6 Protection, Substation Automation, Power Quality and Measurement

6.1 Introduction

The demands on substation automation solutions are continually growing, which leads to greater complexity and more interfaces. High availability, with all individual components working together smoothly, is one of the most important system operator needs in the area of energy automation.

And that is exactly where Energy Automation products and solutions from Siemens come in. With a comprehensive approach to the entire automation chain, the system operator gets an overview of the entire plant, from planning and start up to operation and maintenance.

Energy Automation products and solutions are based on three main pillars that ensure simple operation:

- Reliable IT security through high-quality applications and seamless network structures
- Limitless communications by means of international standards and flexible expandability
- Efficient engineering for the entire automation chain, from the control center to the field device

Energy Automation from Siemens stands for a simplified workflow, reliable operations, and a significantly lower total cost of ownership. Siemens offers expert solutions that will continue to grow with the market's demands but still remain manageable. That is how Energy Automation sets a new benchmark with products and solutions which are clearly simpler and more efficient. In the meantime we have delivered more than 200.000 devices with IEC61850 included.

Energy automation that simply works
Siemens offers a uniform, universal technology for the entire functional scope of secondary equipment, both in the construction and connection of the devices, and in their operation and communication. This results in uniformity of design, coordinated interfaces, and the same operating principle being established throughout, whether in power system and generator protection, in measurement and recording systems, in substation control or protection or in telecontrol.

The devices are highly compact and immune to interference, and are therefore also suitable for direct installation in switchgear panels.

Fig. 6.1-1: **Siemens energy automation products**

Complete technology from one partner
Siemens Energy Sector supplies devices and systems for:
- Power system protection SIPROTEC and Reyrolle
- Substation control and automation SICAM
- Remote control (RTUs)
- Measurement and recording SIMEAS

This technology covers all of the measurement, control, automation and protection functions for substations.

Furthermore, Siemens's activities include:
- Consulting
- Planning
- Design
- Commissioning and service

This uniform technology from a single source saves the user time and money in the planning, assembly and operation of substations.

6.2 Protection Systems

6.2.1 Introduction

Siemens is one of the world's leading suppliers of protection equipment for power systems. Thousands of Siemens relays ensure first-class performance in transmission and distribution systems on all voltage levels, all over the world, in countries with tropical heat or arctic frost. For many years, Siemens has also significantly influenced the development of protection technology:

- In 1976, the first minicomputer (process computer)-based protection system was commissioned: A total of 10 systems for 110 / 20 kV substations was supplied and is still operating satisfactorily today.
- In 1985, Siemens became the first company to manufacture a range of fully numerical relays with standardized communication interfaces. Siemens now offers a complete range of protection relays for all applications with numerical busbar and machine protection.

Section 6.2.2 gives an overview of the various product lines of the Siemens protection.

Section 6.2.3 offers application hints for typical protection schemes such as:
- Cables and overhead lines
- Transformers
- Motors and generators
- Busbars

To ensure a selective protection system, section 6.2.4 gives hints for coordinated protection setting and selection for instrument transformers. The „Relay Selection Guide" in section 6.2.5 provides an overview of the relay function mix as a guide for selecting the right protection relay for the corresponding protection application.

6.2.2 SIPROTEC and Reyrolle Relay Families

Solutions for today's and future power supply systems – for more than 100 years

SIPROTEC has established itself on the energy market for decades as a powerful and complete system family of numerical protection relays and bay controllers from Siemens.

SIPROTEC protection relays from Siemens can be consistently used throughout all applications in medium and high voltage. With SIPROTEC, operators have their systems firmly and safely under control, and have the basis to implement cost-efficient solutions for all duties in modern, intelligent and "smart" grids. Users can combine the units of the different SIPROTEC device series at will for solving manifold duties – because SIPROTEC stands for continuity, openness and future-proof design.

As the innovation driver and trendsetter in the field of protection systems for 100 years, Siemens helps system operators to design their grids in an intelligent, ecological, reliable and efficient way, and to operate them economically. As a pioneer, Siemens has decisively influenced the development of numerical protection systems (fig. 6.2-4). The first application went into operation in Würzburg, Germany, in 1977. Consistent integration of protection and control functions for all SIPROTEC devices was the innovation step in the 90ies. After release of the communication standard IEC 61850 in the year 2004, Siemens was the first manufacturer worldwide to put a system with this communication standard into operation.

How can system operators benefit from this experience?

- Proven and complete applications
- Easy integration into your system
- Highest quality of hardware and software
- Excellent operator friendliness of devices and tools
- Easy data exchange between applications
- Extraordinary consistency between product- and systemengineering
- Reduced complexity by easy operation
- Siemens as a reliable, worldwide operating partner

6

SIPROTEC – a synonym for protection devices

Over 100 years of experience in the field of protection devices and substation automation almost says it all. Yet the highest appreciation must be given to some milestones in the history of this great product. The very first family of SIPROTEC products already had a head start in being ahead of its competitors. Find out how the continuous drive for technological improvements and brilliant minds have kept this success story going and going and going.

Several milestones in the history of SIPROTEC have defined not only the technology of this product family but its fundamental character. With more than one million SIPROTEC units in the field, we are clearly the market leader in Digital Protection Technology.

1902 Schuckert & Co. (1887): DC metering device based on Georg Hummel's principle

1925 First overcurrent relay RA1 and delayed action relay RS1

1940 Introduction of new overcurrent relay RA5

1970 Introduction of analog electronic relays

1977 First digital application in Würzburg, Germany

1980s The digital era for relays begins

1985 Introduction of first numerical relay in combination with control technology SINAUT LSA

1998 Introduction of SIPROTEC 4 family

Fig. 6.2-3: **Siemens protection family**

The products of the long-standing British manufacturer Reyrolle are considered especially powerful and reliable by many markets. With the latest numerical products, Reyrolle – as a part of Siemens shows that the development is being pushed forward, and that new innovations are continuously being developed further for the users' benefit. In this way, Reyrolle completes the offerings for protection devices, particularly in Great Britain and the Commonwealth countries.

Fig. 6.2-4: **SIPROTEC – Pioneer over generations**

SIPROTEC easy

SIPROTEC easy are CT power supplied or auxiliary power supplied, numerical time-overcurrent protection relays, which can be used as line and transformer protection (back-up protection) in electrical power supply systems with single-ended supply. They offer definite time-overcurrent and inverse time-overcurrent protection functions according to IEC and ANSI. The comfortable operation via DIP switch is self-explanatory and simple.

- Two-stage time-overcurrent protection
- Saving the auxiliary power supply by operation via integrated current transformer supply
- Cost-efficient due to the use of instrument transformers with low ratings
- Tripping via pulse output (DC 24 V / 0.1 Ws) or tripping relay output
- Simple, self-explanatory parameterization and operation via DIP switch directly at the device
- Easy installation due to compact assembly on DIN rail.

Fig. 6.2-5: **SIPROTEC easy**

SIPROTEC Compact (series 600)

The devices of the SIPROTEC Compact series (series 600) are compact, numerical protection devices for application in medium-voltage or industrial power supply systems. The corresponding device types are available for the different applications such as time-overcurrent protection, line differential protection, transient ground-fault relay or busbar protection.

- Space-saving due to compact design
- Reliable process connections by means of solid terminal blocks
- Effective fault evaluation by means of integrated fault recording and SIGRA 4
- Communication interface
- Operable and evaluable via DIGSI 4
- Different device types available for directional and non-directional applications.

Fig. 6.2-6: **SIPROTEC Compact (series 600)**

Reyrolle – the alternative solution for your distribution grid
Reyrolle has been synonymous with electrical protection devices in the sectors of sub-transmission, distribution and industrial applications for decades. Historically, Reyrolle relays, initially sold mainly in traditional markets, are now sold worldwide as part of the Siemens protection network.

Since its foundation, Reyrolle has been an innovation driver in product development – based on a strong focus on market, customer and technology. Worldwide established brand names such as "Solkor" and "Argus" demonstrate this. But there is more: A wide range of Reyrolle products has determined technological firsts in the market.

The comprehensive range of Reyrolle products provides the total protection requirements of distribution markets – ranging from overcurrent protection via transformer protection and voltage control to a full spectrum of auxiliary and trip relays. The portfolio includes many famous products such as "Argus", "Duobias", "Solkor", "MicroTAPP", etc.

To serve specific needs in industrial applications, a range of proven products such as "Argus overcurrent", "Solkor line differential" and "Rho motor protection devices" is offered.

Through successive generations, Reyrolle numerical products have been developed to increase value to system operators. This increase in value is the result of consistent development:

- Ease-of-use as a principle – the products allow flexible, easy operation through high user friendliness.
- One size fits all – the latest generation of numerical products features 1A/5A CT Input, and some models are provided with universal DC supplies.
- Learn once, know all – the new product generation provides a similar look and feel as earlier products. If Reyrolle numerical devices have been previously used, there is a high consistency in both programming and interrogation.
- With Reydisp Evolution, a comprehensive software support toolkit for relay setting, fault interrogation and general system information is provided. It is backward-compatible with all previous Reyrolle numerical devices.

Fig. 6.2-7: **Front view of Argus 7SR210**

Fig. 6.2-8: **Rear view of Argus 7SR210**

SIPROTEC Compact
Perfect protection, smallest space reliable and flexible protection for energy distribution and industrial systems with minimum space requirements. The devices of the SIPROTEC Compact family offer an extensive variety of functions in a compact and thus space-saving 1/6 x 19" housing. The devices can be used as main protection in medium-voltage applications or as back-up protection in high-voltage systems.

SIPROTEC Compact provides suitable devices for many applications in energy distribution, such as the protection of feeders, lines or motors. Moreover, it also performs tasks such as system decoupling, load shedding, load restoration, as well as voltage and frequency protection.

The SIPROTEC Compact series is based on millions of operational experience with SIPROTEC 4 and a further-developed, compact hardware, in which many customer suggestions were integrated. This offers maximum reliability combined with excellent functionality and flexibility.

- Simple installation by means of pluggable current and voltage terminal blocks
- Thresholds adjustable via software (3 stages guarantee a safe and reliable recording of input signals)
- Easy adjustment of secondary current transformer values (1 A/5 A) to primary transformers via DIGSI 4
- Quick operations at the device by means of 9 freely programmable function keys
- Clear overview with six-line display
- Easy service due to buffer battery replaceable at the front side
- Use of standard cables via USB port at the front
- Integration in the communication network by means of two further communication interfaces
- High availability due to integrated redundancy (electrical or visual) for IEC 61850 communication
- Reduction of wiring between devices by means of cross-communication via Ethernet (IEC 61850 GOOSE)
- Time synchronization to the millisecond via Ethernet with SNTP for targeted fault evaluation
- Adjustable to the protection requirements by means of "flexible protection functions"
- Comfortable engineering and evaluation via DIGSI 4.

Fig. 6.2-9: **SIPROTEC Compact**

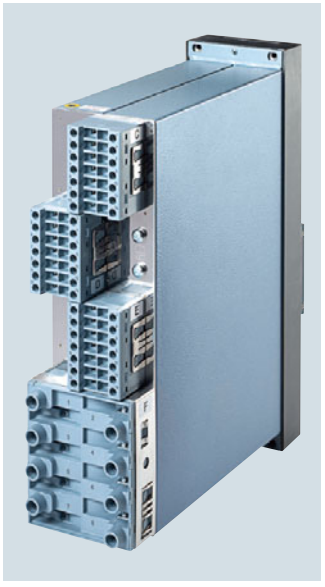


Fig. 6.2-10: **SIPROTEC Compact – rear view**

Fig. 6.2-11: **Feeder automation relay 7SC80**

SIPROTEC Compact – system features
Field devices in energy distribution systems and in industrial applications must cover the most varying tasks, and yet be adjustable easily and at short notice. These tasks comprise, for example:

- Protection of different operational equipment such as lines, cables, motors and busbars
- Decoupling and disconnecting of parts of the power supply system
- Load shedding and load restoration
- Voltage and frequency protection
- Local or remote control of circuit-breakers
- Acquisition and recording of measured values and events
- Communication with neighboring devices or the control center

Fig. 6.2-12 shows exemplary how the most different tasks can be easily and safely solved with the matching SIPROTEC Compact devices.

Operation
During the development of SIPROTEC Compact, special value was placed not only on a powerful functionality, but also on simple and intuitive operation by the operating personnel. Freely assignable LEDs and a six-line display guarantee an unambiguous and clear indication of the process states.

In conjunction with up to 9 function keys and the control keys for the operational equipment, the operating personnel can react quickly and safely to every situation. This ensures a high operational reliability even under stress situations, thus reducing the training effort considerably.

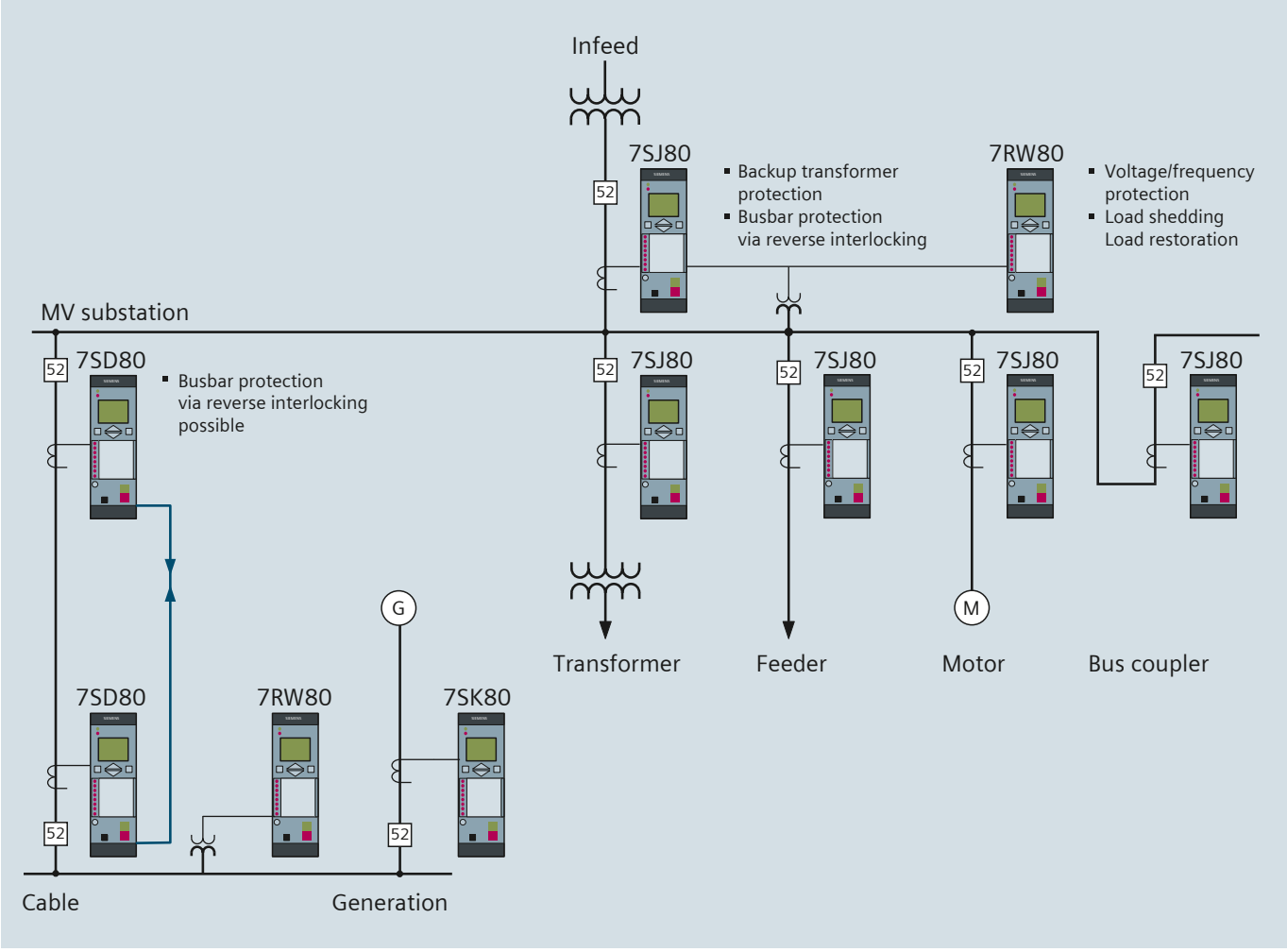


Fig. 6.2-12: **Fields of application in a typical MV system**

The Feeder Automation device 7SC80 is designed for decentralized as well as for centralized feeder automation applications. This solution allows various flexible high speed applications like Fault Location, Isolation, and Service Restoration (FLISR). Detect and locate a fault in the feeder, isolate the faulty section and set the healthy portions of the feeder back into service

Source transfer
Detect and isolate a faulty source and set the de-energised sections of the feeder back into service

Load Balancing
Balance the load within a feeder by moving the Normally Open Point

Section Isolation
Isolate a dedicated section of a feeder for maintenance without affecting other sections

Restore
Set the feeder back to its defined normal/steady state

Fig. 6.2-13 shows an example of a typical ring main application with overhead lines and 5 sections.

Every section is protected and automated by the 7SC80 Feeder Automation device.

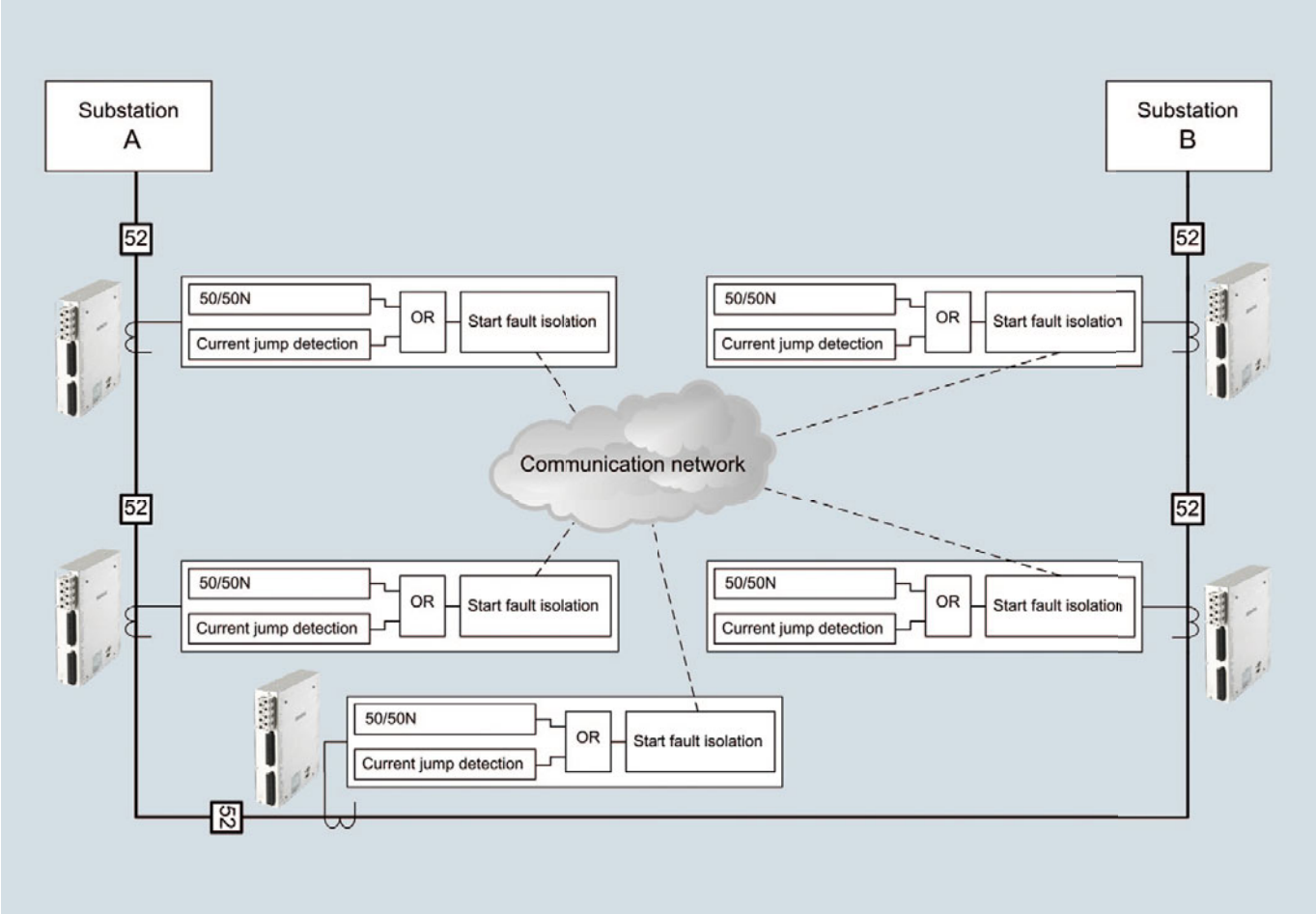


Fig. 6.2-13: **Fields of application with feeder automation controller 7SC80**

Local operation

All operations and information can be executed via an integrated user interface:

2 operation LEDs

In an illuminated 6-line LC display, process and device information can be indicated as text in different lists.

4 navigation keys

8 freely programmable LEDs serve for indication of process or device information. The LEDs can be labeled user-specifically. The LED reset key resets the LEDs.

9 freely configurable function keys support the user in performing frequent operations quickly and comfortably.

Numerical operation keys

USB user interface (type B) for modern and fast communication with the operating software DIGSI.

Keys "O" and "I" for direct control of operational equipment.

Battery compartment accessible from outside.

