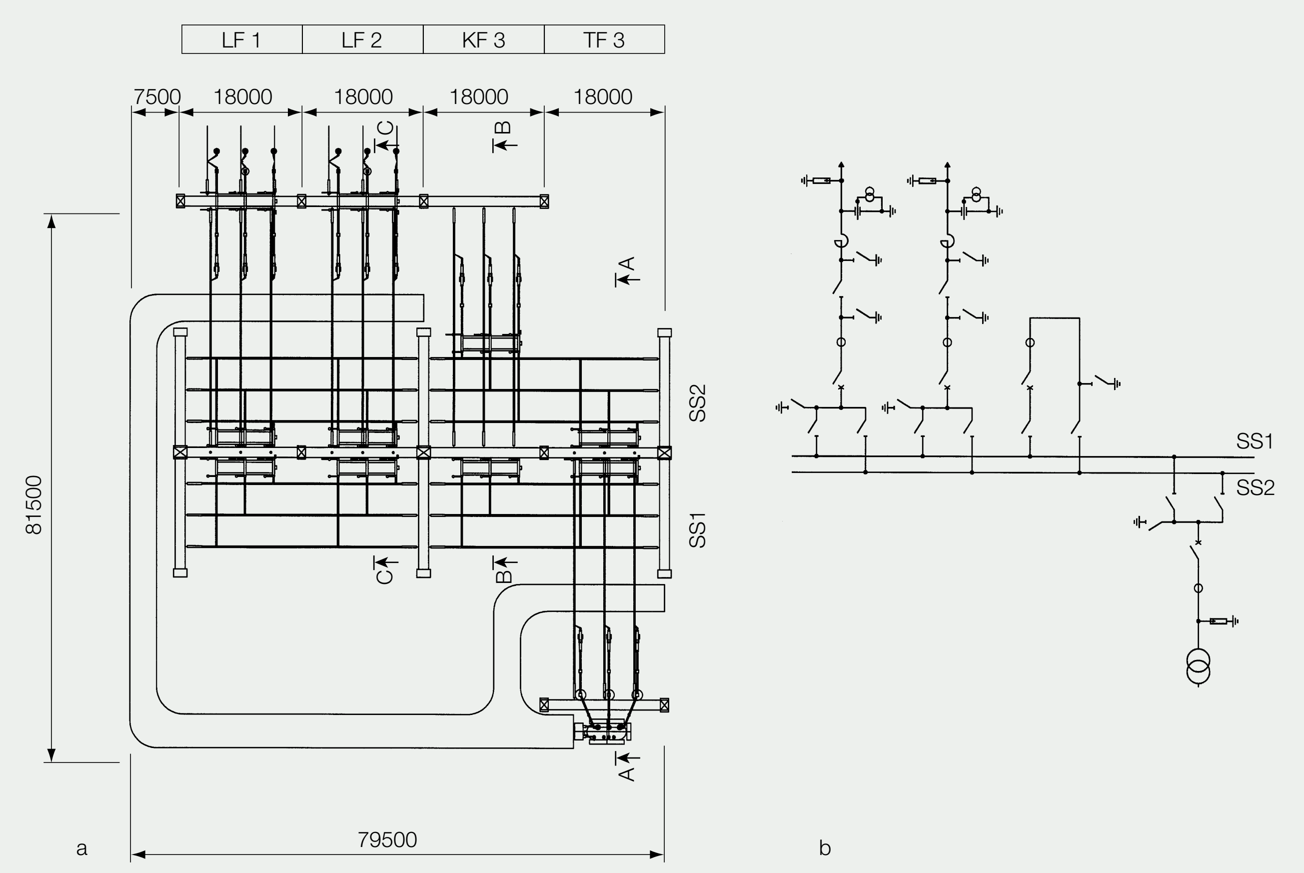
The difference between the single-line diagram for PASS **5a** and that of a conventional AIS **5b** is the missing disconnector and earthing switch on the line side in the former.