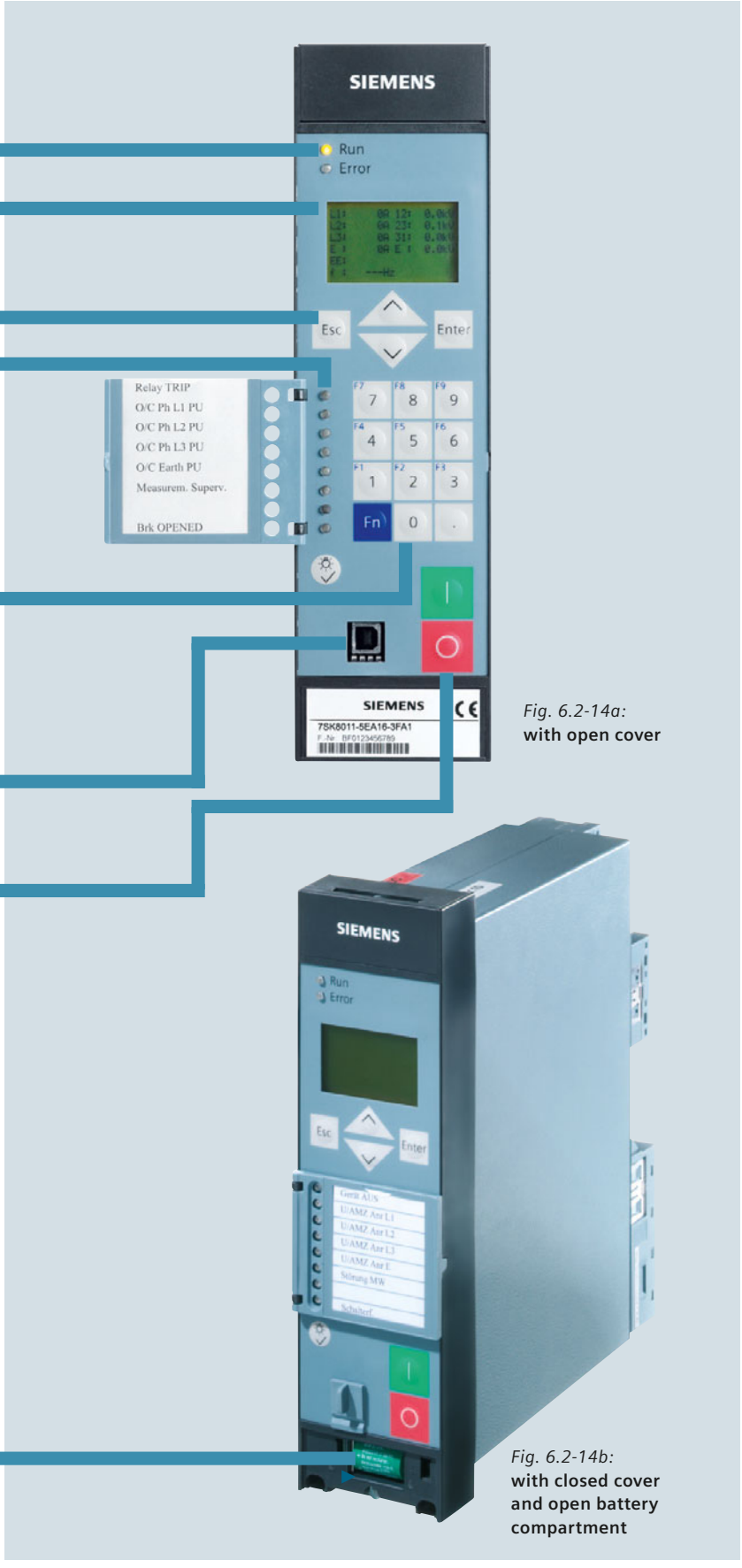


Fig. 6.2-14a:
with open cover

Fig. 6.2-14b:
with closed cover and open battery compartment

6

Construction and hardware

Connection techniques and housing with many advantages
The relay housing is 1/6 of a 19" rack and makes replacement of predecessors model very easy. The height is 244 mm (9.61").

Pluggable current and voltage terminals allow for pre-wiring and simplify the exchange of devices in the case of support. CT shorting is done in the removable current terminal block. It is thus not possible to opencircuit a secondary current transformer.

All binary inputs are independent and the pick-up thresholds are settable using software settings (3 stages). The relay current transformer taps (1 A / 5 A) are new software settings. Up to 9 function keys can be programmed for predefi ned menu entries, switching sequences, etc. The assigned function of the function keys can be shown in the display of the relay.

If a conventional (inductive) set of primary voltage transformers is not available in the feeder, the phase-to-ground voltages can be measured directly through a set of capacitor cones in the medium-voltage switchgear. In this case, the functions directional time-overcurrent protection, ground (ANSI 67N), voltage protection (ANSI 27/59) and frequency protection (ANSI 81O/U) are available. With overcurrent protection 7SJ81 there is also a device for low-power current transformer applications.

** RU = rack unit*

Current terminals – ring cable lugs	
Connection	W_{max} = 9.5 mm
Ring cable lugs	$d1$ = 5.0 mm
Wire cross-section	2.0 – 5.2 mm² (AWG 14 – 10)
Current terminals – single conductors	
Wire cross-section	2.0 – 5.2 mm² (AWG 14 – 10)
Conductor sleeve with plastic sleeve	L = 10 mm (0.39 in) or L = 12 mm (0.47 in)
Stripping length (when used without conductor sleeve)	15 mm (0.59 in) Only solid copper wires may be used.
Voltage terminals – single conductors	
Wire cross-section	0.5 – 2.0 mm² (AWG 20 – 14)
Conductor sleeve with plastic sleeve	L = 10 mm (0.39 in) or L = 12 mm (0.47 in)
Stripping length (when used without conductor sleeve)	12 mm (0.47 in) Only solid copper wires may be used.

Tab. 6.2-1: **Wiring specifications for process connection**

Fig. 6.2-15: **7SK80, 7SJ80, 7SD80 rear view**

Fig. 6.2-16:
Voltage terminal block

Fig. 6.2-17:
Current terminal block

Fig. 6.2-18: **7SJ81 rear view**

Fig. 6.2-19: **7RW80 rear view**

Fig. 6.2-20: **Front view, surface-mounted housing**

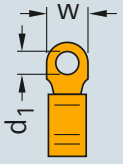


Fig. 6.2-20a:
Ring cable lug

Control and automation functions

Control

In addition to the protection functions, the SIPROTEC Compact units also support all control and monitoring functions that are required for the operation medium-voltage or high-voltage substations. The status of primary equipment or auxiliary devices can be obtained from auxiliary contacts and communicated to the unit via binary inputs. Therefore it is possible to detect and indicate both the OPEN and CLOSED position or a fault or intermediate circuit-breaker or auxiliary contact position.

The switchgear or circuit-breaker can be controlled via:
- Integrated operator panel
- Binary inputs
- Substation control and protection system
- DIGSI 4.

Automation/user-defined logic

With integrated logic, the user can create, through a graphic interface (CFC), specifi c functions for the automation of a switchgear or a substation. Functions are activated using function keys, a binary input or through the communication interface.

Switching authority

Switching authority is determined by set parameters or through communications to the relay. If a source is set to "LOCAL", only local switching operations are possible. The following sequence for switching authority is available: "LOCAL"; DIGSI PC program, "REMOTE". There is thus no need to have a separate Local/Remote switch wired to the breaker coils and relay. The local/remote selection can be done using a function key on the front of the relay.

Command processing

This relay is designed to be easily integrated into a SCADA or control system. Security features are standard and all the functionality of command processing is offered. This includes the processing of single and double commands with or without feedback, sophisticated monitoring of the control hardware and software, checking of the external process, control actions using functions such as runtime monitoring and automatic command termination after output. Here are some typical applications:
- Single and double commands, using 1, 1 plus 1 common or 2 trip contacts
- User-definable bay interlocks
- Operating sequences combining several switching operations, such as control of circuit-breakers, disconnectors and grounding switches
- Triggering of switching operations, indications or alarms by combination with existing information.

Assignment of feedback to command

The positions of the circuit-breaker or switching devices and transformer taps are acquired through feedback. These indication inputs are logically assigned to the corresponding command outputs. The unit can therefore distinguish whether the indication change is a result of switching operation or whether it is an undesired spontaneous change of state.

Chatter disable

The chatter disable feature evaluates whether, in a set period of time, the number of status changes of indication input exceeds a specified number. If exceeded, the indication input is blocked for a certain period, so that the event list will not record excessive operations.

Indication filtering and delay

Binary indications can be filtered or delayed. Filtering serves to suppress brief changes in potential at the indication input. The indication is passed on only if the indication voltage is still present after a set period of time. In the event of an indication delay, there is a delay for a preset time. The information is passed on only if the indication voltage is still present after this time.

Indication derivation

User-definable indications can be derived from individual or a group of indications. These grouped indications are of great value to the user that need to minimize the number of indications sent to the system or SCADA interface.

Communication

As regards communication, the devices offer high flexibility for the connection to industrial and energy automation standards. The concept of the communication modules running the protocols enables exchangeability and retrofittability. Thus, the devices can also be perfectly adjusted to a changing communication infrastructure in the future, e.g., when Ethernet networks will be increasingly used in the utilities sector in the years to come.

USB interface

There is an USB interface on the front of all devices. All device functions can be set using a PC and DIGSI program. Commissioning tools and fault analysis are built into the DIGSI 4 protection operation program and are used through this interface.

Interfaces

A number of communication modules suitable for various applications can be fitted at the bottom of the housing. The modules can be easily replaced by the user. The interface modules support the following applications:
- System/service interface
  Communication with a central control system takes place through this interface. Radial or ring type station bus topologies can be confi gured depending on the chosen interface. Furthermore, the units can exchange data through this interface via Ethernet and the IEC 61850 protocol and can also be accessed using DIGSI. Alternatively, up to 2 external temperature detection devices with max. 12 metering sensors can be connected to the system/service interface.
- Ethernet interface
  The Ethernet interface has been designed for quick access to several protection devices via DIGSI. In the case of the motor protection 7SK80, it is possible to connect max. 2 external temperature detection devices with max. 12 metering sensors to the Ethernet interface. As for the line differential protection, the optical interface is located at this interface.

System interface protocols (retrofittable):

- IEC 61850
  The IEC 61850 protocol based on Ethernet is standardized as worldwide standard for protection and control systems in the utilities sector. Via this protocol it is possible to exchange information also directly between feeder units, so that simple masterless systems for feeder and switchgear interlocking can be set up. Furthermore, the devices can be accessed with DIGSI via the Ethernet bus.
- IEC 60870-5-103
  IEC 60870-5-103 is an international standard for the transmission of protection data and fault records. All messages from the unit and also control commands can be transferred by means of published, Siemens-specific extensions to the protocol. Optionally, a redundant IEC 60870-5-103 module is available. This redundant module allows to read and change individual parameters.
- PROFIBUS-DP protocol
  PROFIBUS-DP protocol is a widespread protocol in the industrial automation. Through PROFIBUS-DP, SIPROTEC units make their information available to a SIMATIC controller or receive commands from a central SIMATIC controller or PLC. Measured values can also be transferred to a PLC master.
- MODBUS RTU protocol
  This simple, serial protocol is mainly used in industry and by power utilities, and is supported by a number of relay manufacturers. SIPROTEC units function as MODBUS slaves, making their information available to a master or receiving information from it. A time-stamped event list is available.
- DNP 3.0 protocol
  Power utilities use the serial DNP 3.0 (Distributed Network Protocol) for the station and network control levels. SIPROTEC units function as DNP slaves, supplying their information to a master system or receiving information from it.

System solutions

IEC 60870

Devices with IEC 60870-5-103 interfaces can be connected to SICAM in parallel via the RS485 bus or radially via optical fiber. Via this interface, the system is open for connection of devices from other manufacturers.

Due to the standardized interfaces, SIPROTEC devices can also be integrated into systems from other manufacturers, or into a SIMATIC system. Electrical RS485 or optical interfaces are available. Optoelectronic converters enable the optimal selection of transmission physics. Thus, cubicle-internal wiring with the RS485 bus, as well as interference-free optical connection to the master can be implemented at low cost.

IEC 61850

An interoperable system solution is offered for IEC 61850 together with SICAM. Via the 100 Mbit/s Etherbus, the devices are connected electrically or optically to the station PC with SICAM. The interface is standardized, thus enabling the direct connection of devices from other manufacturers to the Ethernet bus.

With IEC 61850, the devices can also be installed in systems of other manufacturers.

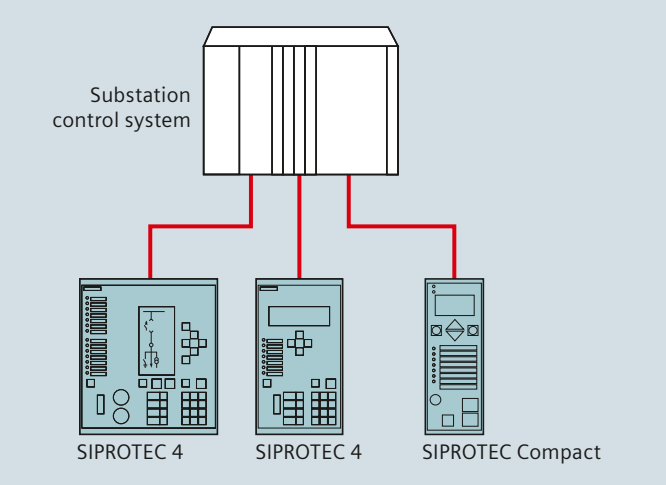


Fig. 6.2-21: **IEC 60870-5-103, radial optical-fiber connection to the substation control system**

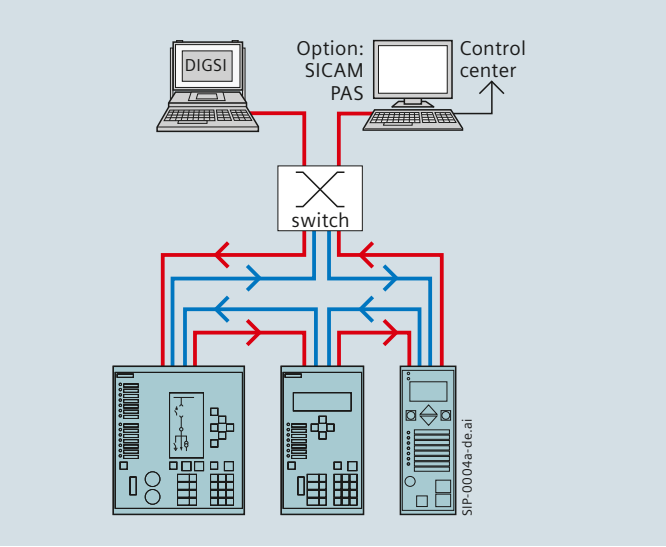


Fig. 6.2-22: **Bus structure for station bus with Ethernet and IEC 61850, ring-shaped optical-fiber connection**

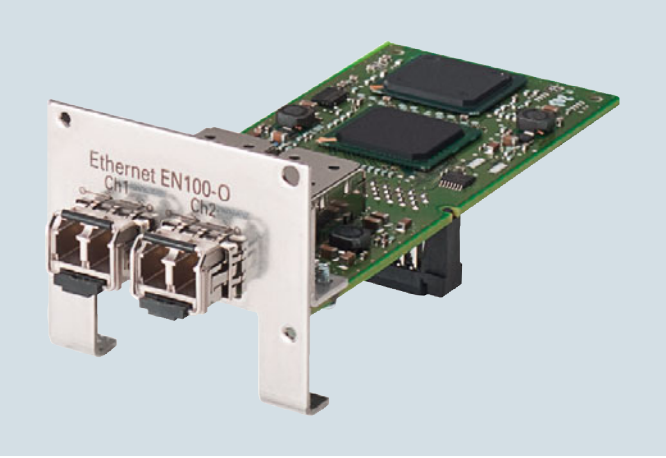


Fig. 6.2-23: **Optical Ethernet communication module for IEC 61850**

SIPROTEC 4 – the proven, reliable and future-proof protection for all applications

SIPROTEC 4 represents a worldwide successful and proven device series with more than 1 million devices in field use.

Due to the homogenous system platform, the unique engineering program DIGSI 4 and the great field experience, the SIPROTEC 4 device family has gained the highest appreciation of users all over the world. Today, SIPROTEC 4 is considered the standard for numerical protection systems in all fields of application.

SIPROTEC 4 provides suitable devices for all applications from power generation and transmission up to distribution and industrial systems.

SIPROTEC 4 is a milestone in protection systems. The SIPROTEC 4 device series implements the integration of protection, control, measuring and automation functions optimally in one device. In many fields of application, all tasks of the secondary systems can be performed with one single device. The open and future-proof concept of SIPROTEC 4 has been ensured for the entire device series with the implementation of IEC 61850.

- Proven protection functions guarantee the safety of the systems operator's equipment and employees
- Comfortable engineering and evaluation via DIGSI 4
- Simple creation of automation solutions by means of the integrated CFC
- Targeted and easy operation of devices and software thanks to user-friendly design
- Powerful communication components guarantee safe and effective solutions
- Maximum experience worldwide in the use of SIPROTEC 4 and in the implementation of IEC 61850 projects
- Future-proof due to exchangeable communication interfaces and integrated CFC.

Fig. 6.2-24: **SIPROTEC 4**

Fig. 6.2-25: **SIPROTEC 4 rear view**

Fig. 6.2-26: **SIPROTEC 4 in power plant application**

To fulfill vital protection redundancy requirements, only those functions that are interdependent and directly associated with each other are integrated into the same unit. For backup protection, one or more additional units should be provided.

All relays can stand fully alone. Thus, the traditional protection principle of separate main and backup protection as well as the external connection to the switchyard remain unchanged.

"One feeder, one relay" concept
Analog protection schemes have been engineered and assembled from individual relays. Interwiring between these relays and scheme testing has been carried out manually in the workshop.

Data sharing now allows for the integration of several protection and protection-related tasks into one single numerical relay. Only a few external devices may be required for completion of the total scheme. This has significantly lowered the costs of engineering, assembly, panel wiring, testing and commissioning. Scheme failure probability has also been lowered.

Engineering has moved from schematic diagrams toward a parameter definition procedure. The powerful user-definable logic of SIPROTEC 4 allows flexible customized design for protection, control and measurement.

Measuring included
For many applications, the accuracy of the protection current transformer is sufficient for operational measuring. The additional measuring current transformer was required to protect the measuring instruments under short-circuit conditions. Due to the low thermal withstand capability of the measuring instruments, they could not be connected to the protection current transformer. Consequently, additional measuring core current transformers and measuring instruments are now only necessary where high accuracy is required, e.g., for revenue metering.

Corrective rather than preventive maintenance
Numerical relays monitor their own hardware and software. Exhaustive self-monitoring and failure diagnostic routines are not restricted to the protection relay itself but are methodically carried through from current transformer circuits to tripping relay coils.

Equipment failures and faults in the current transformer circuits are immediately reported and the protection relay is blocked.

Thus, service personnel are now able to correct the failure upon occurrence, resulting in a significantly upgraded availability of the protection system.

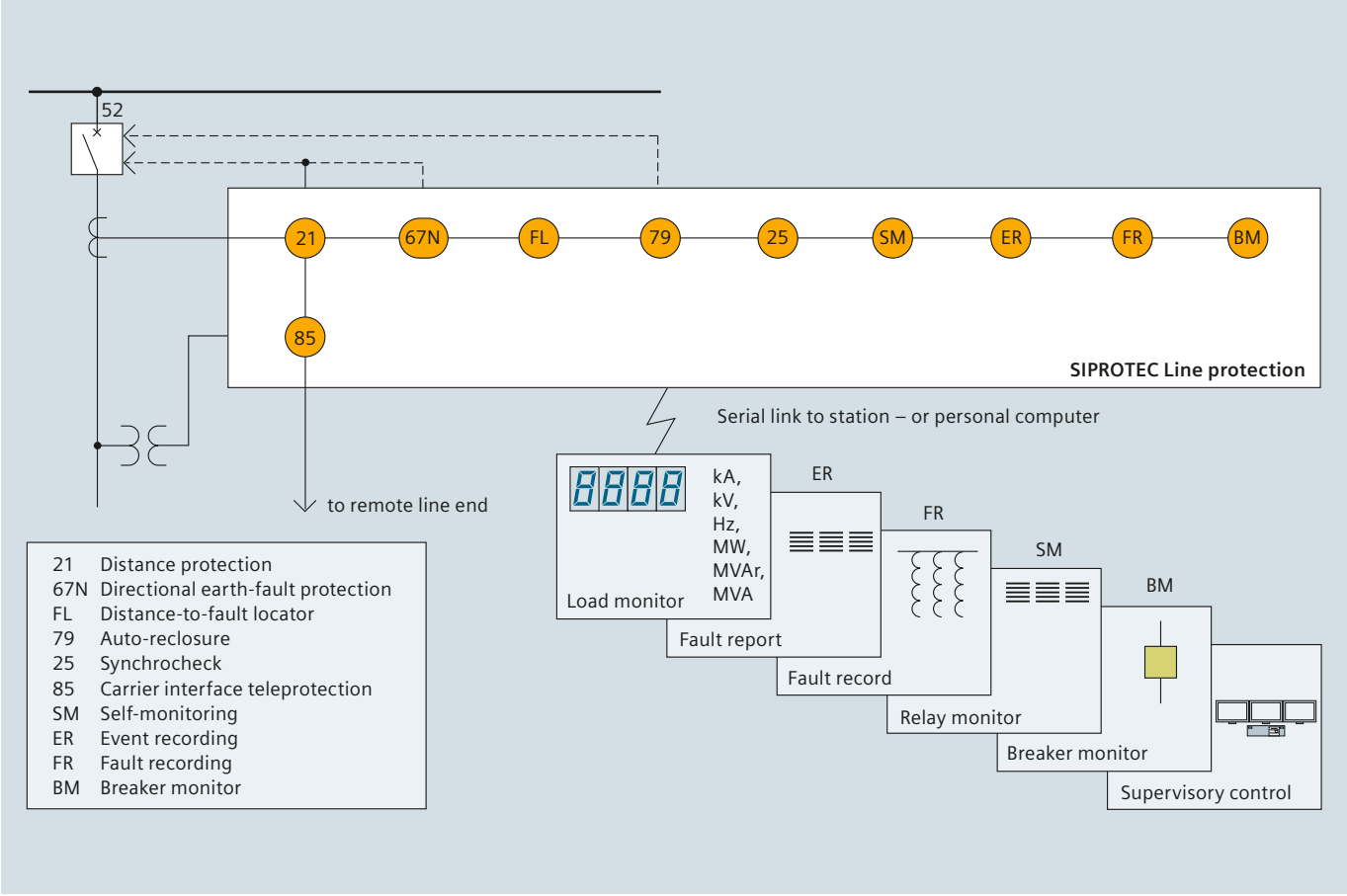


Fig. 6.2-27: **Numerical relays offer increased information availability**

Adaptive relaying
Numerical relays now offer reliable, convenient and comprehensive matching to changing conditions. Matching may be initiated either by the relay's own intelligence or from other systems via contacts or serial telegrams. Modern numerical relays contain a number of parameter sets that can be pretested during commissioning of the scheme. One set is normally operative. Transfer to the other sets can be controlled via binary inputs or a serial data link (fig. 6.2-28).

There are a number of applications for which multiple setting groups can upgrade the scheme performance, for example:
- For use as a voltage-dependent control of overcurrent-time relay pickup values to overcome alternator fault current decrement to below normal load current when the automatic voltage regulator (AVR) is not in automatic operation
- For maintaining short operation times with lower fault currents, e.g., automatic change of settings if one supply transformer is taken out of service
- For "switch-onto-fault" protection to provide shorter time settings when energizing a circuit after maintenance so that normal settings can be restored automatically after a time delay
- For auto-reclosure programs, that is, instantaneous operation for first trip and delayed operation after unsuccessful reclosure
- For cold load pickup problems where high starting currents may cause relay operation
- For "ring open" or "ring closed" operation.

Implemented functions
SIPROTEC relays are available with a variety of protective functions (please refer to section 6.2.6). The high processing power of modern numerical units allows further integration of non-protective add-on functions.

The question as to whether separate or combined relays should be used for protection and control cannot be unambiguously answered. In transmission-type substations, separation into independent hardware units is still preferred, whereas a trend toward higher function integration can be observed on the distribution level. Here, the use of combined feeder / line relays for protection, monitoring and control is becoming more common (fig. 6.2-29).

Relays with protection functions only and relays with combined protection and control functions are being offered. SIPROTEC 4 relays offer combined protection and control functions. SIPROTEC 4 relays support the "one relay one feeder" principle, and thus contribute to a considerable reduction in space and wiring requirements.

With the well-proven SIPROTEC 4 family, Siemens supports both stand-alone and combined solutions on the basis of a single hardware and software platform. The user can decide within wide limits on the configuration of the control and protection, and the reliability of the protection functions (fig. 6.2-30).

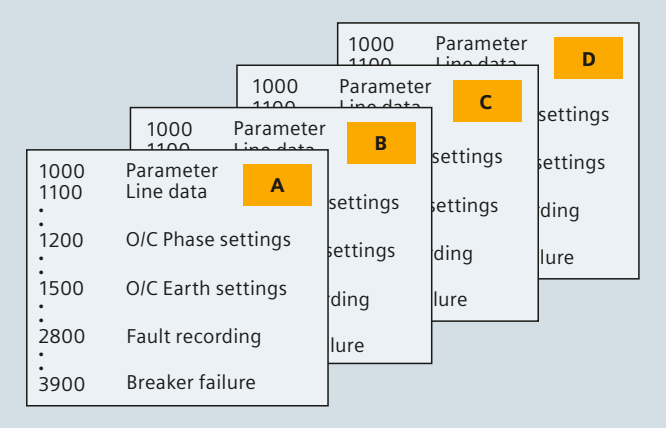


Fig. 6.2-28: **Alternate parameter groups**

Fig. 6.2-29: **Left: switchgear with numerical relay (7SJ62) and traditional control; right: switchgear with combined protection and control relay (7SJ64)**

The following solutions are available within one relay family:
- Separate control and protection relays
- Feeder protection and remote control of the line circuit-breaker via the serial communication link
- Combined relays for protection, monitoring and control.

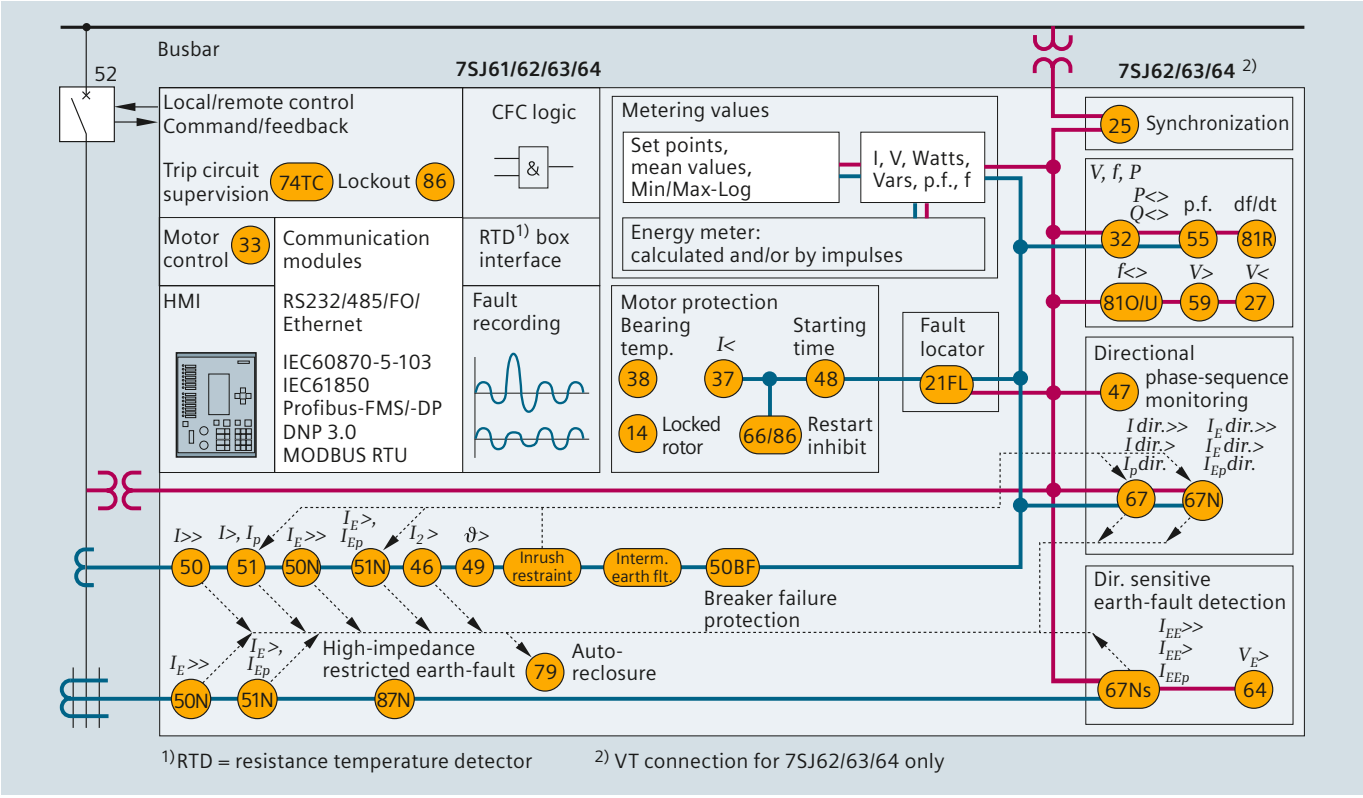


Fig. 6.2-30: **SIPROTEC 4 relays 7SJ61/62/63, 64 implemented functions**

Terminals: standard relay version with screw-type terminals	
Current terminals	
Connection	W_{max} =12 mm
Ring cable lugs	*d1* =5 mm
Wire size	2.7 – 4 mm² (AWG 13 – 11)
Direct connection	Solid conductor, flexible lead, connector sleeve
Wire size	2.7 – 4 mm² (AWG 13 – 11)
Voltage terminals	
Connection	W_{max} =10 mm
Ring cable lugs	*d1* = 4 mm
Wire size	1.0 – 2.6 mm² (AWG 17 – 13)
Direct connection	Solid conductor, flexible lead, connector sleeve
Wire size	0.5 – 2.5 mm² (AWG 20 – 13)
Some relays are alternatively available with plug-in voltage terminals	
Current terminals	
Screw type (see standard version)	
Voltage terminals	
2-pin or 3-pin connectors	
Wire size	0.5 – 1.0 mm²
	0.75 – 1.5 mm²
	1.0 – 2.5 mm²

Mechnical design

SIPROTEC 4 relays are available in 1/3 to 1/1 of 19" wide housings with a standard height of 243 mm. Their size is compatible with that of other relay families. Therefore, compatible exchange is always possible (fig. 6.2-31 to fig. 6.2-33).

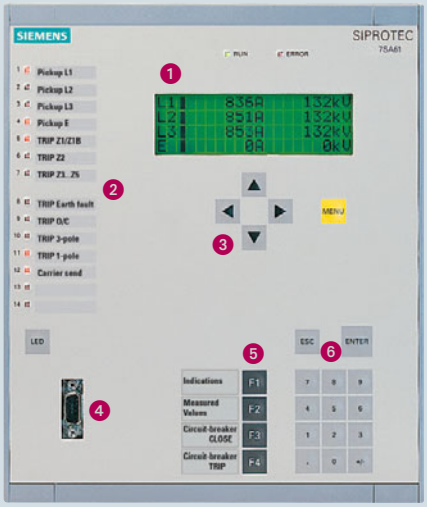
All wires (cables) are connected at the rear side of the relay with or without ring cable lugs. A special relay version with a detached cable-connected operator panel (fig. 6.2-34) is also available. It allows, for example, the installation of the relay itself in the low-voltage compartment, and of the operator panel separately in the door of the switchgear.

Fig. 6.2-31: **1/1 of 19" housing**

Fig. 6.2-32: **1/2 of 19" housing**

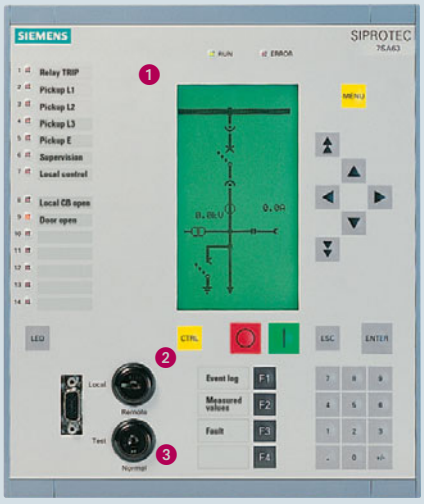
Fig. 6.2-33: **1/3 of 19" housing**

Fig. 6.2-34: **SIPROTEC 4 combined protection, control and monitoring relay with detached operator panel**



1. On the backlit LCD display, process and device information can be displayed as text.
2. Freely assignable LEDs are used to display process or device information. The LEDs can be labeled according to user requirements. An LED reset key resets the LEDs and can be used for LED testing.
3. Keys for navigation
4. RS232 operator interface (for DIGSI)
5. 4 configurable function keys permit the user to execute frequently used actions simply and fast.
6. Numerical keys

Fig. 6.2-35: **Local operation: All operator actions can be executed and information displayed via an integrated user interface. Two alternatives for this interface are available.**



1. Process and relay information can be displayed on the large illuminated LC display either graphically in the form of a mimic diagram or as text in various lists.
2. The keys mainly used for control of the switchgear are located on the "control axis" directly below the display.
3. Two key-operated switches ensure rapid and reliable changeover between "local" and "remote" control, and between "interlocked" and "non-interlocked" operation.

Fig. 6.2-36: **Additional features of the interface with graphic display**

Apart from the relay-specific protection functions, the SIPROTEC 4 units have a multitude of additional functions that
- provide the user with information for the evaluation of faults
- facilitate adaptation to customer-specific application
- facilitate monitoring and control of customer installations.

Operational measured values
The large scope of measured and limit values permits improved power system management as well as simplified commissioning.

The r.m.s. values are calculated from the acquired current and voltage along with the power factor, frequency, active and reactive power. The following functions are available depending on the relay type
- Currents IL1, IL2, IL3, IN, IEE (67Ns)
- Voltages VL1,VL2, VL3, VL1-L2,VL2-L3, VL3-L1
- Symmetrical components I1, I2,3I0; V1, V2,3V0
- Power Watts, Vars, VA / P, Q, S
- Power factor p.f. (cos φ)
- Frequency
- Energy ± kWh ± kVarh, forward and reverse power flow
- Mean as well as minimum and maximum current and voltage values
- Operating hours counter
- Mean operating temperature of overload function
- Limit value monitoring
  Limit values are monitored using programmable logic in the CFC. Commands can be derived from this limit value indication.
- Zero suppression
  In a certain range of very low measured values, the value is set to zero to suppress interference.

Metered values (some types)
For internal metering, the unit can calculate energy metered values from the measured current and voltage values. If an external meter with a metering pulse output is available, some SIPROTEC 4 types can obtain and process metering pulses via an indication input.

The metered values can be displayed and passed on to a control center as an accumulation with reset. A distinction is made between forward, reverse, active and reactive energy.

Operational indications and fault indications with time stamp
The SIPROTEC 4 units provide extensive data for fault analysis as well as control. All indications listed here are stored, even if the power supply is disconnected.
- Fault event log
  The last eight network faults are stored in the unit. All fault recordings are time-stamped with a resolution of 1 ms.
- Operational indications
  All indications that are not directly associated with a fault (e.g., operating or switching actions) are stored in the status indication buffer. The time resolution is 1 ms (fig. 6.2-37, fig. 6.2-38).

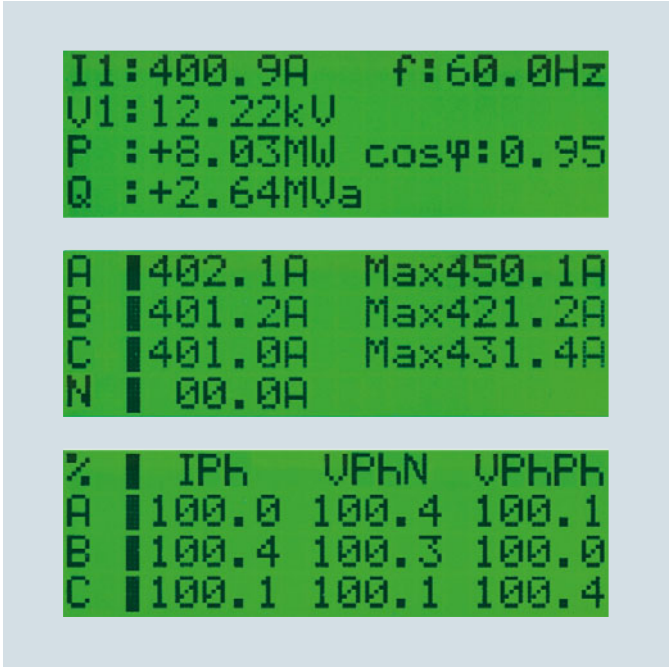


Fig. 6.2-37: **Operational measured values**

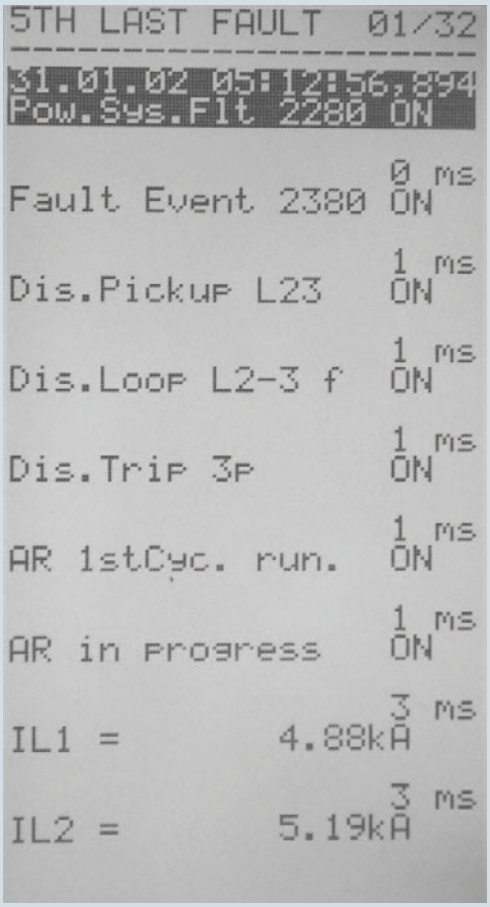


Fig. 6.2-38: **Fault event log on graphical display of the device**

Display editor
A display editor is available to design the display on SIPROTEC 4 units with graphic display. The predefined symbol sets can be expanded to suit the user. The drawing of a single-line diagram is extremely simple. Load monitoring values (analog values) and any texts or symbols can be placed on the display where required.

Four predefined setting groups for adapting relay settings
The settings of the relays can be adapted quickly to suit changing network configurations. The relays include four setting groups that can be predefined during commissioning or even changed remotely via a DIGSI 4 modem link. The setting groups can be activated via binary inputs, via DIGSI 4 (local or remote), via the integrated keypad or via the serial substation control interface.

Fault recording up to five or more seconds
The sampled values for phase currents, earth (ground) currents, line and zero-sequence currents are registered in a fault record. The record can be started using a binary input, on pickup or when a trip command occurs. Up to eight fault records may be stored. For test purposes, it is possible to start fault recording via DIGSI 4. If the storage capacity is exceeded, the oldest fault record in each case is overwritten.

For protection functions with long delay times in generator protection, the r.m.s. value recording is available. Storage of relevant calculated variables (V1, VE, I1, I2, IEE, P, Q, f-fn) takes place at increments of one cycle. The total time is 80 s.

Time synchronization
A battery-backed clock is a standard component and can be synchronized via a synchronization signal (DCF77, IRIG B via satellite receiver), binary input, system interface or SCADA (e.g., SICAM). A date and time is assigned to every indication.

Selectable function keys
Four function keys can be assigned to permit the user to perform frequently recurring actions very quickly and simply.

Typical applications are, for example, to display the list of operating indications or to perform automatic functions such as "switching of circuit-breaker".

Continuous self-monitoring
The hardware and software are continuously monitored. If abnormal conditions are detected, the unit immediately signals. In this way, a great degree of safety, reliability and availability is achieved.

Reliable battery monitoring
The battery provided is used to back up the clock, the switching statistics, the status and fault indications, and the fault recording in the event of a power supply failure. Its function is checked by the processor at regular intervals. If the capacity of the battery is found to be declining, an alarm is generated. Regular replacement is therefore not necessary.

All setting parameters are stored in the Flash EPROM and are not lost if the power supply or battery fails. The SIPROTEC 4 unit remains fully functional.

Commissioning support
Special attention has been paid to commissioning. All binary inputs and output contacts can be displayed and activated directly. This can significantly simplify the wiring check for the user. Test telegrams to a substation control system can be initiated by the user as well.

CFC: Programming logic
With the help of the CFC (Continuous Function Chart) graphic tool, interlocking schemes and switching sequences can be configured simply via drag and drop of logic symbols; no special knowledge of programming is required. Logical elements, such as AND, OR, flip-flops and timer elements are available. The user can also generate user-defined annunciations and logical combinations of internal or external signals.

Communication interfaces
With respect to communication, particular emphasis has been placed on high levels of flexibility, data integrity and utilization of standards commonly used in energy automation. The design of the communication modules permits interchangeability on the one hand, and on the other hand provides openness for future standards.

Local PC interface
The PC interface accessible from the front of the unit permits quick access to all parameters and fault event data. Of particular advantage is the use of the DIGSI 4 operating program during commissioning.

Retrofitting: Communication modules

It is possible to supply the relays directly with two communication modules for the service and substation control interfaces, or to retrofit the communication modules at a later stage. The modules are mounted on the rear side of the relay. As a standard, the time synchronization interface is always supplied.

The communication modules are available for the entire SIPROTEC 4 relay range. Depending on the relay type, the following protocols are available: IEC 60870-5-103, PROFIBUS DP, MODBUS RTU, DNP 3.0 and Ethernet with IEC 61850. No external protocol converter is required (fig. 6.2-39 to fig. 6.2-43).

With respect to communication, particular emphasis is placed on the requirements in energy automation:

- Every data item is time-stamped at the source, that is, where it originates.
- The communication system automatically handles the transfer of large data blocks (e.g., fault records or parameter data files). The user can apply these features without any additional programming effort.
- For reliable execution of a command, the relevant signal is first acknowledged in the unit involved. When the command has been enabled and executed, a check-back indication is issued. The actual conditions are checked at every command-handling step. Whenever they are not satisfactory, controlled interruption is possible.

Fig. 6.2-39: **Protection relay**

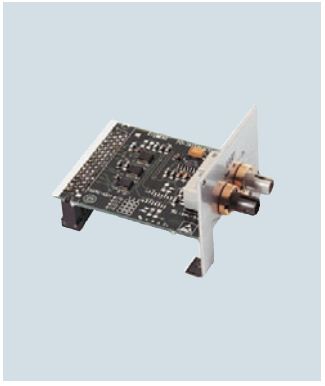


Fig. 6.2-40: **Communication module, optical**

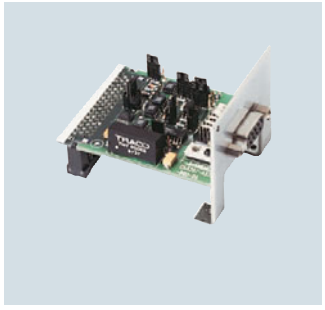


Fig. 6.2-41: **Communication module RS232,RS485**

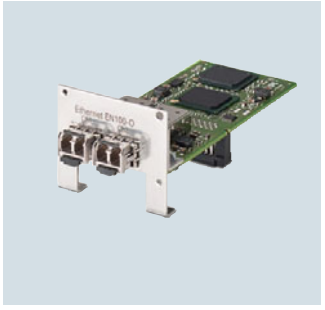
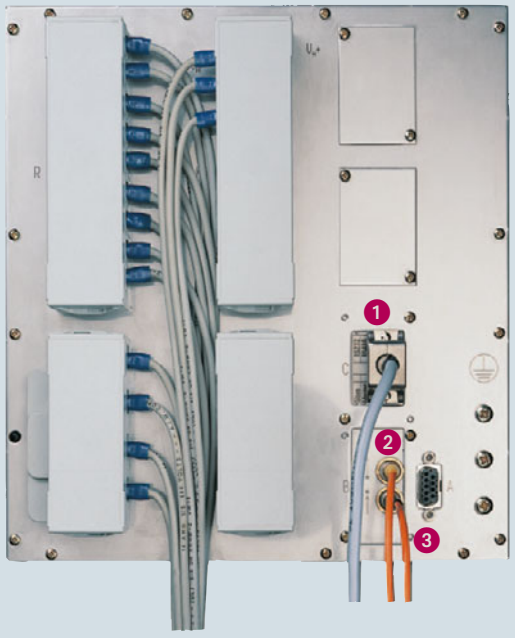


Fig. 6.2-42: **Communication module, optical ring**



The following interfaces can be applied:

1 Service interface (optional)
Several protection relays can be centrally operated with DIGSI 4, e.g., via a star coupler or RS485 bus. On connection of a modem, remote control is possible. This provides advantages in fault clearance, particularly in unmanned power plants. (Alternatively, the external temperature monitoring box can be connected to this interface.)

2 System interface (optional)
This is used to carry out communication with a control system and supports, depending on the module connected, a variety of communication protocols and interface designs.

3 Time synchronization interface
A synchronization signal (DCF 77, IRIG B via satellite receiver) may be connected to this input if no time synchronization is executed on the system interface. This offers a high-precision time tagging.

Fig. 6.2-43: **Rear view with wiring, terminal safety cover and serial interfaces**

Safe bus architecture

- Optical-fiber double ring circuit via Ethernet
  The optical-fiber double ring circuit is immune to electromagnetic interference. Upon failure of a section between two units, the communication system continues to operate without interruption. If a unit were to fail, there is no effect on the communication with the rest of the system (fig. 6.2-44).
- RS485 bus
  With this data transmission via copper wires, electromagnetic interference is largely eliminated by the use of twisted-pair conductors. Upon failure of a unit, the remaining system continues to operate without any faults (fig. 6.2-45).
- Star structure
  The relays are connected with a optical-fiber cable with a star structure to the control unit. The failure of one relay / connection does not affect the others (fig. 6.2-46).

Depending on the relay type, the following protocols are available:

- IEC 61850 protocol
  Since 2004, the Ethernet-based IEC 61850 protocol is the worldwide standard for protection and control systems used by power supply corporations. Siemens is the first manufacturer to support this standard. By means of this protocol, information can also be exchanged directly between feeder units so as to set up simple masterless systems for feeder and system interlocking. Access to the units via the Ethernet bus will also be possible with DIGSI.
- IEC 60870-5-103
  IEC 60870-5-103 is an internationally standardized protocol for efficient communication between the protection relays and a substation control system. Specific extensions that are published by Siemens can be used.
- PROFIBUS DP
  For connection to a SIMATIC PLC, the PROFIBUS DP protocol is recommended. With the PROFIBUS DP, the protection relay can be directly connected to a SIMATIC S5 / S7. The transferred data are fault data, measured values and control commands.