In many conventional types of substation, the line-side disconnector is needed only to isolate the high-voltage equipment when maintenance has to be carried out. For many PASS substation configurations, the line-side disconnect and earthing switches can be eliminated on account of the high reliability

***Single-line diagram of PASS (a) and conventional AIS (b) configuration for a double busbar bay*** **5**

LS *Circuit-breaker*
TS *Disconnectors*
ES *Earthing switch*
I-W *Current transformer*
U-W *Voltage transformer*
L *Line*
SS *Busbar*



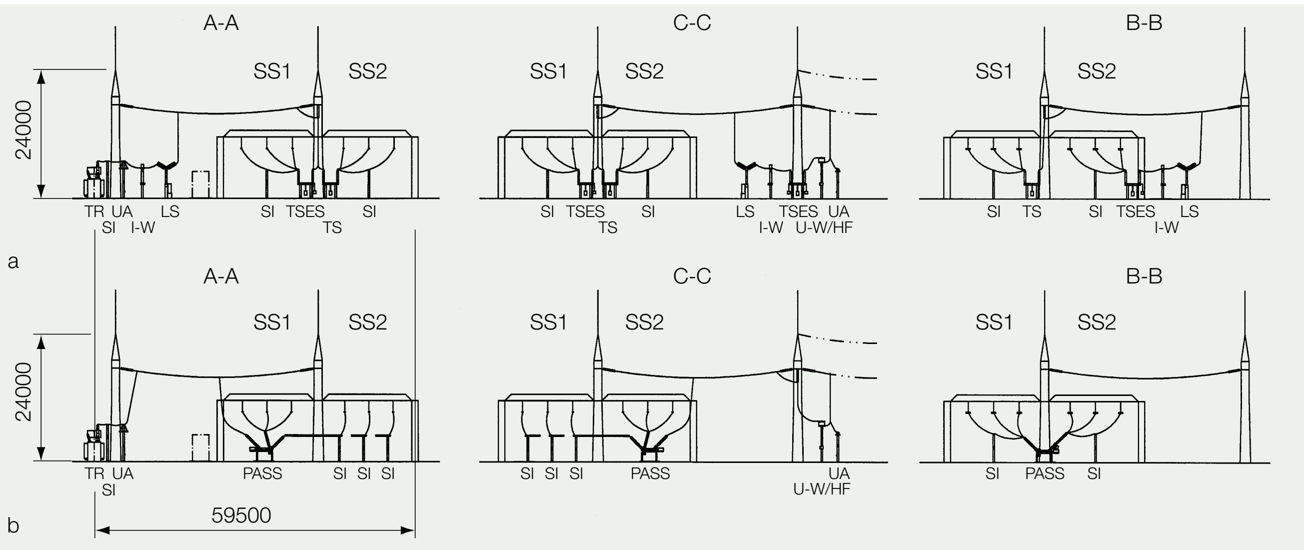


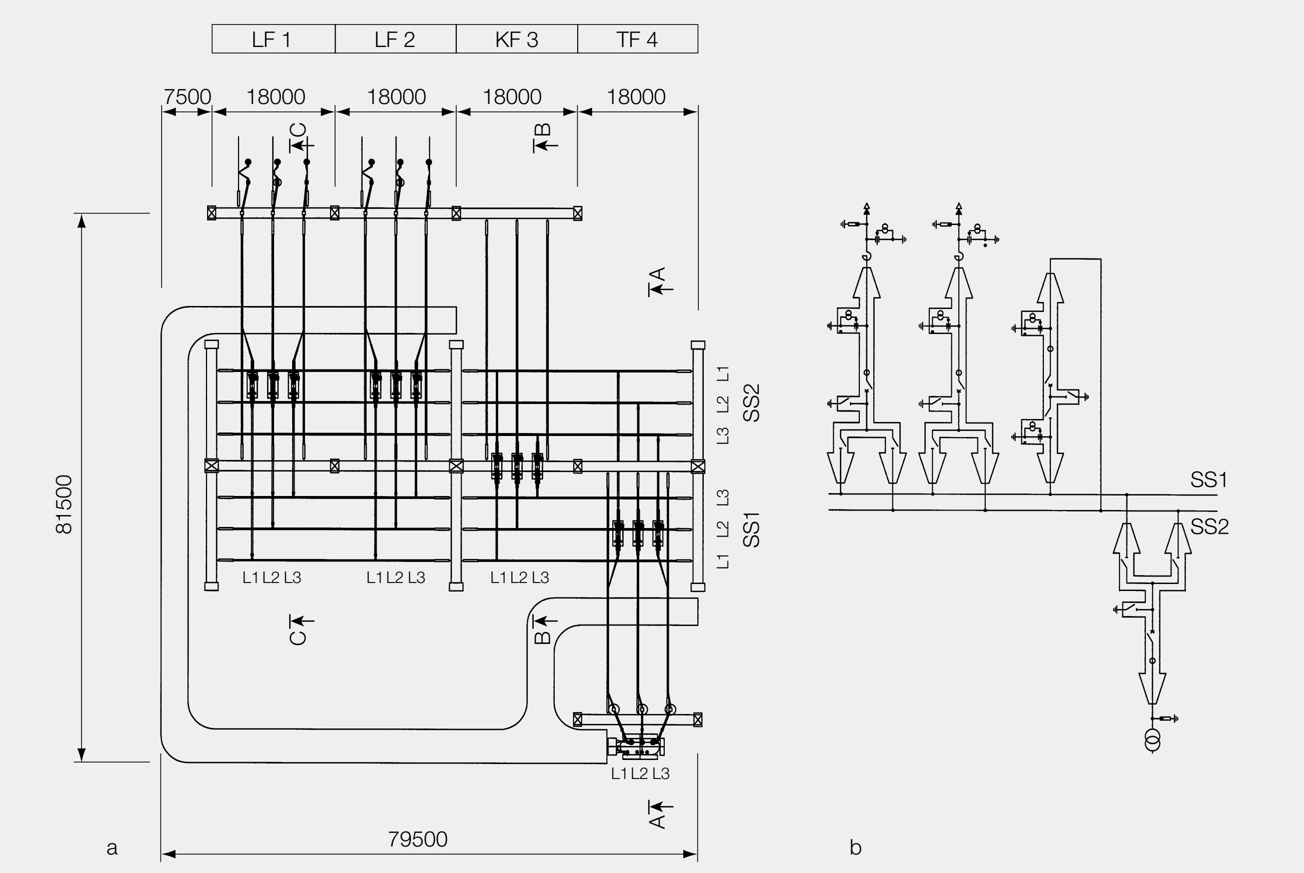

***Plan view (a) and single-line diagram (b) of an older 220-kV substation with double busbar*** **6**

LF *Line bay*
KF *Coupler bay*
TF *Transformer bay*
SS *Busbar*

***Transformer bay, coupler bay and line bay of the substation shown in 6 before (a) and after (b) retrofitting with PASS*** **7**

SS *Busbars*
TR *Transformer*
SI *Post insulator*
UA *Surge arrester*
I-W *Current transformerr*
LS *Circuit-breaker*
TSES *Disconnector/earthing switch*
TS *Disconnector*
U-W/HF *Voltage transformer*






***Plan view (a) and single-line diagram (b) of the 220-kV substation retrofitted with PASS, with double busbar*** **8**

LF *Line bay*
KF *Coupler bay*
TF *Transformer bay*
L *Line*
SS *Busbars*