Substation automation system

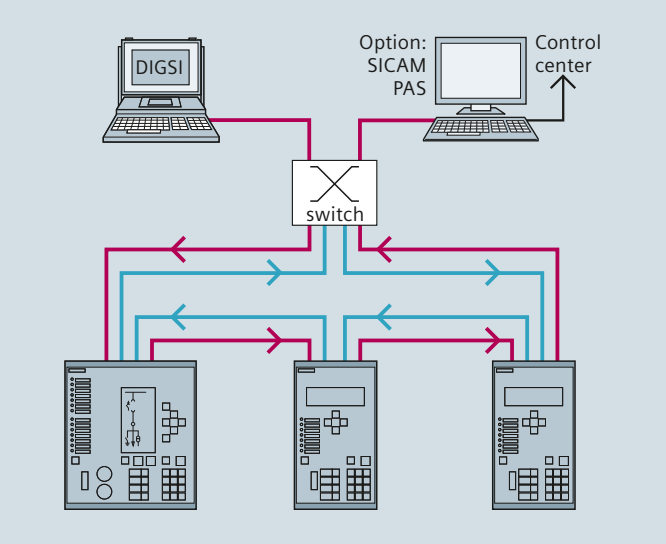


Fig. 6.2-44: **Ring bus structure for station bus with Ethernet and IEC 61850**

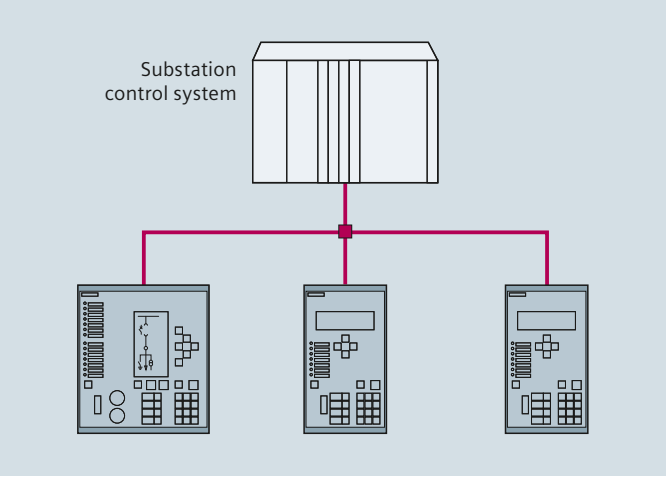


Fig. 6.2-45: **PROFIBUS: Electrical RS485 bus wiring**

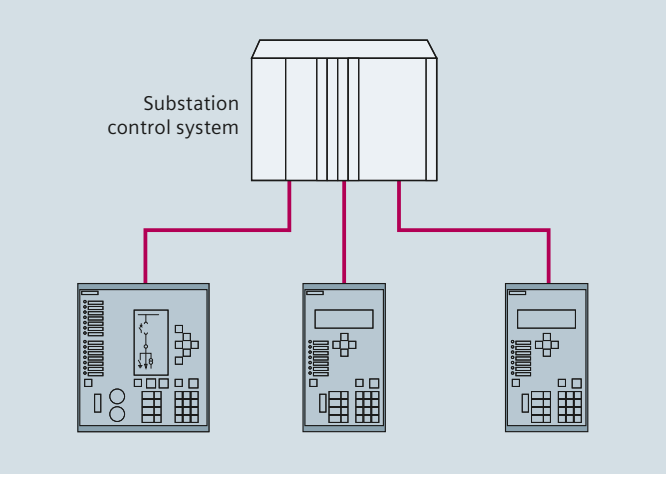


Fig. 6.2-46: **IEC 60870-5-103: Star structure with optical-fiber cables**

MODBUS RTU
MODBUS is also a widely utilized communication standard and is used in numerous automation solutions.

DNP 3.0
DNP 3.0 (Distributed Network Protocol, version 3) is a messaging-based communication protocol. The SIPROTEC 4 units are fully Level 1 and Level 2-compliant with DNP 3.0, which is supported by a number of protection unit manufacturers.

Control
In addition to the protection functions, the SIPROTEC 4 units also support all control and monitoring functions required for operating medium-voltage or high-voltage substations. The main application is reliable control of switching and other processes. The status of primary equipment or auxiliary devices can be obtained from auxiliary contacts and communicated to the relay via binary inputs.

Therefore, it is possible to detect and indicate both the OPEN and CLOSED positions or a faulty or intermediate breaker position. The switchgear can be controlled via:
- Integrated operator panel
- Binary inputs
- Substation control system
- DIGSI 4

Automation
With the integrated logic, the user can set specific functions for the automation of the switchgear or substation by means of a graphic interface (CFC). Functions are activated by means of function keys, binary inputs or via the communication interface.

Switching authority
The following hierarchy of switching authority is applicable: LOCAL, DIGSI 4 PC program, REMOTE. The switching authority is determined according to parameters or by DIGSI 4. If the LOCAL mode is selected, only local switching operations are possible. Every switching operation and change of breaker position is stored in the status indication memory with detailed information and time tag.

Command processing
The SIPROTEC 4 protection relays offer all functions required for command processing, including the processing of single and double commands, with or without feedback, and sophisticated monitoring. Control actions using functions, such as runtime monitoring and automatic command termination after output check of the external process, are also provided by the relays. Typical applications are:
- Single and double commands using 1, 1 plus 1 common or 2 trip contacts
- User-definable feeder interlocking
- Operating sequences combining several switching operations, such as control of circuit-breakers, disconnectors (isolators) and earthing switches
- Triggering of switching operations, indications or alarms by logical combination of existing information (fig. 6.2-47).

Fig. 6.2-47: **Protection engineer at work**

The positions of the circuit-breaker or switching devices are monitored by feedback signals. These indication inputs are logically assigned to the corresponding command outputs. The unit can therefore distinguish whether the indication changes as a consequence of a switching operation or due to a spontaneous change of state.

Indication derivation
A further indication (or a command) can be derived from an existing indication. Group indications can also be formed. The volume of information to the system interface can thus be reduced and restricted to the most important signals.

SIPROTEC 5 – the new benchmark for protection, automation and monitoring of transmission grids

The SIPROTEC 5 series is based on the long field experience of the SIPROTEC device series, and has been especially designed for the new requirements of modern high-voltage systems. For this purpose, SIPROTEC 5 is equipped with extensive functionalities and device types. With the holistic and consistent engineering tool DIGSI 5, a solution has also been provided for the increasingly complex processes, from the design via the engineering phase up to the test and operation phase.

Thanks to the high modularity of hardware and software, the functionality and hardware of the devices can be tailored to the requested application and adjusted to the continuously changing requirements throughout the entire life cycle.

Besides the reliable and selective protection and the complete automation function, SIPROTEC 5 offers an extensive database for operation and monitoring of modern power supply systems. Synchrophasors (PMU), power quality data and extensive operational equipment data are part of the scope of supply.

- Powerful protection functions guarantee the safety of the system operator's equipment and employees
- Individually configurable devices save money on initial investment as well as storage of spare parts, maintenance, expansion and adjustment of your equipment
- Clear and easy-to-use of devices and software thanks to user-friendly design
- Increase of reliability and quality of the engineering process
- High reliability due to consequent implementation of safety and security
- Powerful communication components guarantee safe and effective solutions
- Full compatibility between IEC 61850 Editions 1 and 2
- Efficient operating concepts by flexible engineering of IEC 61850 Edition 2
- Comprehensive database for monitoring of modern power grids
- Optimal smart automation platform for transmission grids based on integrated synchrophasor measurement units (PMU) and power quality functions.

Fig. 6.2-48: **SIPROTEC 5 – modular hardware**

Fig. 6.2-49: **SIPROTEC 5 – rear view**

Fig. 6.2-50: **Application in the high-voltage system**

Innovation highlights
With SIPROTEC 5, we have combined a functionality that has been proven and refined over years with a high-performance and flexible new platform, extended with trendsetting innovations for present and future demands.

Holistic workflow
The tools for end-to-end engineering from system design to operation will make your work easier throughout the entire process.

The highlight of SIPROTEC 5 is the greater-than-ever emphasis on daily ease of operation. SIPROTEC 5 provides support along all the steps in the engineering workflow, allowing for system view management and configuration down to the details of individual devices, saving time and cost without compromising quality (fig. 6.2-51).

Holistic workflow in SIPROTEC 5 means:
- Integrated, consistent system and device engineering – from the single-line diagram of the unit all the way to device parameterization
- Simple, intuitive graphical linking of primary and secondary equipment
- Easily adaptable library of application templates for the most frequently used applications
- Manufacturer-independent tool for easy system engineering
- Libraries for your own configurations and system parts
- Multiuser concept for parallel engineering
- Open interfaces for seamless integration into your process environment
- A user interface developed and tested jointly with many users that pays dividends in daily use
- Integrated tools for testing during engineering, commissioning, and for simulating operational scenarios, e.g., grid disruptions or switching operations.

For system operators, holistic workflow in SIPROTEC 5 means:
An end-to-end tool from system design to operation – even allowing crossing of functional and departmental boundaries – saves time, assures data security and transparency throughout the entire lifecycle of the system.

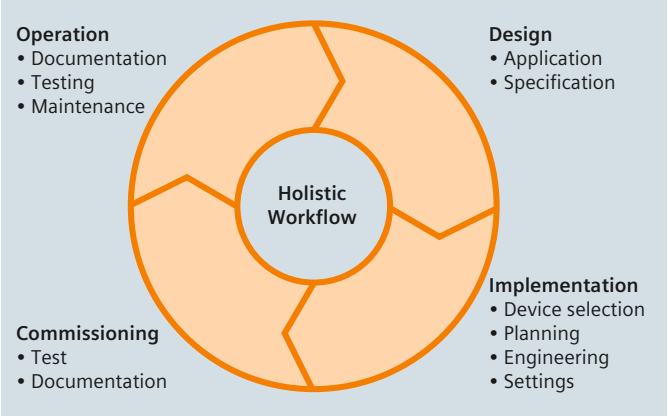


Fig. 6.2-51: **End-to-end tools – from design to operation**

Perfectly tailored fit
Individually configurable devices provide you with cost-effective solutions that match your needs precisely throughout the entire lifecycle.

SIPROTEC 5 sets new standards in cost savings and availability with its innovative modular and flexible hardware, software and communication. SIPROTEC 5 provides a perfectly tailored fit for your switchgear and applications unparalleled by any other system.

Perfectly tailored fit with SIPROTEC 5 means:
- Modular system design in hardware, software and communication ensures the perfect fit for your needs
- Functional integration of a wide range of applications, such as protection, control, measurement, power quality or fault recording
- The same expansion and communication modules for all devices in the family
- Innovative terminal technology ensures easy assembly and interchangeability with the highest possible degree of safety
- Identical functions and consistent interfaces throughout the entire system family mean less training requirement and increased safety, e.g., an identical automatic reclosing (AR) for line protection devices 7SD8, 7SA8, 7SL8
- Functions can be individually customized by editing for your specific requirements
- Innovations are made available to all devices at the same time and can easily be retrofitted as needed via libraries.

For system operators, perfectly tailored fit with SIPROTEC 5 means:
Individually configurable devices save money in the initial investment, spare parts storage, maintenance, extending and adapting of systems.

Smart automation for transmission grids
The extraordinary range of integrated functionalities for all the demands of your smart grid.

Climate change and dwindling fossil fuels are forcing a total re-evaluation of the energy supply industry, from generation to distribution and consumption. This is having fundamental effects on the structure and operation of the power grids.

Smart automation is a major real-time component designed to preserve the stability of these grids and at the same time conserve energy and reduce costs.

SIPROTEC 5 offers the optimum smart automation platform for smart grids.

Smart automation for transmission grids with SIPROTEC 5 means:
- Open, scalable architecture for IT integration and new functions
- The latest standards in the area of communication and Cyber Security

- "Smart functions", e.g., for power system operation, analysis of faults or power quality (power systems monitoring, power control unit, fault location)
- Integrated automation with optimized logic modules based on the IEC 61131-3 standard
- Highly precise acquisition and processing of process values and transmission to other components in the smart grid
- Protection, automation and monitoring in the smart grid.

Functional integration

Due to the modular design of its hardware and software and the powerful engineering tool DIGSI 5, SIPROTEC 5 is ideally suited for protection, automation, measurement and monitoring tasks in the electrical power systems.

The devices are not only pure protection and control equipment, their performance enables them to assure functional integration of desired depth and scope. For example, they can also serve to perform monitoring, phasor measurement, fault recording, a wide range of measurement functions and much more, concurrently, and they have been designed to facilitate future functionality expansion.

SIPROTEC 5 provides an extensive, precise data acquisition and bay level recording for these functions. By combining device functionality with communication flexibility, SIPROTEC 5 has the ability to meet a wide range of today's applications and specific project specifications as well as the functional expansion capability to adapt to changing needs in the future.

With SIPROTEC 5 it is possible to improve the safety and reliability of the operator's application. Fig. 6.2-52 shows the possible functional expansion of a SIPROTEC 5 device.

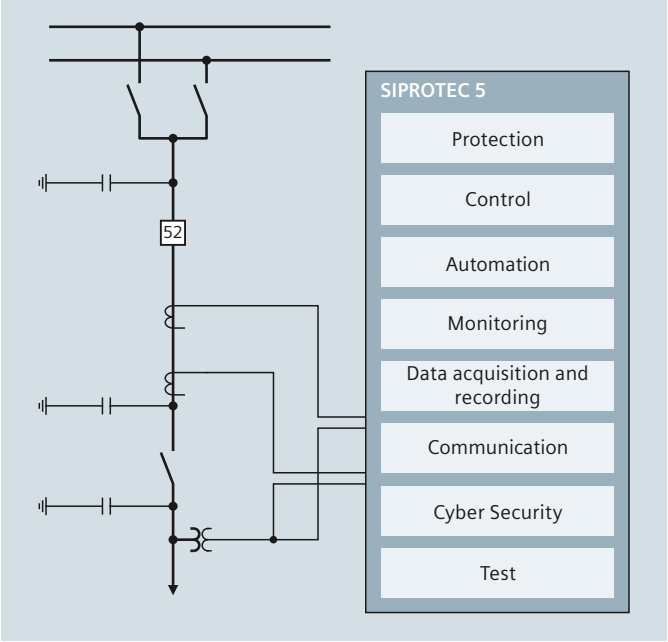


Fig. 6.2-52: **Possible functional expansion of SIPROTEC 5 devices**

Functional integration – Protection

SIPROTEC 5 provides all the necessary protection functions to address reliability and security of power transmission systems. System configurations with multiple busbars and breaker-and-a-half schemes are both supported. The functions are based on decades of experience in putting systems into operation, including feedback and suggestions from system operators.

The modular, functional structure of SIPROTEC 5 allows exceptional flexibility and enables the creation of a protection functionality that is specific to the conditions of the system while also being capable of further changes in the future.

Functional integration – Control

SIPROTEC 5 includes all bay level control and monitoring functions that are required for efficient operation of the substations. The application templates supplied provide the full functionality needed by the system operators. Protection and control functions access the same logical elements.

A new level of quality in control is achieved with the application of communication standard IEC 61850. For example, binary information from the field can be processed and data (e.g., for interlocking across multiple fields) can be transmitted between the devices. Cross communications via GOOSE enables efficient solutions, since here the hardwired circuits are replaced with data telegrams. All devices are provided for up to 4 switching devices (circuit-breakers, disconnectors, earthing switches) in the basic control package. Optionally, additional switching devices and the switching sequence block can be activated (Continuous Function Chart (CFC)).

Functional integration – Automation

An integrated graphical automation function enables operators to create logic diagrams clearly and simply. DIGSI 5 supports this with powerful logic modules based on the standard IEC 61131-3.

Example automation applications are:
- Interlocking checks
- Switching sequences (switching sequence function chart (CFC))
- Message derivations from switching actions
- Messages or alarms by linking available information
- Load shedding a feeder (arithmetic function chart (CFC) and switching sequence function chart (CFC))
- Management of decentralized energy feeds
- System transfer depending on the grid status
- Automatic grid separations in the event of grid stability problems.

Of course, SIPROTEC 5 provides a substation automation system such as SICAM PAS with all necessary information, thus ensuring consistent, integrated and efficient solutions for further automation.

Functional integration – Monitoring
SIPROTEC 5 devices can take on a wide variety of monitoring tasks. These are divided into four groups:
- Self monitoring
- Monitoring grid stability
- Monitoring power quality
- Monitoring of equipment (condition monitoring).

Self monitoring
SIPROTEC 5 devices are equipped with many self-monitoring procedures. These procedures detect faults internal to the device as well as external faults in the secondary circuits and store them in buffers for recording and reporting. This stored information can then be used to help determine the cause of the self monitoring fault in order to take appropriate corrective actions.

Grid stability
Grid monitoring combines all of the monitoring systems that are necessary to assure grid stability during normal grid operation. SIPROTEC 5 provides all necessary functionalities, e.g., fault recorders, continuous recorders, fault locators and phasor measurement units (PMUs) for grid monitoring.

Power quality
For this, SIPROTEC 5 provides corresponding power quality recorders. These can be used to detect weak points early so that appropriate corrective measures can be taken.

The large volume of data is archived centrally and analyzed neatly with a SICAM PQS system.

Equipment
The monitoring of equipment (condition monitoring) is an important tool in asset management and operational support from which both the environment and the company can benefit.

Functional integration – Data acquisition and recording
The recorded and logged field data is comprehensive. It represents the image and history of the field. It is also used by the functions in the SIPROTEC 5 device for monitoring, interbay and substation automation tasks. It therefore provides the basis for these functions now and in the future.

Functional integration – Communication
SIPROTEC 5 devices are equipped with high-performance communication interfaces. These are integrated interfaces or interfaces that are extendable with plug-in modules to provide a high level of security and flexibility. There are various communication modules available. At the same time, the module is independent of the protocol used. This can be loaded according to the application. Particular importance was given to the realization of full communication redundancy:
- Multiple redundant communication interfaces
- Redundant, independent protocols with control center possible (e.g. IEC 60870-5-103 and IEC 61850 or double IEC 60870-5-103 or DNP3 and DNP IP)
- Full availability of the communication ring when the switching cell is enabled for servicing operations
- Redundant time synchronization (e.g. IRIG-B and SNTP).

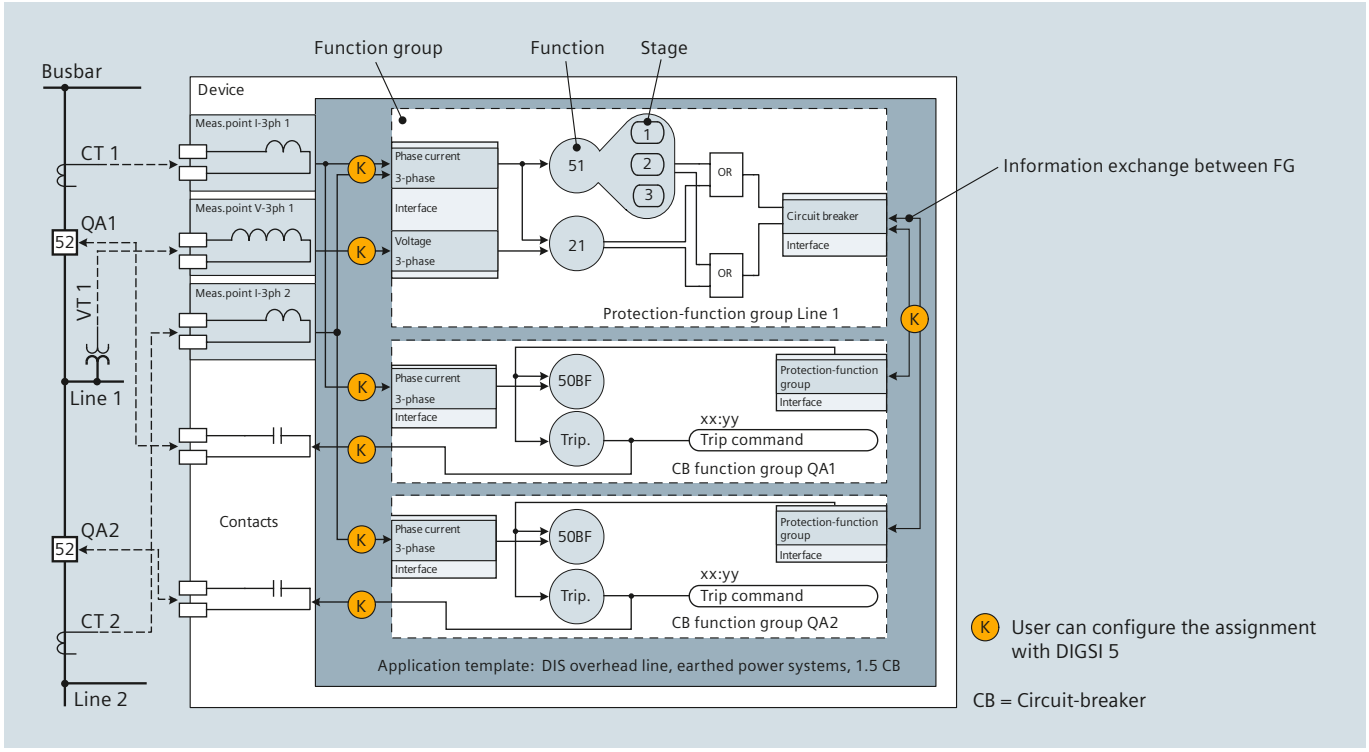


Fig. 6.2-53: **System configuration with application template for one breaker-and-a-half scheme**

Functional integration – Cyber Security

A multi-level security concept for the device and DIGSI 5 provides the user with a high level of protection against communication attacks from the outside and conforms to the requirements of the BDEW Whitebook and NERC CIP.

Functional integration – Test

To shorten testing and commissioning times, extensive test and diagnostic functions are available to the user in DIGSI 5. These are combined in the DIGSI 5 Test Suite.

The test spectrum includes, among other tests:

- Hardware and wiring test
- Function and protection-function test
- Simulation of digital signals and analog sequences by integrated test equipment
- De-bugging of function charts
- Circuit-breaker test and AR (automatic reclosing) test function
- Communication testing
- Loop test for communication connections
- Protocol test.

The engineering, including the device test, can therefore be done with one tool.

Application templates

Application templates allow systems operators to fast track their solution. A library of application templates is available that can be tailored to the specific functional scope for typical applications.

Fig. 6.2-54 shows an example of a system configuration with a breaker-and-a-half scheme. The functions in the application template are combined in functional groups (FG). The functional groups (FG) correspond to the primary components (protection object: line; switching device: circuit-breaker), thereby simplifying the direct reference to the actual system. For example, if the switchgear concerned includes 2 circuit- breakers, this is also represented by 2 "circuit-breaker" functional groups – a schematic map of the actual system.

Fig. 6.2-54: **SIPROTEC 5 device with built-in modules**

Optimizing the application template for the specific application

The system operator can adapt the application templates to the corresponding application and create his own in-house standards. The required number of protection stages or zones can be increased without difficulty. Additional functions can be loaded into the device directly from an extensive function library. Since the functions conform to a common design structure throughout the SIPROTEC 5 system, protection functions and even entire function groups including parameterization can be copied from one device to another.

Hardware and order configurator

The SIPROTEC 5 hardware building blocks offer a freely configurable device. System operators have the choice:

Either to use a pre-configured device with a quantity structure already tailored to the corresponding application, or to build a device from the extensive SIPROTEC 5 hardware building blocks themselves to exactly fit their application.

The flexible hardware building blocks offer:

- Base modules and expansion modules, each with different I/O modules
- Various on-site operation panels
- A large number of modules for communication, measured value conversion and memory extension

The SIPROTEC 5 hardware building blocks offer:

Durability and robustness

- Tailored hardware extension
- Robust housings
- Excellent EMC shielding in compliance with the most recent standards and IEC 61000-4
- Extended temperature range –25 °C to +70 °C/–13 °F to +158 °F.

Modular principle

- Freely configurable and extendable devices
- Large process data range (up to 24 current and voltage transformers for protection applications and up to 40 for central busbar protection, as well as more than 200 inputs and outputs for recording applications possible)
- Operation panel that is freely selectable for all device types (e.g., large or small display, with or without key switches, detached operation panel)
- Identical wiring of flush-mounting and surface-mounting housings.

Product selection via the order configurator

The order configurator assists in the selection of SIPROTEC 5 products. The order configurator is a Web application that can be used with any browser. The SIPROTEC 5 configurator can be used to configure complete devices or individual components, such as communication modules or extension modules. At the end of the configuration process, the product code and a detailed presentation of the configuration result are provided. It clearly describes the product and also serves as the order number.

6.2.3 Operating Programs DIGSI 4, IEC 61850 System Configurator and SIGRA 4

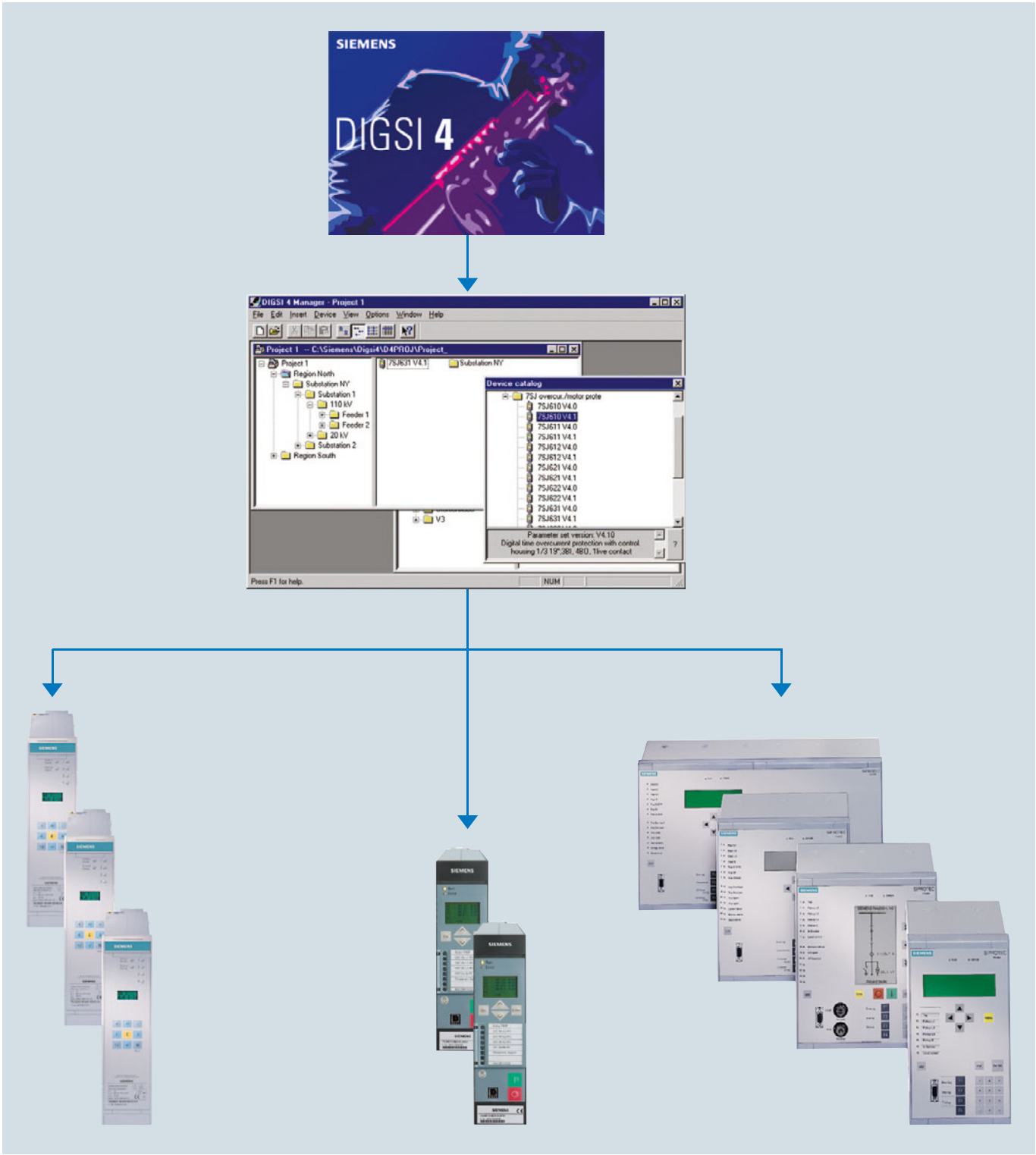


Fig. 6.2-55: **DIGSI 4 operating program**

DIGSI 4, an operating software for all SIPROTEC protection devices

Description

The PC operating program DIGSI 4 is the user interface to the SIPROTEC devices, regardless of their version. It is designed with a modern, intuitive user interface. With DIGSI 4, SIPROTEC devices are configured and evaluated – it is the tailored program for industrial and energy distribution systems.

Functions

Simple protection setting

From the numerous protection functions it is possible to easily select only those which are really required (see fig. 6.2-56). This increases the clearness of the other menus.

Device setting with primary or secondary values

The settings can be entered and displayed as primary or secondary values. Switching over between primary and secondary values is done with one mouse click in the tool bar (see fig. 6.2-56).

Assignment matrix

The DIGSI 4 matrix shows the user the complete configuration of the device at a glance (fig. 6.2-57). For example, the assignment of the LEDs, the binary inputs and the output relays is displayed in one image. With one click, the assignment can be changed.

CFC: Projecting the logic instead of programming

With the CFC (continuous function chart), it is possible to link and derive information without software knowledge by simply drawing technical processes, interlocks and operating sequences.

Logical elements such as AND, OR, timers, etc., as well as limit value requests of measured values are available (fig. 6.2-58).

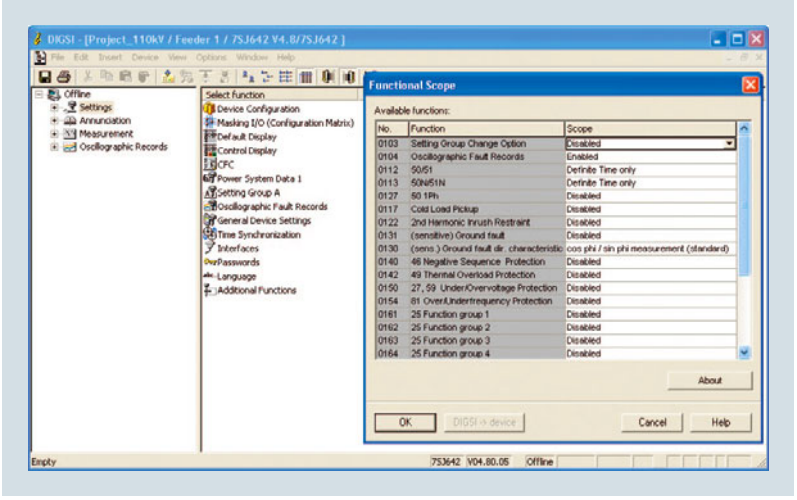


Fig. 6.2-56: **DIGSI 4, main menu, selection of protection functions**

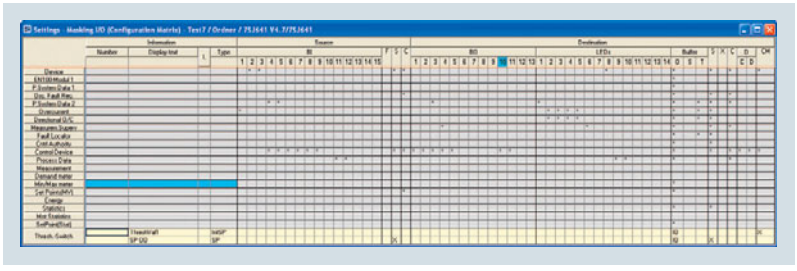


Fig. 6.2-57: **DIGSI 4, assignment matrix**

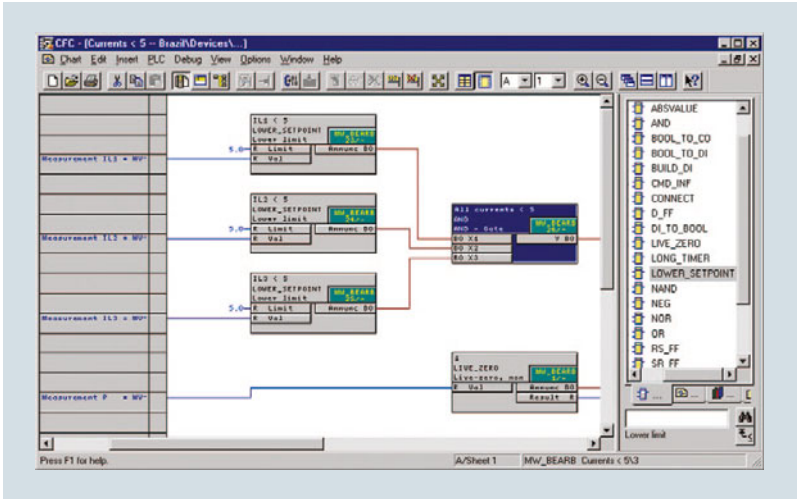


Fig. 6.2-58: **CFC plan**

Commissioning
Special attention has been paid to commissioning. All binary inputs and outputs can be set and read out in targeted way. Thus, a very simple wiring test is possible. Messages can be sent to the serial interface deliberately for test purposes.

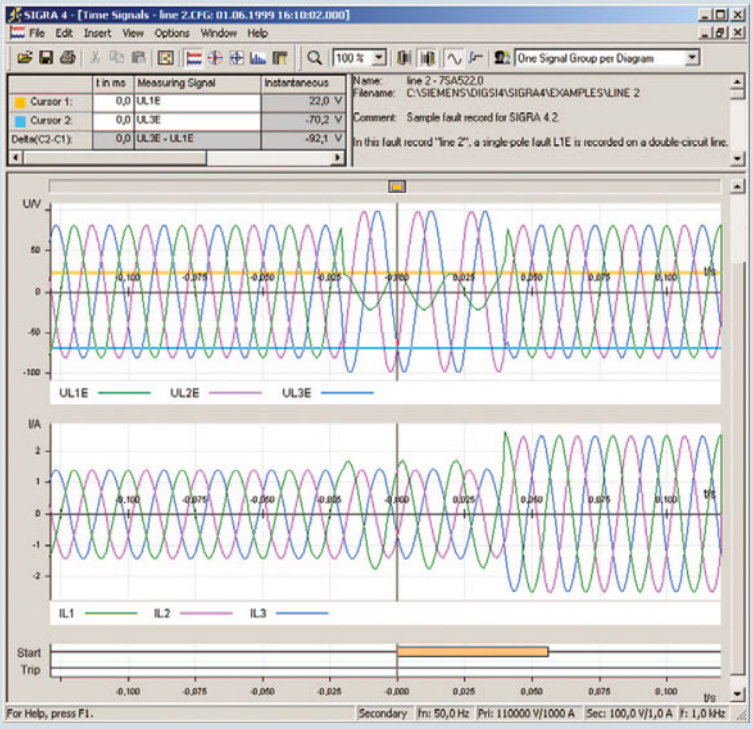


Fig. 6.2-59: **Typical time-signal representation**

IEC 61850 system configurator
The IEC 61850 system configurator, which is started out of the system manager, is used to determine the IEC 61850 network structure as well as the extent of data exchange between the participants of a IEC 61850 station. To do this, subnets are added in the "network" working area – if required –, available participants are assigned to the subnets, and addressing is defined. The "assignment" working area is used to link data objects between the participants, e.g., the starting indication of the U*I*inverse-time overcurrent protection *I*> function of feeder 1, which is transferred to the incoming supply in order to prompt the reverse interlocking of the *V*/*I*inverse-time overcurrent protection *I*>> function there
(see fig. 6.2-58).

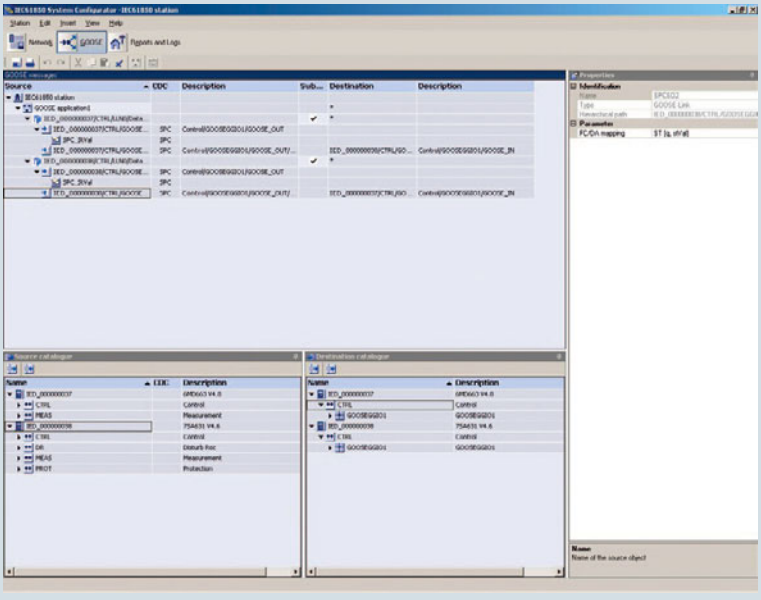


Fig. 6.2-60: **IEC 61850 system configurator**

SIGRA 4, powerful analysis of all protection fault records

Description

It is of crucial importance after a line fault that the fault is quickly and fully analyzed so that the proper measures can be immediately derived from the evaluation of the cause. As a result, the original line condition can be quickly restored and the downtime reduced to an absolute minimum. It is possible with SIGRA 4 to display records from digital protection units and fault recorders in various views and measure them, as required, depending on the relevant task.

In addition to the usual time-signal display of the measured variables record, it is also designed to display vector diagrams, circle diagrams, bar charts for indicating the harmonics and data tables. From the measured values which have been recorded in the fault records, SIGRA 4 calculates further values, such as: absent quantities in the three-wire system, impedances, outputs, symmetrical components, etc. By means of two measuring cursors, it is possible to evaluate the fault trace simply and conveniently. With SIGRA, however, you can add additional fault records. The signals of another fault record (e.g. from the opposite end of the line) are added to the current signal pattern by means of Drag&Drop. SIGRA 4 offers the possibility to display signals from various fault records in one diagram and fully automatically synchronize these signals to a common time base. In addition to finding out the details of the line fault, the localization of the fault is of special interest.

A precise determination of the fault location will save time that can be used for the on-site inspection of the fault. This aspect is also supported by SIGRA 4 – with its "offline fault localization" feature.

SIGRA 4 can be used for all fault records using the COMTRADE file format.

The functional features and advantages of SIGRA 4 can, however, only be optimally shown on the product itself. For this reason, it is possible to test SIGRA 4 for 30 days with the trial version.

Functions overview

- 6 types of diagrams: time signal representation (usual), circle diagram (e.g.forR/X),vectordiagram (reading of angles), bar charts (e.g. for visualization of harmonics), table (lists values of several signals at the same instant) and fault locator (shows the location of a fault)
- Calculate additional values such as positive impedances, r.m.s. values, symmetric components, vectors, etc.
- Two measurement cursors, synchronized in each view
- Powerful zoom function
- User-friendly configuration via drag & drop
- Innovative signal configuration in a clearly-structured matrix
- Time-saving user profiles, which can be assigned to individual relay types or series
- Addition of other fault records to the existing fault record
- Synchronization of several fault records to a common time basis
- Easy documentation by copying diagrams to documents of other MS Windows programs
- Offline fault localization

Hardware requirements

- Pentium 4 with 1-GHz processor or similar
- 1 GB of RAM (2 GB recommended)
- Graphic display with a resolution of 1024 × 768 (1280 × 1024 recommended)
- 50 MB free storage space on the hard disk
- DVD-ROM drive
- Keyboard and mouse

Software requirements

- MS Windows XP Professional
- MS Windows Vista Home Premium, Business and Ultimate
- MS Windows Server 2003 Standard Edition with Service Pack 2 used as a Workstation computer
- MS Windows 7 Professional and Enterprise Ultimate

Functions

Different views of a fault record

In addition to the standard time signal representation, SIGRA 4 also supports the display of circle diagrams (e.g. R/X diagrams), vectors, which enable reading of angles, and bar charts (e.g. for visualization of harmonics). To do this, SIGRA uses the values recorded in the fault record to calculate additional values such as positive impedances, r.m.s. values, symmetric components, vectors, etc.

Measurement of a fault record

Two measurement cursors enable fast and convenient measurement of the fault record. The measured values of the cursor positions and their differences are presented in tables. The cursors operate interactively and across all views, whereby all cursor movement is synchronized in each view: In this manner, the cursor line enables simultaneous "intersection" of a fault occurrence in both a time signal characteristic and circle diagram characteristic. And of course a powerful zoom function ensures that you do not lose track of even the tiniest detail. The views of SIGRA 4 can accommodate any number of diagrams and in each diagram any number of signals.

Operational features

The main aim of the developers of SIGRA 4, who were assisted by ergonomic and design experts, was to produce a system that was simple, intuitive and user-friendly:

- The colours of all the lines have been defined so that they are clear and easily distinguishable. However, the colour, as well as the line style, the scale and other surface features, can be adjusted to suit individual requirements.
- Pop-up menus for each situation offer customized functionality – thus eliminating the need to browse through numerous menu levels (total operational efficiency).
- Configuration of the individual diagrams is simple and intuitive: Object-oriented, measured variables can be simply dragged and dropped from one diagram to another (also diagrams of different types).
- "Snap-to-grid" and "snap-to-object" movement of the cursor lines for easy and accurate placement.
- Redundancy: Most user tasks can be achieved via up to five different operational methods, thus ensuring quick and easy familiarization with the analysis software.
- Utilization of the available screen space is automatically optimized by an intelligent function that, like the "synchronous mouse cursors", has since been patented.

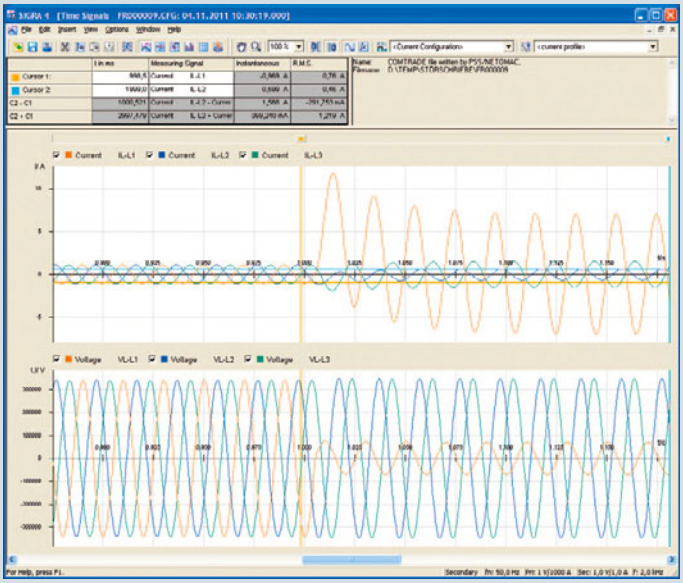


Fig. 6.2-62: **Typical time signal representation**

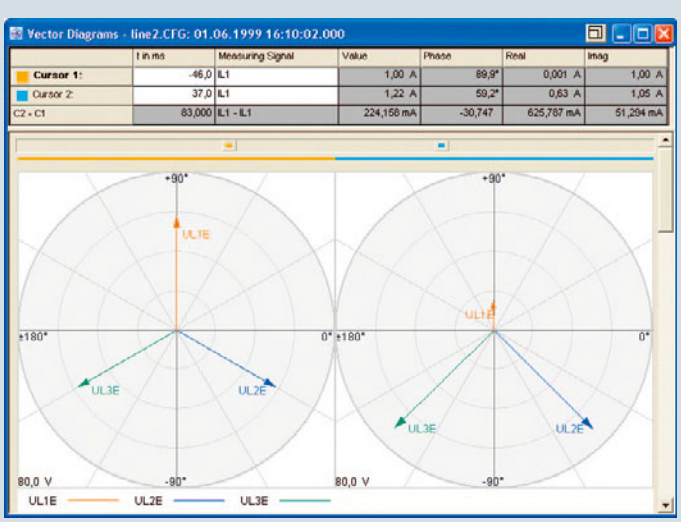


Fig. 6.2-63: **Vector diagrams**

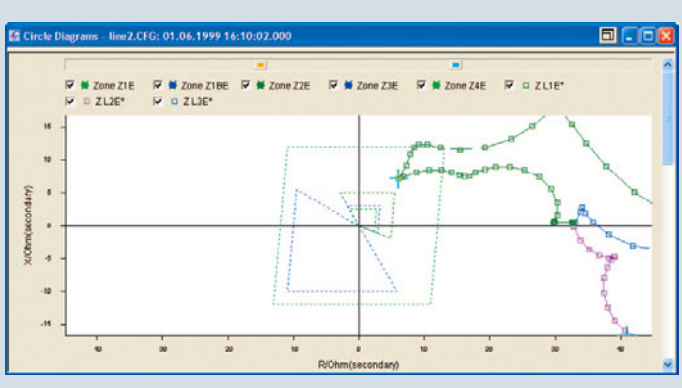


Fig. 6.2-64: **Circle diagram**

User friendly tools support you in your daily work:

- Storage of user defined views (e.g zoom, size), in so-called user profiles and to assign them to individual relay types or series. Then simply select from the toolbar and you can display each fault record quickly and easily as required. No need to waste time scrolling, zooming or resizing and moving windows.
- Additional fault records, e.g. from the other end of a line, can be added to existing records.
- A special function allows several fault records to be synchronized on a mutual time basis, thus considerably improving the quality of fault analysis.
- Fault localization with data from one line end the fault record data (current and voltage measurement) values are imported from the numerical protection unit into SIGRA 4. The fault localisator in SIGRA 4 is then started by the user and the result represented in % or in km of the line length, depending on the parameters assigned.
- Fault localization with data from both line ends. The algorithm of the implemented fault location does not need a zero-phase sequence system. Thus, measuring errors due to earth impedance or interference with the zero current of the parallel line are ruled out. Errors with contact resistance on lines with infeed from both ends are also correctly recorded. The above influences are eliminated due to the import of fault record data from both line ends into SIGRA. For this purpose, the imported data are synchronized in SIGRA and the calculation of the fault location is then started. Consequently, fault localization is independent from the zero-phase sequence system and the line infeed conditions and produces precise resultstoallowasfastaninspectionofthe fault location as possible.
- So-called marks, which users can insert at various instants as required, enable suitable commentary of the fault record. Each individual diagram can be copied to a document of another MS Windows program via the “clipboard”: Documenting fault records really could not be easier.