and long-term availability of PASS. A comparison of the availability of the double busbar bays in **5** shows that the long-term non-availability in the case of the PASS bay lies between 0.060 and 0.120 h/a, whereas for the AIS bay it is 0.525 h/a. In each of these cases, the reliability data from *Table 1* was taken into account. The long-term availability of PASS substations is therefore 5 to 10 times that of functionally comparable AIS substations. For example, in a double busbar substation with 20 PASS bays a failure would occur every ten years, being repaired on average in 12 to 24 hours.

The line is earthed by closing the circuit-breaker after the busbar disconnector has been opened and the earthing switch has been closed. In such cases, the closing circuit-breaker acts as a fast-acting earthing

**Table 1:**
**Reliability data for PASS and conventional AIS substations**

| Components | Double busbar switchbay PASS λ (F/y) | MTTF (y) | MTTR (h) | AIS λ (F/y) | MTTF (y) | MTTR (h) |
|---|---|---|---|---|---|---|
| Busbar | 0.007 1) | 143 1) | 3.5 1) | 0.007 1) | 143 1) | 3.5 1) |
| Circuit-breaker | – | – | – | 0.007 1) | 143 1) | 72 1 |
| Disconnector | – | – | – | 0.0061 2) | 164 2) | 3.6 2) |
| PASS | 0.005 3) | 200 3) | 12–24 3) | | | |

MTTF Mean time to failure
MTTR Mean time to repair
λ Failure rate, assumed constant

1) IEEE Press: Applied reliability assessment in electric power systems. Page 398.

2) IEEE Std. 493–1990: Recommended practice for the design of reliable industrial and commercial power systems.

3) Planning data for PASS: MTTF = 200 years (experience with GIS), MTTR = 12–24 hours (repair/replacement concept)

switch. This practice is common in medium-voltage switchgear.

## Applications

### Retrofitting AIS substations

When retrofitting AIS substations, the existing components in each phase are replaced by one PASS module.

**6** shows the plan view and single-line diagram of an older 220-kV double busbar substation with two line bays, one bus coupler bay and one transformer bay. Often, the steel structures and busbars are still in good condition, so that only the circuit-breakers, current transformers and disconnect and earthing switches need to be replaced on account of their age. When the substation is located at a critical node in the power system, the shorter power supply interruption when PASS is installed is an additional benefit for the utility.

**7** shows a transformer, bus coupler and line bay before and after retrofitting with PASS. No modification to the existing structures or busbars is necessary with PASS, and the only other changes that are required in this substation are to the post insulators and the tubular and stranded conductors.

The plan view and single-line diagram shown in **8** are of a 220-kV double busbar substation retrofitted with PASS. The space required for the substation shown in **6** and **8**, which has a length of 81.5 m and a width of 79.5 m, is 6,480 m$^2$, and remains unchanged after retrofitting.

However, unused spaces have been created to the left and right of the busbar area which would allow easy dismantling of a PASS pole if this becomes necessary. To allow fast, direct replacement, it is recommended that the new foundation be built before the conversion is carried out.

### Extension of an AIS substation with limited space

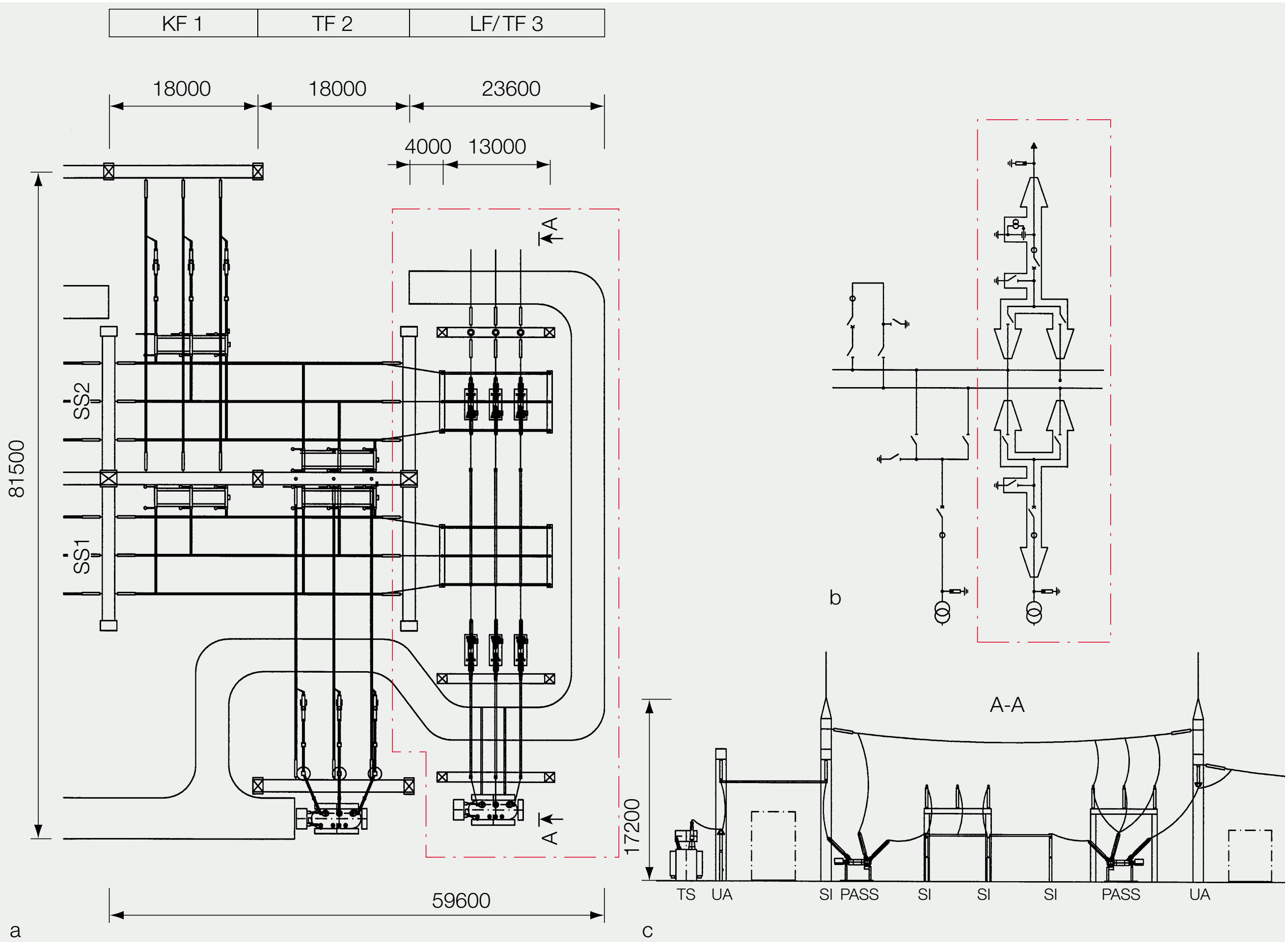
The substation shown in **6** is to be extended by a transformer and a line bay next to the