Scope of delivery

The software product is quick and easy to install from a CD-ROM. It has a comprehensive “help” system. An user-friendly and practical manual offers easy step-by-step instructions on how to use SIGRA.

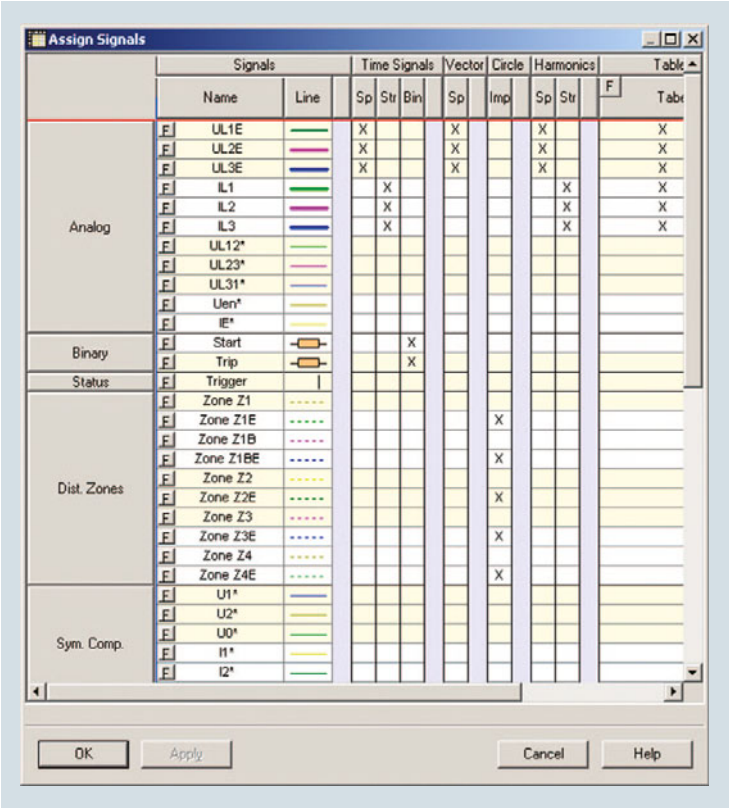


Fig. 6.2-65: **Concise matrix for assigning signals to diagrams**

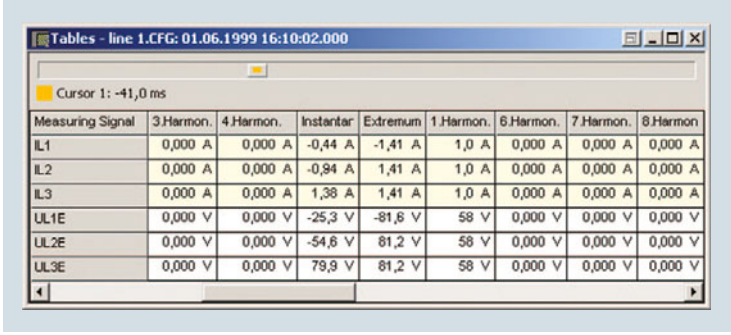


Fig. 6.2-66: **Table with values at a definite time**

6.2.4 Typical Protection Schemes

1. Cables and overhead lines

Radial systems

Notes:

1) Auto-reclosure (ANSI 79) only with overhead lines.

2) Negative sequence overcurrent protection 46 as sensitive backup protection against asymmetrical faults.

General notes:

- The relay at the far end (D) is set with the shortest operating time. Relays further upstream have to be time-graded against the next downstream relay in steps of about 0.3 s.
- Inverse time or definite time can be selected according to the following criteria:
  - Definite time:
    Source impedance is large compared to the line impedance, that is, there is small current variation between near and far end faults.
  - Inverse time:
    Longer lines, where the fault current is much less at the far end of the line than at the local end.
  - Strong or extreme inverse-time:
    Lines where the line impedance is large compared to the source impedance (high difference for close-in and remote faults), or lines where coordination with fuses or reclosers is necessary. Steeper characteristics also provide higher stability on service restoration (cold load pickup and transformer inrush currents).

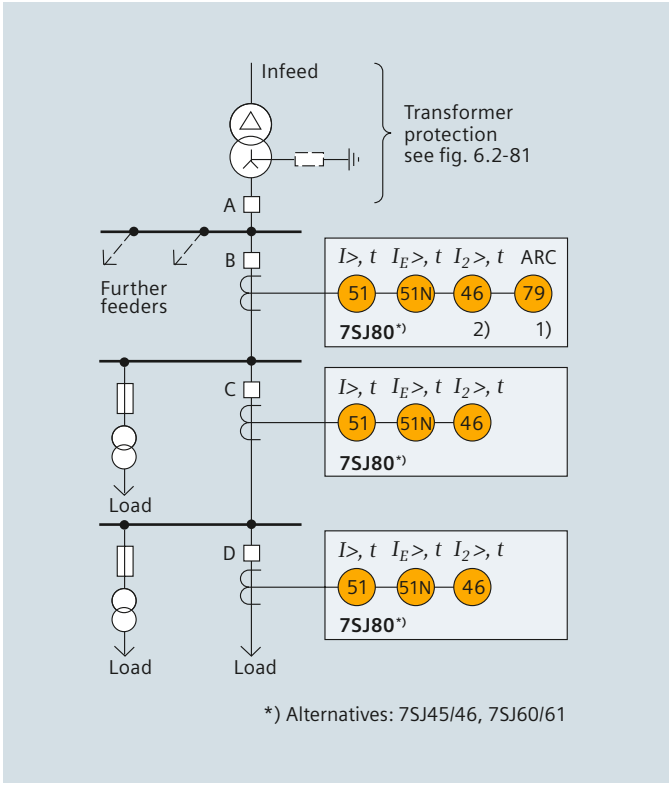


Fig. 6.2-67: **Radial systems**

Ring-main circuit

General notes:

- Operating time of overcurrent relays to be coordinated with downstream fuses of load transformers (preferably with strong inverse-time characteristic with about 0.2 s grading-time delay)
- Thermal overload protection for the cables (option)
- Negative sequence overcurrent protection (46) as sensitive protection against asymmetrical faults (option)

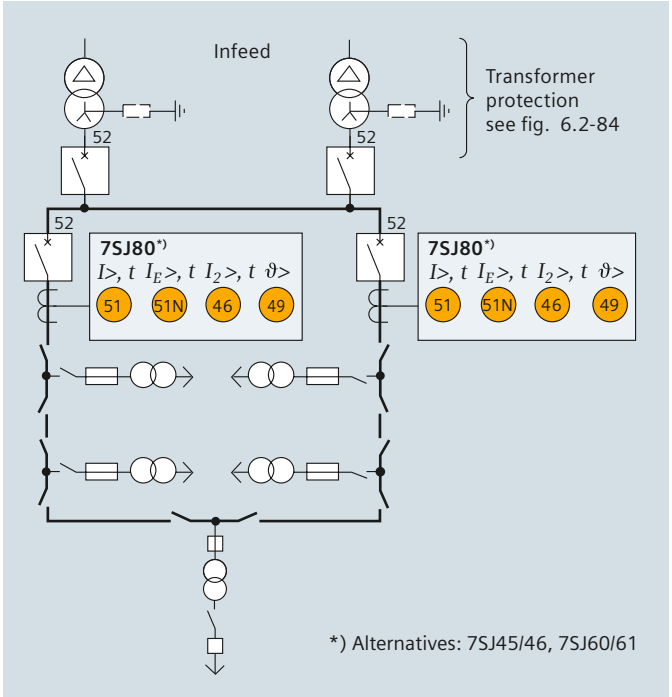


Fig. 6.2-68: **Ring-main circuit**

Switch-onto-fault protection

If switched onto a fault, instantaneous tripping can be effected. If the internal control function is used (local, via binary input or via serial interface), the manual closing function is available without any additional wiring. If the control switch is connected to a circuit-breaker bypassing the internal control function, manual detection using a binary input is implemented.

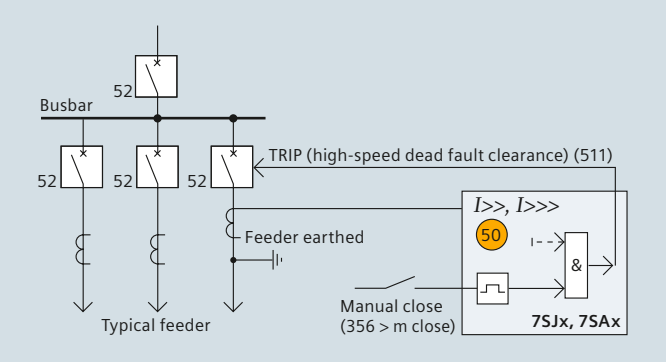


Fig. 6.2-69: **Switch-onto-fault protection**

Directional comparison protection (cross-coupling)

Cross-coupling is used for selective protection of sections fed from two sources with instantaneous tripping, that is, without the disadvantage of time coordination. The directional comparison protection is suitable if the distances between the protection stations are not significant and pilot wires are available for signal transmission. In addition to the directional comparison protection, the directional coordinated overcurrent-time protection is used for complete selective backup protection. If operated in a closed-circuit connection, an interruption of the transmission line is detected.

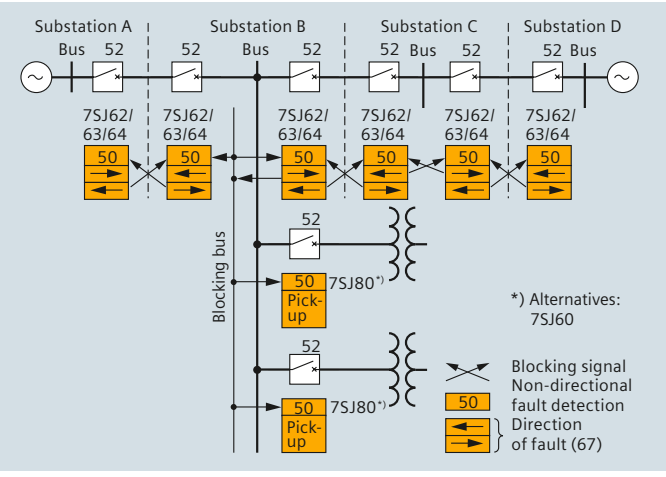


Fig. 6.2-70: **Directional comparison protection**

Distribution feeder with reclosers

General notes:

- The feeder relay operating characteristics, delay times and auto-reclosure cycles must be carefully coordinated with downstream reclosers, sectionalizers and fuses.
  The 50/50N instantaneous zone is normally set to reach out to the first main feeder sectionalizing point. It has to ensure fast clearing of close-in faults and prevent blowing of fuses in this area ("fuse saving"). Fast auto-reclosure is initiated in this case. Further time-delayed tripping and reclosure steps (normally two or three) have to be graded against the recloser.
- The overcurrent relay should automatically switch over to less sensitive characteristics after long breaker interruption times in order to enable overriding of subsequent cold load pickup and transformer inrush currents.

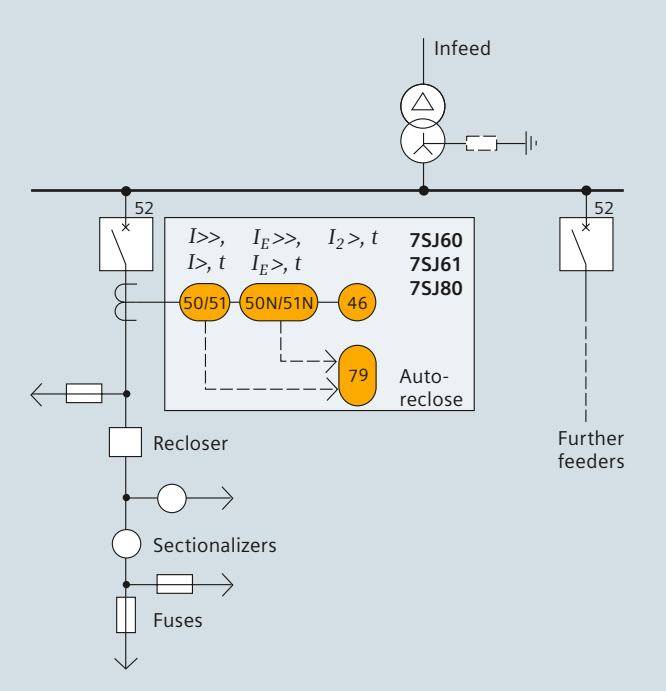


Fig. 6.2-71: **Distribution feeder with reclosers**

3-pole multishot auto-reclosure (AR, ANSI 79)
Auto-reclosure (AR) enables 3-phase auto-reclosing of a feeder that has previously been disconnected by overcurrent protection.

SIPROTEC 7SJ61 allows up to nine reclosing shots. The first four dead times can be set individually. Reclosing can be blocked or initiated by a binary input or internally. After the first trip in a reclosing sequence, the high-set instantaneous elements (I>>>, I>>, I_E>>) can be blocked. This is used for fuse-saving applications and other similar transient schemes using simple overcurrent relays instead of fuses. The low-set definite-time (I>, I_E>) and the inverse-time (I_p, I_{Ep}) overcurrent elements remain operative during the entire sequence.

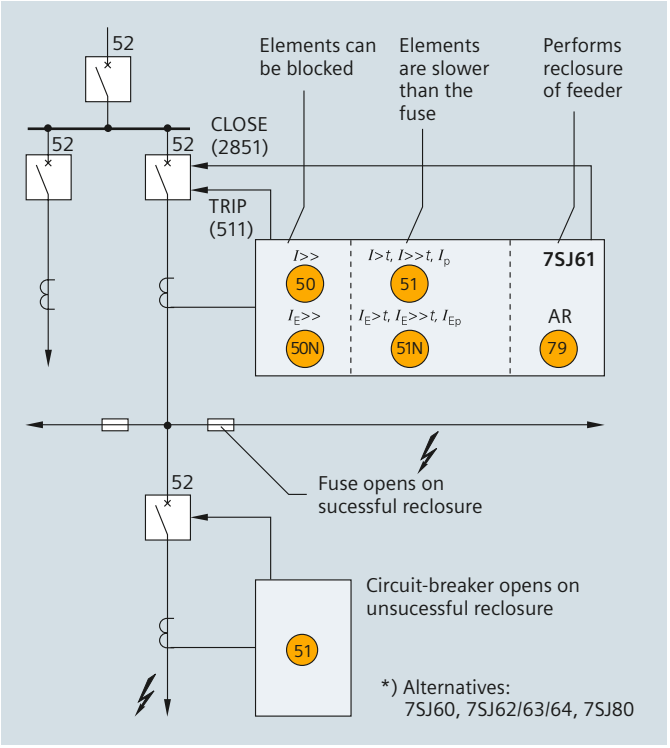


Fig. 6.2-72: **3-pole multishot auto-reclosure (AR, ANSI 79)**

Parallel feeder circuit

General notes:

- The preferred application of this circuit is in the reliable supply of important consumers without significant infeed from the load side.
- The 67/67N directional overcurrent protection trips instantaneously for faults on the protected line. This saves one time-grading interval for the overcurrent relays at the infeed.
- The 51/51N overcurrent relay functions must be time-graded against the relays located upstream.

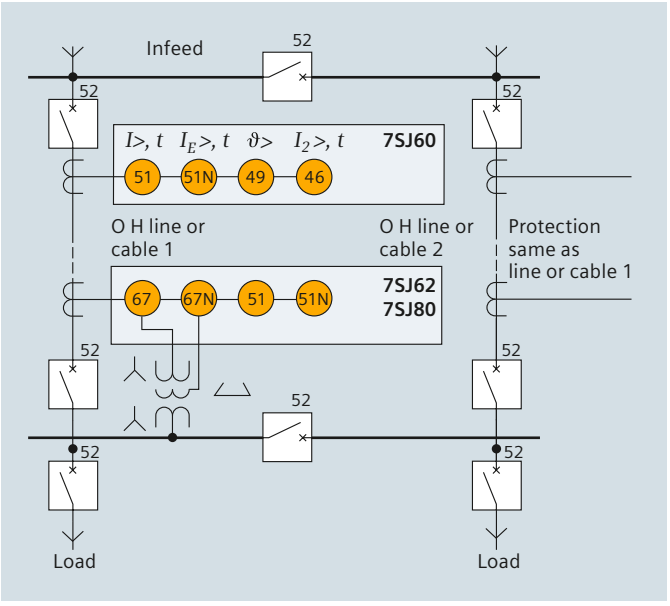


Fig. 6.2-73: **Parallel feeder circuit**

Reverse-power monitoring at double infeed

If a busbar is fed from two parallel infeeds and a fault occurs on one of them, only the faulty infeed should be tripped selectively in order to enable supply to the busbar to continue from the remaining supply. Unidirectional devices that can detect a short-circuit current or energy flow from the busbar toward the incoming feeder should be used. Directional time-overcurrent protection is usually set via the load current. However, it cannot clear weak-current faults. The reverse-power protection can be set much lower than the rated power, thus also detecting the reverse-power flow of weak-current faults with fault currents significantly below the load current.

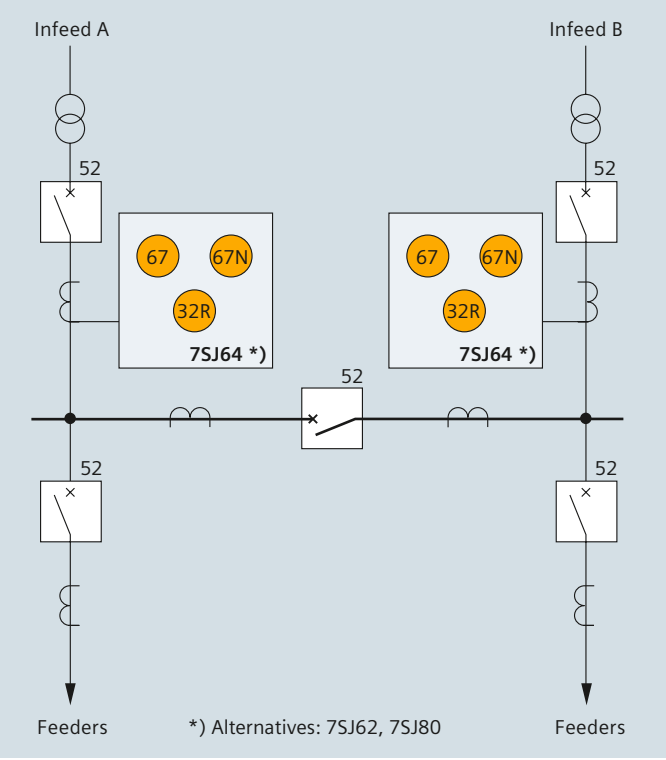


Fig. 6.2-74: **Reverse-power monitoring at double infeed**

Synchronization function

Note:
Also available in relays 7SA6, 7SD5, 7SA522, 7VK61.

General notes:

- When two subsystems must be interconnected, the synchronization function monitors whether the subsystems are synchronous and can be connected without risk of losing stability.
- This synchronization function can be applied in conjunction with the auto-reclosure function as well as with the control function CLOSE commands (local / remote).

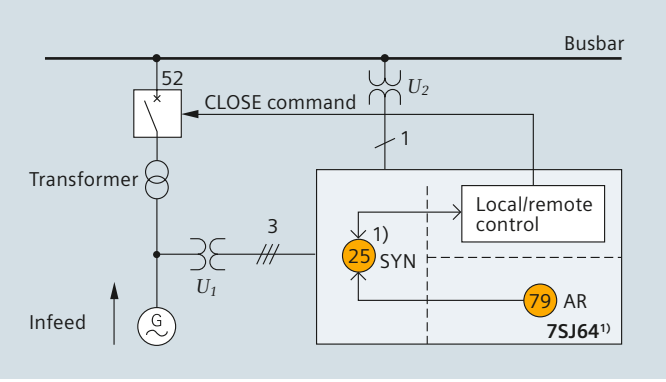


Fig. 6.2-75: **Synchronization function**

Cables or short overhead lines with infeed from both ends

Notes:

1) Auto-reclosure only with overhead lines
2) Differential protection options:
- Type 7SD5 or 7SD610 with direct optical-fiber connection up to about 100 km or via a 64 kbit/s channel (optical-fiber, microwave)
- Type 7SD52 or 7SD610 with 7XV5662 (CC-CC) with 2 and 3 pilot wires up to about 30 km
- Type 7SD80 with pilot wire and/or fibre optic protection data interface.

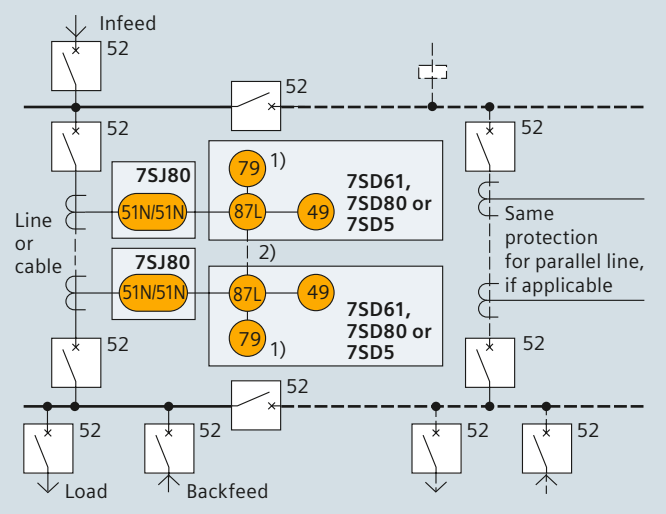


Fig. 6.2-76: **Cables or short overhead lines with infeed from both ends**

Overhead lines or longer cables with infeed from both ends

Notes:

1) Teleprotection logic (85) for transfer trip or blocking schemes. Signal transmission via pilot wire, power line carrier, digital network or optical fiber (to be provided separately). The teleprotection supplement is only necessary if fast fault clearance on 100 % line length is required, that is, second zone tripping (about 0.3 s delay) cannot be accepted for far end faults. For further application notes on teleprotection schemes, refer to the table on the following page.
2) Directional earth-fault protection 67N with inverse-time delay against high-resistance faults
3) Single or multishot auto-reclosure (79) only with overhead lines.