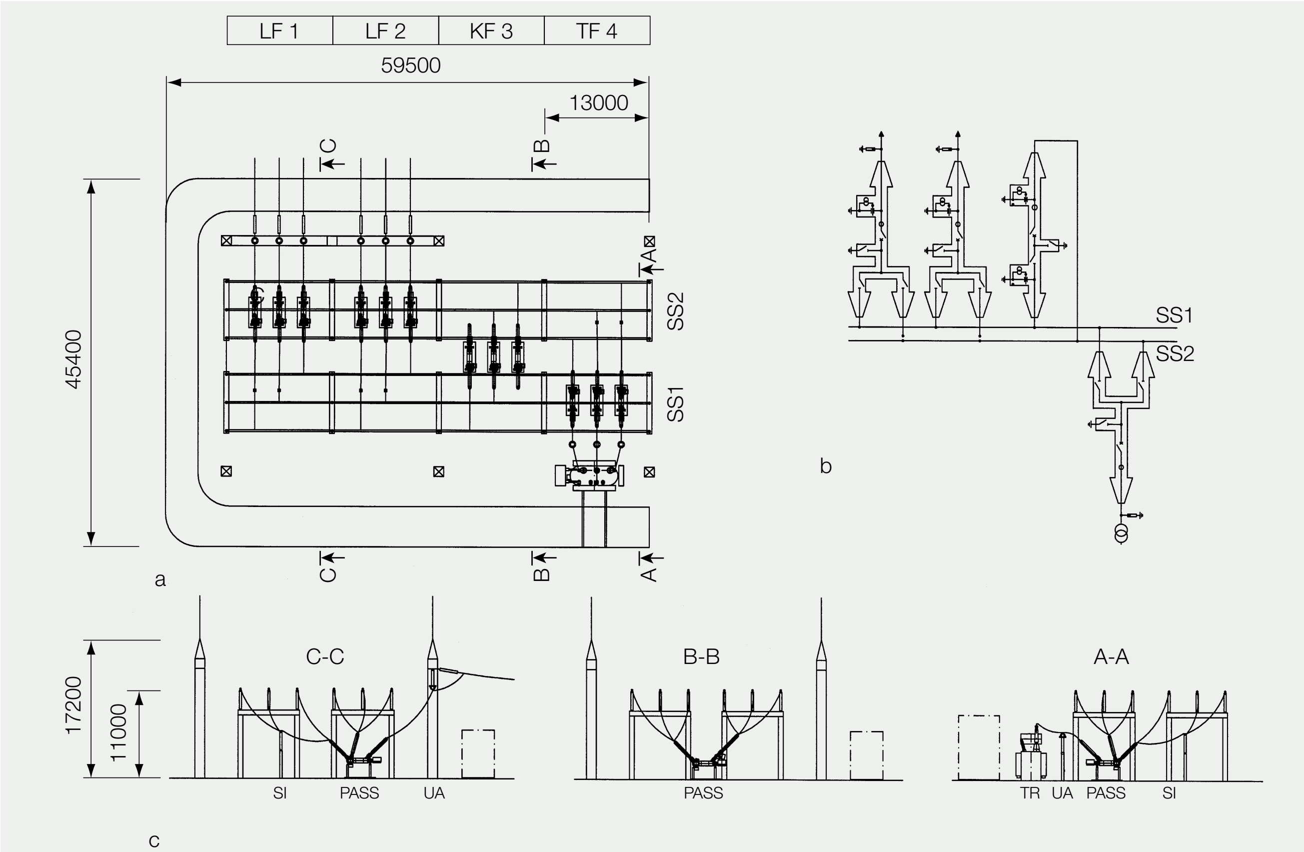
***Section of the substation shown in 6, including the added transformer bay and line bay (inside red line)*** **9**

a *Plan view*
b *Single-line diagram*
c *Section A-A*

KF *Coupler bay*
TF *Transformer bay*
LF *Line bay*

SS *Busbars*
UA *Surge arrester*
SI *Post insulator*






***New PASS double busbar substation for 220 kV. The older substation shown in 6 will have this configuration when the new technology is used.*** **10**

a *Plan view* b *Single-line diagram* c *Sectional views*

existing transformer bay. Since there is only a limited amount of space for the extension, an optimum, space-saving configuration is essential. **9** shows a section of the existing substation **6**, including the added transformer bay and line bay, as well as the single-line diagram and the sectional view of the extended line/transformer bay. Only one bay width is necessary for the common transformer and line feeder. This so-called in-line configuration is only possible with conventional double busbar systems when a U-shaped arrangement is chosen. With the in-line transformer/line bay arrangement, a bay width of 13 m, plus 4 m for the connection of the existing busbars to the new bay, is required. For each additional bay the substation width needs to be enlarged by only 13 m.

If the substation were to be extended using the conventional side-by-side layout, it would have to be enlarged by two times 18 m, ie 36 m.

### Temporary use of PASS for maintenance work

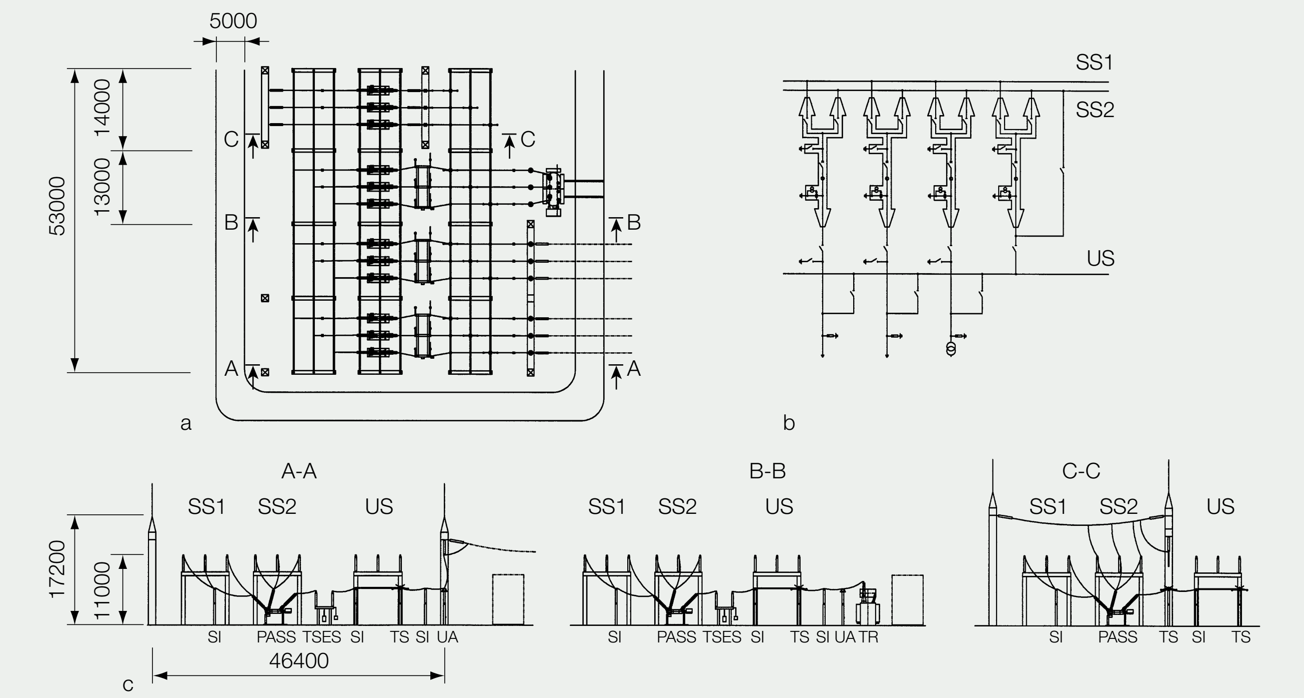
When carrying out extensive maintenance work on one or more AIS bays, PASS can be installed in parallel with the existing bays to avoid having to interrupt the power supply during the work. Afterwards, the PASS modules can be simply removed.