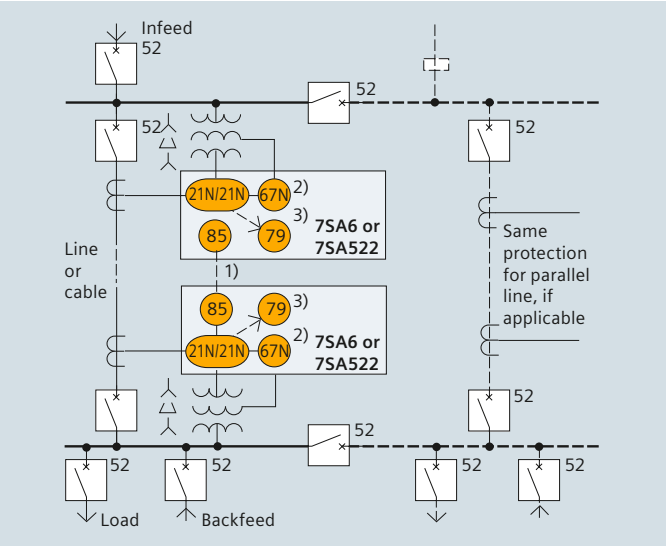


Fig. 6.2-77: **Overhead lines or longer cables with infeed from both ends**

Subtransmission line

Note:

Connection to open delta winding if available. Relays 7SA6 / 522 and 7SJ62 can, however, also be set to calculate the zero-sequence voltage internally.

General notes:

- Distance teleprotection is proposed as main protection and time-graded directional overcurrent as backup protection.
- The 67N function of 7SA6 / 522 provides additional high-resistance earth-fault protection. It can be used in parallel with the 21 / 21N function.
- Recommended teleprotection schemes: PUTT on medium and long lines with phase shift carrier or other secure communication channel POTT on short lines. BLOCKING with On / Off carrier (all line lengths).

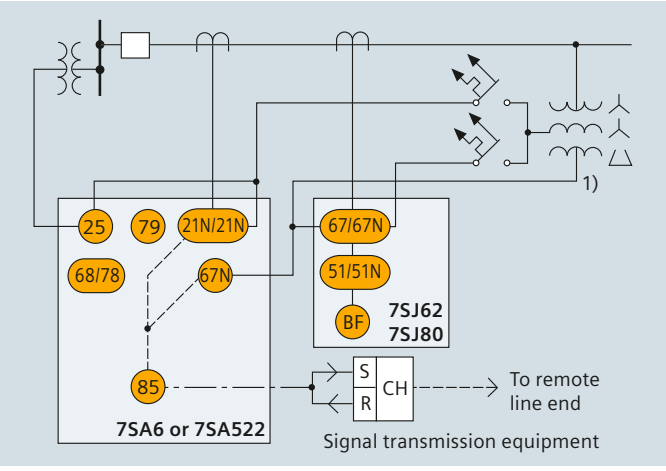


Fig. 6.2-78: **Subtransmission line**

		Permissive underreach transfer trip (PUTT)	Permissive overreach transfer trip (POTT)	Blocking	Unblocking
Preferred application	Signal transmission system	Dependable and secure communication channel: • Power line carrier with frequency shift modulation. HF signal coupled to 2 phases of the protected line, or even better, to a parallel circuit to avoid transmission of the HF signal through the fault location. • Microwave radio, especially digital (PCM) • Optical-fiber cables		Reliable communication channel (only required during external faults) • Power line carrier with amplitude modulation (ON / OFF). The same frequency may be used on all terminals)	Dedicated channel with continuous signal transfer • Power line carrier with frequency shift keying. Continuous signal transmission must be permitted.
	Characteristic of line	Best suited for longer lines – where the underreach zone provides sufficient resistance coverage	• Excellent coverage on short lines in the presence of fault resistance. • Suitable for the protection of multi-terminal lines with intermediate infeed	All line types – preferred practice in the US	Same as POTT
Advantages		• Simple technique • No coordination of zones and times with the opposite end required. The combination of different relay types therefore presents no problems	• Can be applied without underreaching zone 1 stage (e.g., overcompensated series uncompensated lines) • Can be applied on extremely reshort lines (impedance less than minimum relay setting) • Better for parallel lines as mutual coupling is not critical for the overreach zone • Weak infeed terminals are no problem (Echo and Weak Infeed logic is included)	Same as POTT	Same as POTT but: • If no signal is received (no block and no uncompensated block) then tripping by the overreach zone is released after 20 ms
Drawbacks		• Overlapping of the zone 1 reaches must be ensured. On parallel lines, teed feeders and tapped lines, the influence of zero sequence coupling and intermediate infeeds must be carefully considered to make sure a minimum overlapping of the zone 1 reach is always present. • Not suitable for weak infeed terminals	• Zone reach and signal timing coordination with the remote end is necessary (current reversal)	Same as POTT • Slow tripping – all teleprotection trips must be delayed to wait for the eventual blocking signal • Continuous channel monitoring is not possible	Same as POTT

Table 6.2-2: **Application criteria for frequently used teleprotection schemes**

Transmission line with reactor (fig. 6.2-79)

Notes:

1) 51N only applicable with earthed reactor neutral.
2) If phase CTs at the low-voltage reactor side are not available, the high-voltage phase CTs and the CT in the neutral can be connected to a restricted earth-fault protection using one 7VH60 high-impedance relay.

General notes:

- Distance relays are proposed as main 1 and main 2 protection. Duplicated 7SA6 is recommended for series-compensated lines.
- Operating time of the distance relays is in the range of 15 to 25 ms depending on the particular fault condition. These tripping times are valid for faults in the underreaching distance zone (80 to 85 % of the line length). Remote end faults must be cleared by the superimposed teleprotection scheme. Its overall operating time depends on the signal transmission time of the channel, typically 15 to 20 ms for frequency shift audio-tone PLC or microwave channels, and lower than 10 ms for ON / OFF PLC or digital PCM signaling via optical fibers. Teleprotection schemes based on distance relays therefore have operating times on the order of 25 to 30 ms with digital PCM coded communication. With state-of-the-art two-cycle circuit-breakers, fault clearing times well below 100 ms (4 to 5 cycles) can normally be achieved.
- Dissimilar carrier schemes are recommended for main 1 and main 2 protection, for example, PUTT, and POTT or Blocking / Unblocking.
- Both 7SA522 and 7SA6 provide selective 1-pole and / or 3-pole tripping and auto-reclosure. The earth-current directional comparison protection (67N) of the 7SA6 relay uses phase selectors based on symmetrical components. Thus, 1-pole auto-reclosure can also be executed with high-resistance faults. The 67N function of the 7SA522 relay can also be used as time-delayed directional overcurrent backup.
- The 67N functions are provided as high-impedance fault protection. 67N is often used with an additional channel as a separate carrier scheme. Use of a common channel with distance protection is only possible if the mode is compatible (e.g., POTT with directional comparison). The 67N may be blocked when function 21 / 21N picks up. Alternatively, it can be used as time-delayed backup protection.

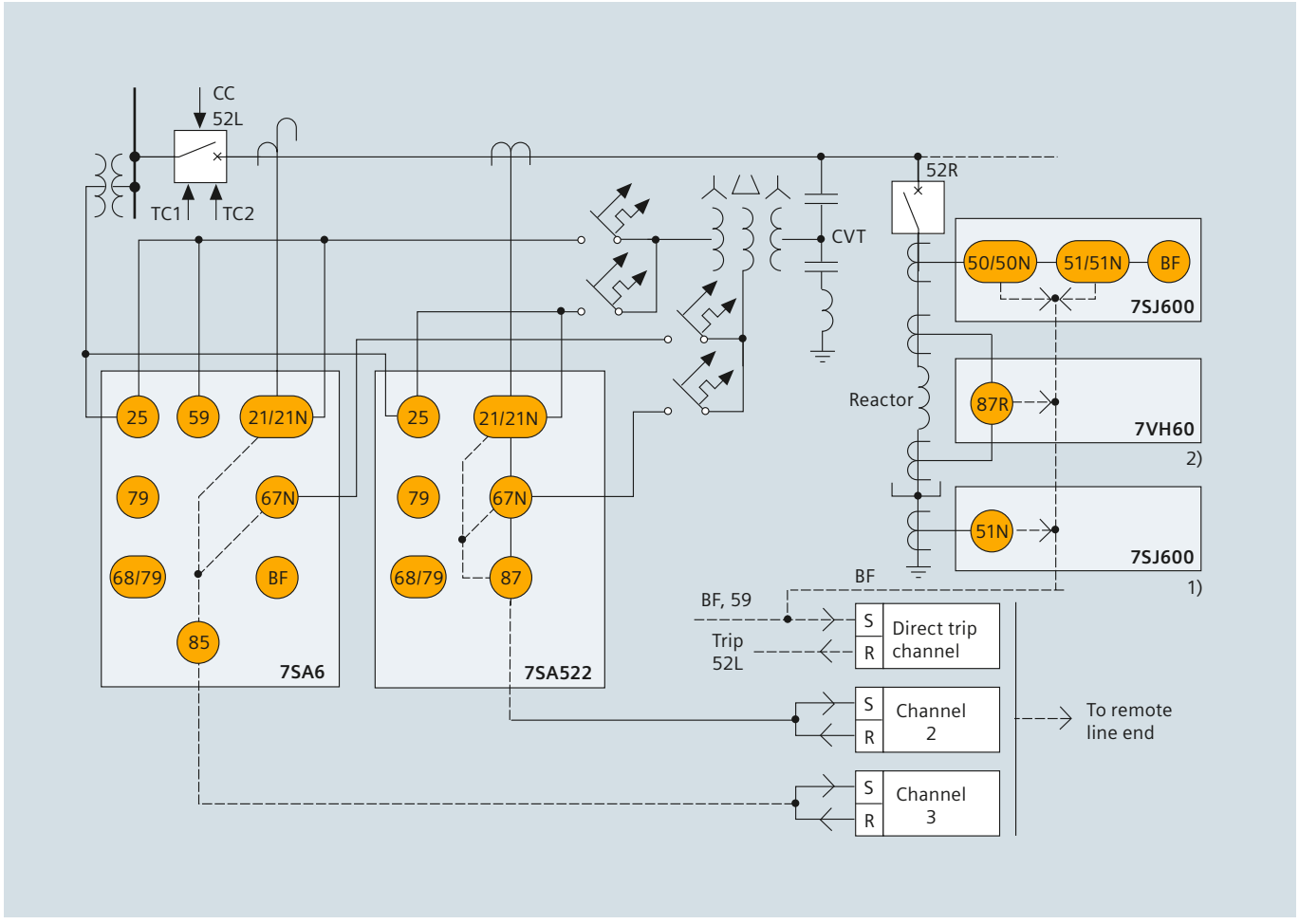


Fig. 6.2-79: **Transmission line with reactor**

Transmission line or cable (with wide-band communication)

General notes:

- Digital PCM-coded communication (with n × 64 kbit/s channels) between line ends is becoming more and more frequently available, either directly by optical or microwave point-to-point links, or via a general-purpose digital communication network.
  In both cases, the relay-type current differential protection 7SD52 / 61 can be applied. It provides absolute phase and zone selectivity by phase-segregated measurement, and is not affected by power swing or parallel line zero-sequence coupling effects. It is, furthermore, a current-only protection that does not need a VT connection. For this reason, the adverse effects of CVT transients are not applicable.
  This makes it particularly suitable for double and multi-circuit lines where complex fault situations can occur.
  The 7SD5 / 61 can be applied to lines up to about 120 km in direct relay-to-relay connections via dedicated optical fiber cores (see also application 10), and also to much longer distances of up to about 120 km by using separate PCM devices for optical fiber or microwave transmission.
  The 7SD5 / 61 then uses only a small part (64-512 64 kbit/s) of the total transmission capacity (on the order of Mbits/s).
- The 7SD52 / 61 protection relays can be combined with the distance relay 7SA52 or 7SA6 to form a redundant protection system with dissimilar measuring principles complementing each other (fig. 6.2-80). This provides the highest degree of availability. Also, separate signal transmission ways should be used for main 1 and main 2 line protection, e.g., optical fiber or microwave, and power line carrier (PLC).
  The current comparison protection has a typical operating time of 15 ms for faults on 100 % line length, including signaling time.

General notes for fig. 6.2-81:

- SIPROTEC 7SD5 offers fully redundant differential and distance relays accommodated in one single bay control unit, and provides both high-speed operation of relays and excellent fault coverage, even under complicated conditions. Precise distance-to-fault location avoids time-consuming line patrolling, and reduces the downtime of the line to a minimum.
- The high-speed distance relay operates fully independently from the differential relay. Backup zones provide remote backup for upstream and downstream lines and other power system components

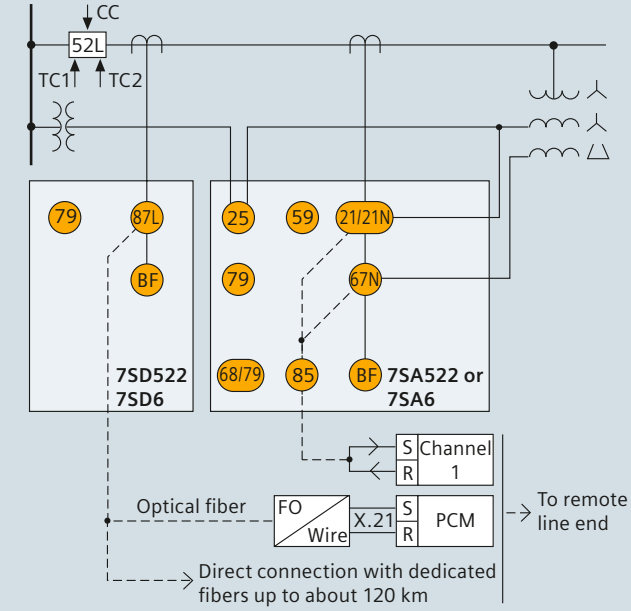


Fig. 6.2-80: **Redundant transmission line protection**

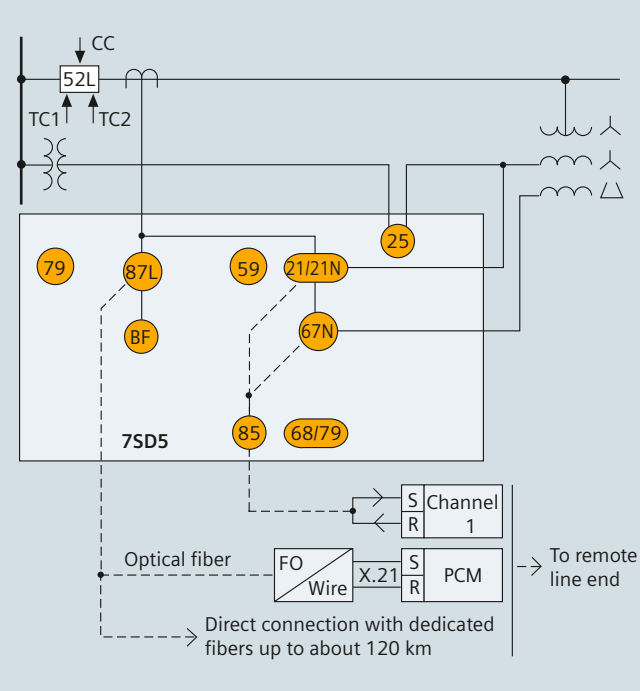


Fig. 6.2-81: **Transmission line protection with redundant algorithm in one device**

Transmission line, one-breaker-and-a-half terminal

Notes:

1) When the line is switched off and the line line disconnector (isolator) is open, high through-fault currents in the diameter may cause maloperation of the distance relay due to unequal CT errors (saturation).
   Normal practice is therefore to block the distance protection (21 / 21N) and the directional earth-fault protection (67N) under this condition via an auxiliary contact of the line line disconnector (isolator). A standby overcurrent function (50 / 51N, 51 / 51N) is released instead to protect the remaining stub between the breakers ("stub" protection).
2) Overvoltage protection only with 7SA6 / 52.

General notes:

- The protection functions of one diameter of a breaker-and-a-half arrangement are shown.
- The currents of two CTs have each to be summed up to get the relevant line currents as input for main 1 and 2 line protection. The location of the CTs on both sides of the circuit-breakers is typical for substations with dead-tank circuit-breakers. Live-tank circuit-breakers may have CTs only on one side to reduce cost. A fault between circuit-breakers and CT (end fault) may then still be fed from one side even when the circuit-breaker has opened. Consequently, final fault clearing by cascaded tripping has to be accepted in this case.
  The 7VK61 relay provides the necessary end fault protection function and trips the circuit-breakers of the remaining infeeding circuits.

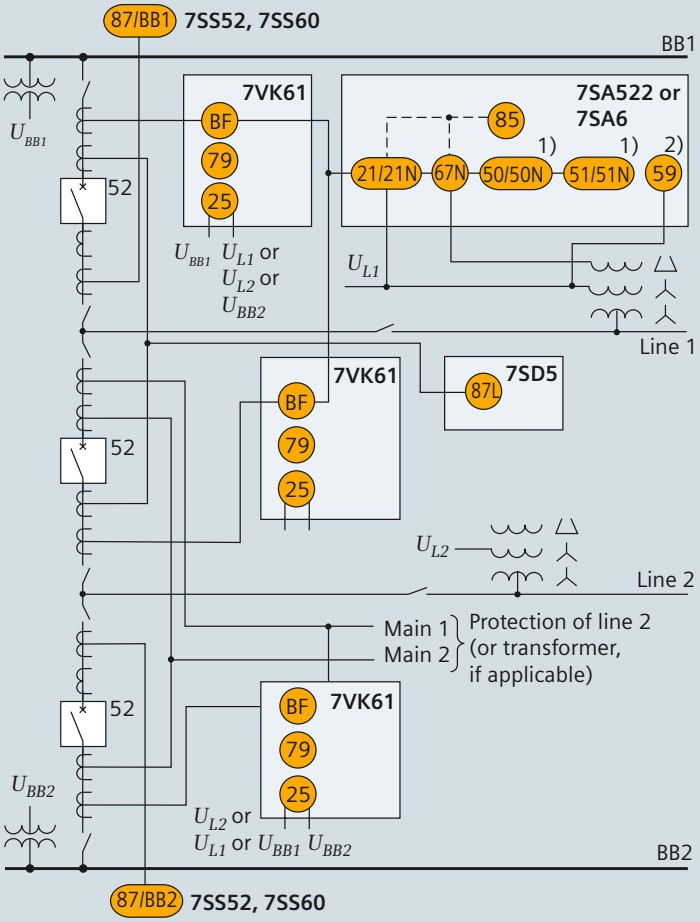


Fig. 6.2-82: **Transmission line, one-breaker-and-a-half terminal, using 3 breaker management relays 7VK61**

General notes for fig. 6.2-82 and fig. 6.2-83:

- For the selection of the main 1 and main 2 line protection schemes, the comments of application examples fig. 6.2-77 and fig. 6.2-78 apply.
- Auto-reclosure (79) and synchrocheck function (25) are each assigned directly to the circuit-breakers and controlled by main 1 and 2 line protection in parallel. In the event of a line fault, both adjacent circuit-breakers have to be tripped by the line protection. The sequence of auto-reclosure of both circuit-breakers or, alternatively, the auto-reclosure of only one circuit-breaker and the manual closure of the other circuit-breaker, may be made selectable by a control switch.
- A coordinated scheme of control circuits is necessary to ensure selective tripping interlocking and reclosing of the two circuit-breakers of one line (or transformer feeder).
- The voltages for synchrocheck have to be selected according to the circuit-breaker and disconnector (isolator) position by a voltage replica circuit.

General notes for fig. 6.2-83:

- In this optimized application, the 7VK61 is only used for the center breaker. In the line feeders, functions 25, 79 and BF are also performed by transmission line protection 7SA522 or 7SA6.

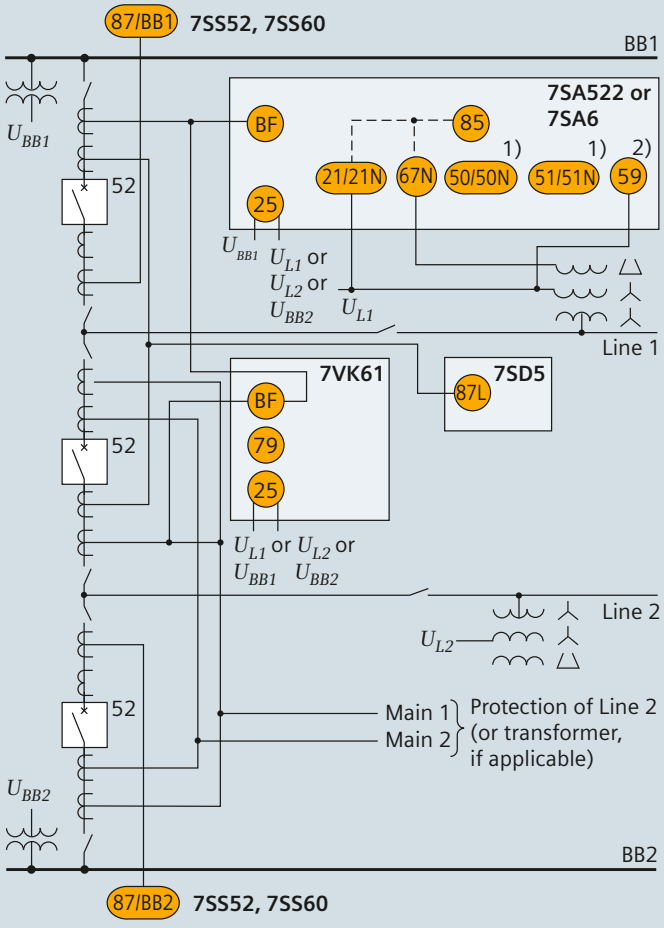


Fig. 6.2-83: **Tranmission line, breaker-and-a-half terminal, using 1 breaker management relay 7VK61**

2. Transformers

Small transformer infeed

General notes:

- Earth faults on the secondary side are detected by current relay 51N. However, it has to be time-graded against downstream feeder protection relays.
- The restricted earth-fault relay 87N can optionally be applied to achieve fast clearance of earth faults in the transformer secondary winding.
  Relay 7VH60 is of the high-impedance type and requires class × CTs with equal transformation ratios.
- Primary circuit-breaker and relay may be replaced by fuses.