### New substations with PASS

**10** shows the identical double busbar set-up as in **6**, except that the whole substation has been built with PASS. The functionality of the AIS substation, which would require multiple main components, can be achieved with just three PASS modules per bay.

The substation with PASS has the following advantages over AIS substations:

- Smaller distances between phases due to the use of tubular busbars in a low-profile arrangement, compared with the stranded conductors and traditional high-profile arrangement; fewer steel structures are therefore required.
- Shorter stranded conductor connections to the PASS modules.
- Reduced steady-state and electromagnetic forces due to the shorter connections.
- Reduced bay width and bay length as a result of the integrated functions and shorter stranded conductors.
- Fewer insulators, ie reduced risk of spark-over as a result of pollution.
- Insulator chains eliminated or reduced in number.




***220-kV double-busbar substation with transfer bus US*** **11**

a *Plan view*

b *Single-line diagram*

c *Sectional views*

- Fewer steel structures and grounding materials.
- Fewer foundations and cable trenches.

The plan view of the PASS substation with a length of 45.4 m and a width of 59.5 m, equivalent to a total area of 2,700 m$^2$, is shown in **10**. The PASS substation in this examples requires only 42 percent of the space taken up by the AIS in **6**

PASS allows new substation layouts and designs with fewer structural frames and supports. The number of necessary foundations is therefore also reduced. Besides the double busbar layout shown in **10**, the in-line double busbar configuration is also possible. The difference lies in the reduced lengths and widths of the bays.

The in-line arrangement is especially suitable for applications where space is restricted and where the substation is to be installed below an overhead transmission line.

PASS can also be used for other substation configurations, eg ring-bus, two-breaker, 1$^1/_2$-breaker or H-arrangements, etc, at rated voltages of 123 kV and above. **11** shows, as an example, a plan view and sectional view of a 220-kV double busbar arrangement with transfer bus, as used commonly in Europe.

**Conclusions**

The introduction of digital technology to the control and protection of HV substations and the accumulated operating experience with GIS substations has paved the way to new high-voltage switchbays (PASS) which are especially well suited for the refurbishment of the large number of substations dating from the 1950s and 1960s. The special advantages of PASS come to the fore when extensive conversions are planned. PASS meets market requirements for a reduction in planning, faster completion of retrofit projects, and lower investment, operating and lifetime costs in an optimum way.

In the long term, the one to one retrofit strategy used widely in the past will prove not to be the most economical solution.

For extensions that become necessary, PASS has the benefits of great versatility and a small footprint.

The advantages for new substations, besides those already mentioned, are the reduction by 60 to 70 percent in required land area, compared with conventional concepts. This underlines the overall economy of PASS for such applications.

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