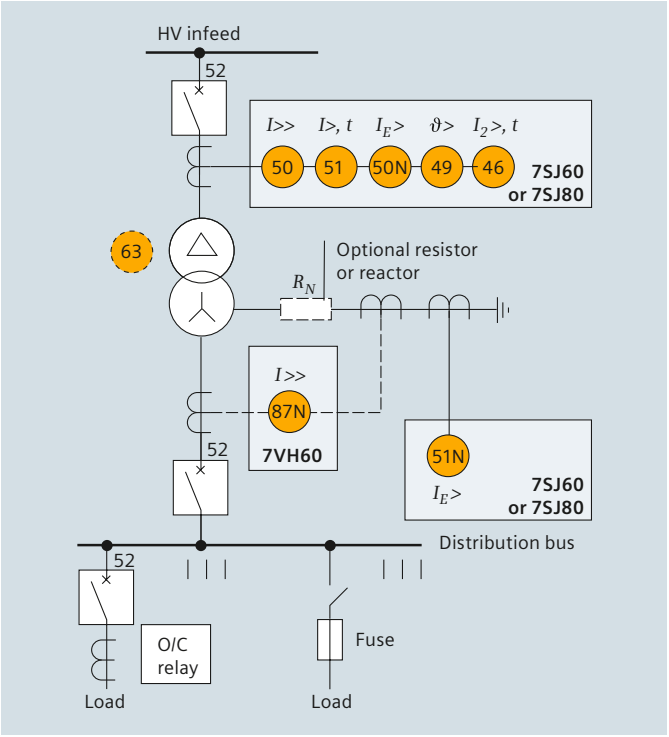


Fig. 6.2-84: **Small transformer infeed**

Large or important transformer infeed

General note:

- Relay 7UT612 provides numerical ratio and vector group adaptation. Matching transformers as used with traditional relays are therefore no longer applicable.

Notes:

1) If an independent high-impedance-type earth-fault function is required, the 7VH60 earth-fault relay can be used instead of the 87N inside the 7UT612. However, class × CT cores would also be necessary in this case (see small transformer protection).
2) 51 and 51N may be provided in a separate 7SJ60 if required.

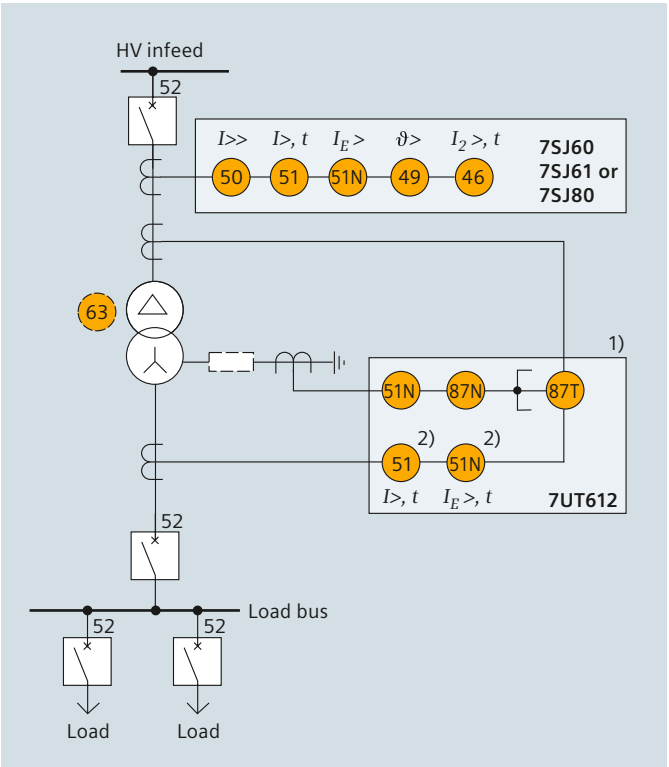


Fig. 6.2-85: **Large or important transformer infeed**

Dual infeed with single transformer

General notes:

- Line CTs are to be connected to separate stabilizing inputs of the differential relay 87T in order to ensure stability in the event of line through-fault currents.
- Relay 7UT613 provides numerical ratio and vector group adaptation. Matching transformers, as used with traditional relays, are therefore no longer applicable.

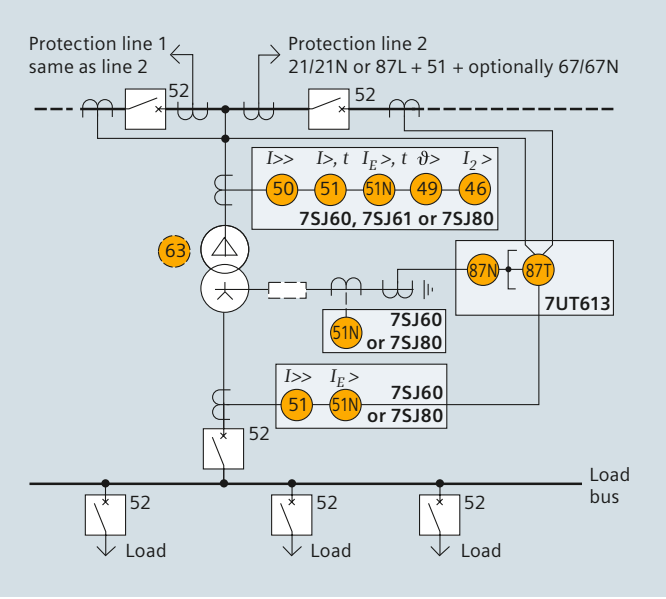


Fig. 6.2-86: **Dual infeed with single transformer**

Parallel incoming transformer feeders

Note:
The directional functions 67 and 67N do not apply for cases where the transformers are equipped with the transformer differential relays 87T.

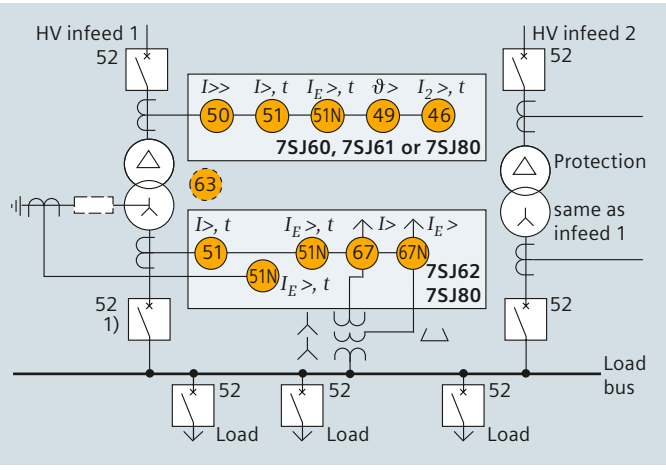


Fig. 6.2-87: **Parallel incoming transformer feeders**

Parallel incoming transformer feeders with bus tie

General notes:

- Overcurrent relay 51, 51N each connected as a partial differential scheme. This provides simple and fast busbar protection and saves one time-grading step.

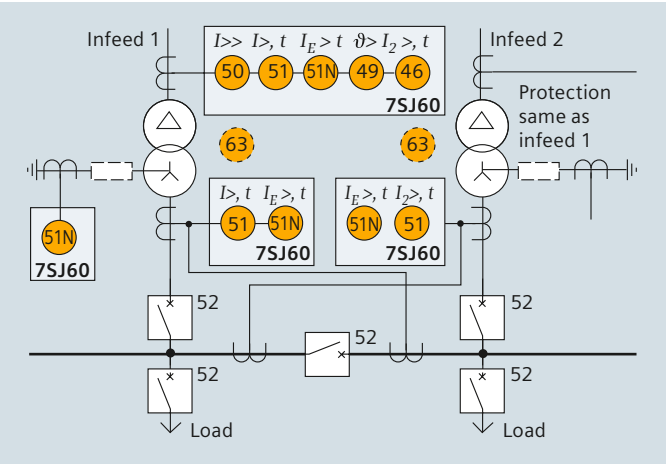


Fig. 6.2-88: **Parallel incoming transformer feeders with bus tie**

Three-winding transformer

Notes:

1) The zero-sequence current must be blocked before entering the differential relay with a delta winding in the CT connection on the transformer side with earthed starpoint. This is to avoid false operation during external earth faults (numerical relays provide this function by calculation). About 30 % sensitivity, however, is then lost in the event of internal faults. Optionally, the zero-sequence current can be regained by introducing the winding neutral current in the differential relay (87T). Relay type 7UT613 provides two current inputs for this purpose. By using this feature, the earth-fault sensitivity can be upgraded again to its original value.
Restricted earth-fault protection (87T) is optional. It provides backup protection for earth faults and increased earth-fault sensitivity (about 10 % IN, compared to about 20 to 30 % IN of the transformer differential relay). Separate class × CT-cores with equal transmission ratio are also required for this protection.
2) High impedance and overcurrent in one 7SJ61.

General notes:

- In this example, the transformer feeds two different distribution systems with cogeneration. Restraining differential relay inputs are therefore provided at each transformer side.
- If both distribution systems only consume load and no through-feed is possible from one MV system to the other, parallel connection of the CTs of the two MV transformer windings is admissible, which allows the use of a two-winding differential relay (7UT612).

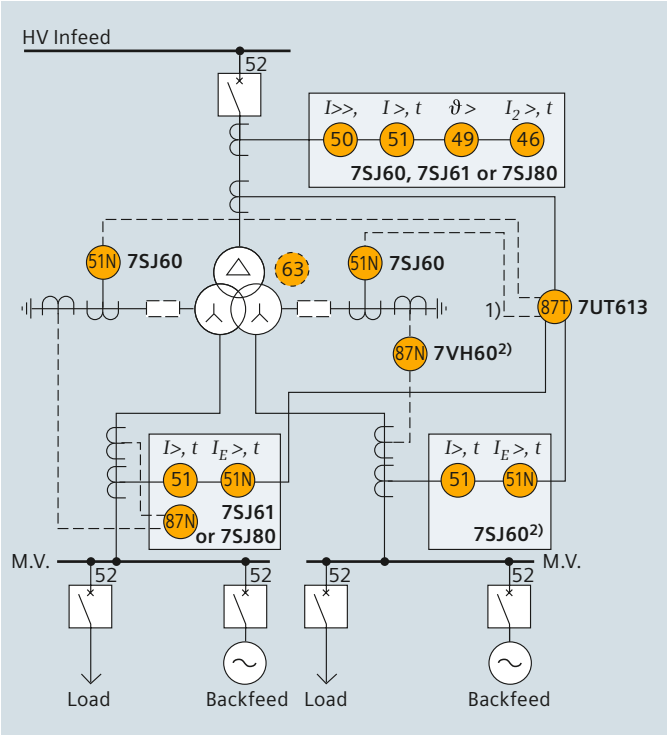


Fig. 6.2-89: **Three-winding transformer**

Autotransformer

Notes:

1) 87N high-impedance protection requires special class × current transformer cores with equal transformation ratios.
2) The 7SJ60 relay can alternatively be connected in series with the 7UT613 relay to save this CT core.

General note:

- Two different protection schemes are provided: 87T is chosen as the low-impedance three-winding version (7UT613). 87N is a 1-phase high-impedance relay (7VH60) connected as restricted earth-fault protection. (In this example, it is assumed that the phase ends of the transformer winding are not accessible on the neutral side, that is, there exists a CT only in the neutral earthing connection.)

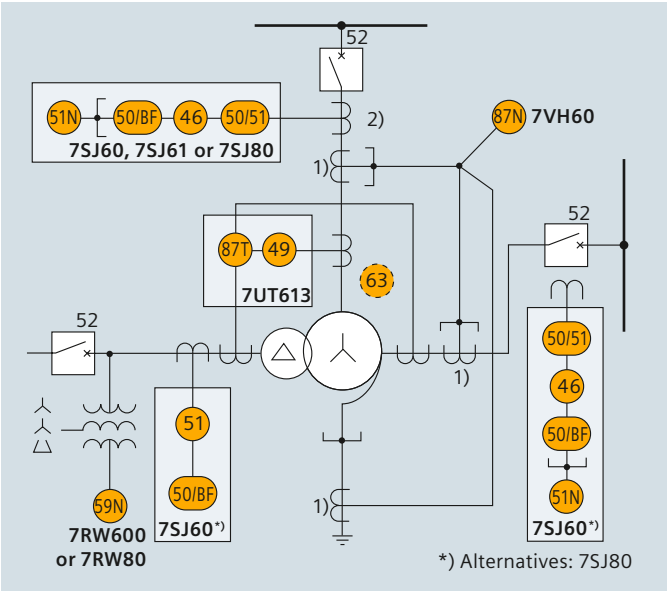


Fig. 6.2-90: **Autotransformer**

Large autotransformer bank

General notes:

- The transformer bank is connected in a breaker-and-a-half arrangement.
  Duplicated differential protection is proposed:
  Main 1: Low-impedance differential protection 87TL (7UT613) connected to the transformer bushing CTs.
  Main 2: High-impedance differential overall protection 87TL (7VH60). Separate class × cores and equal CT ratios are required for this type of protection.
- Backup protection is provided by distance protection relay (7SA52 and 7SA6), each "looking" with an instantaneous first zone about 80 % into the transformer and with a time-delayed zone beyond the transformer.
- The tertiary winding is assumed to feed a small station supply system with isolated neutral.

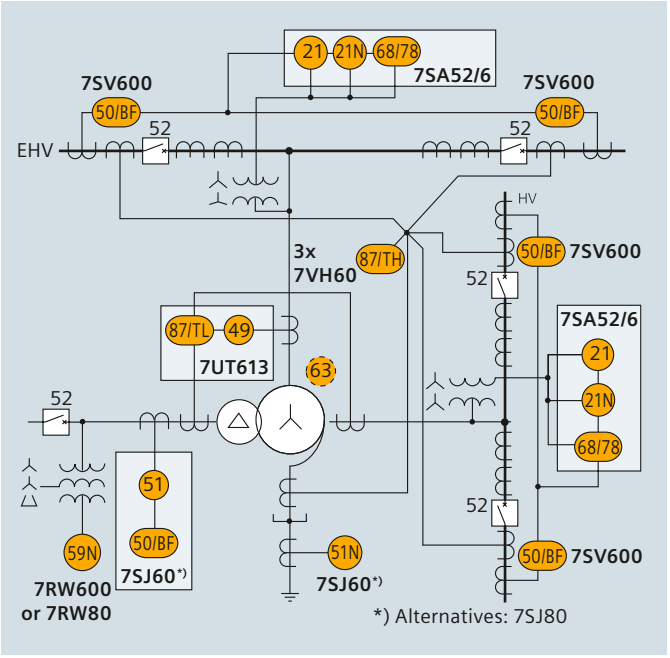


Fig. 6.2-91: **Large autotransformer bank**

3. Motors

Small and medium-sized motors < about 1 MW

a) With effective or low-resistance earthed infeed ($I_E \geq I_{N\,Motor}$)

General note:

- Applicable to low-voltage motors and high-voltage motors with low-resistance earthed infeed ($I_E \geq I_{N\,Motor}$)

b) With high-resistance earthed infeed ($I_E \leq I_{N\,Motor}$)

Notes:

1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed system (for dimensioning of the sensitive directional earth-fault protection, see also application circuit no. 30)
3) The 7SJ602 relay can be applied for isolated and compensated systems.

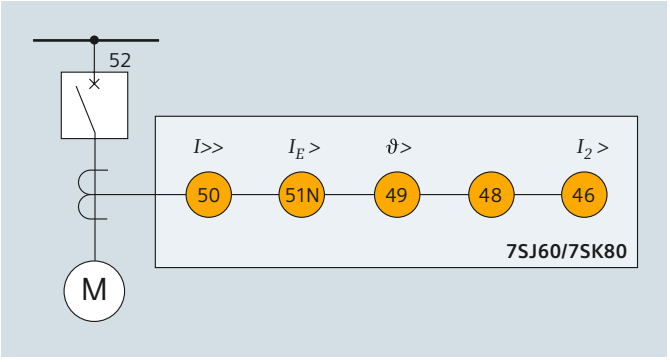


Fig. 6.2-92: **Motor protection with effective or low-resistance earthed infeed**

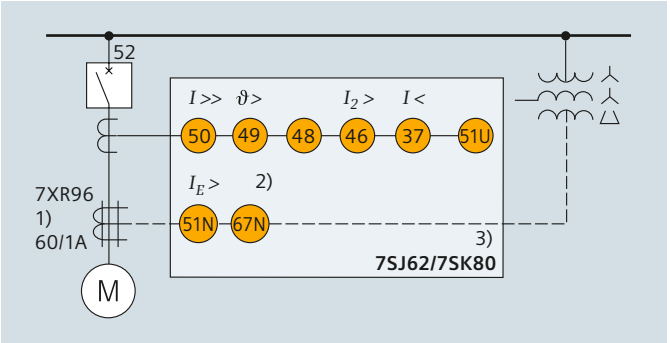


Fig. 6.2-93: **Motor protection with high-resistance earthed infeed**

Large HV motors > about 1 MW

Notes:

1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed system.
3) This function is only needed for motors where the startup time is longer than the safe stall time t_E. According to IEC 60079-7, the t_E time is the time needed to heat up AC windings, when carrying the starting current I_A, from the temperature reached in rated service and at maximum ambient air temperature to the limiting temperature. A separate speed switch is used to supervise actual starting of the motor. The motor circuit-breaker is tripped if the motor does not reach speed in the preset time. The speed switch is part of the motor supply itself.
4) Pt100, Ni100, Ni120
5) 49T only available with external temperature monitoring device (7XV5662)

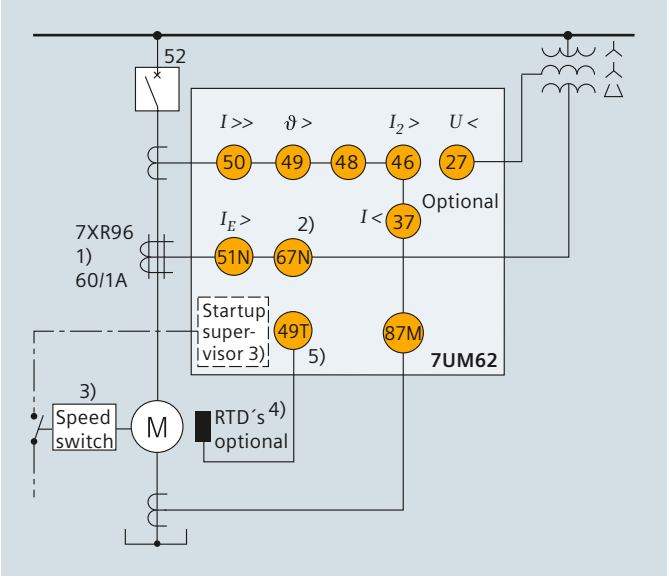


Fig. 6.2-94: **Protection of large HV motors > about 1 MW**

Cold load pickup

By means of a binary input that can be wired from a manual close contact, it is possible to switch the overcurrent pickup settings to less sensitive settings for a programmable amount of time. After the set time has expired, the pickup settings automatically return to their original setting. This can compensate for initial inrush when energizing a circuit without compromising the sensitivity of the overcurrent elements during steady-state conditions.

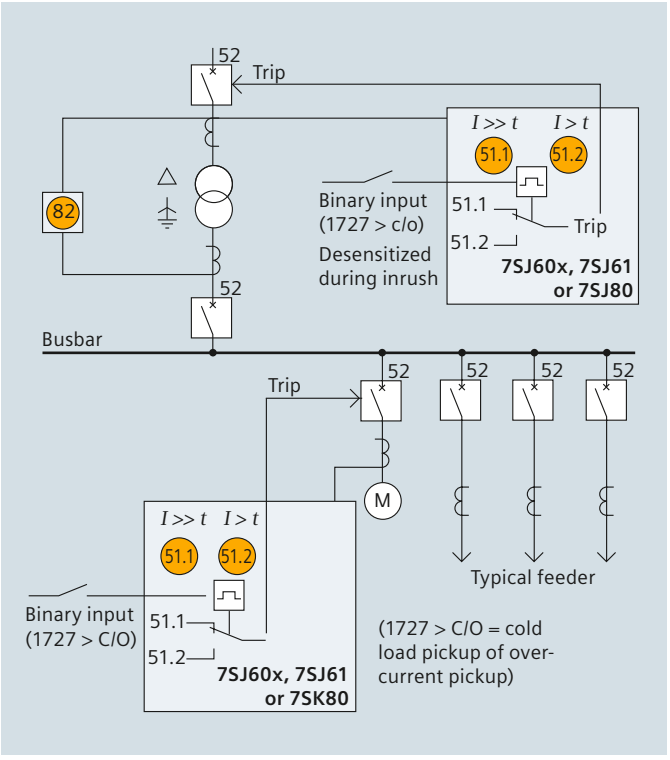


Fig. 6.2-95: **Cold load pickup**

4. Generators

Generators < 500 kW (fig. 6.2-96 and fig. 6.2-97)

Note:
If a core-balance CT is provided for sensitive earth-fault protection, relay 7SJ602 with separate earth-current input can be used.

Generators, typically 1–3 MW
(fig. 6.2-98)

Note:
Two VTs in V connection are also sufficient.

Generators > 1–3 MW
(fig. 6.2-99)

Notes:
1) Functions 81 and 59 are required only where prime mover can assume excess speed and the voltage regulator may permit rise of output voltage above upper limit.
2) Differential relaying options:
   – Low-impedance differential protection 87.
   – Restricted earth-fault protection with low-resistance earthed neutral (fig. 6.2-98).

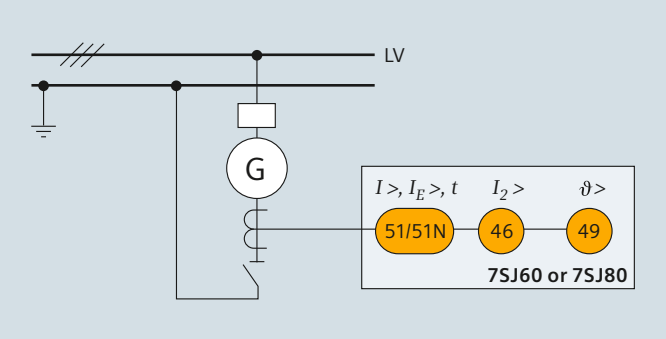


Fig. 6.2-96: **Generator with solidly earthed neutral**

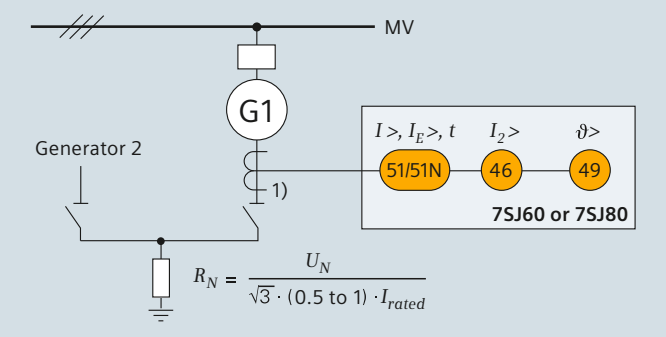


Fig. 6.2-97: **Generator with resistance-earthed neutral**

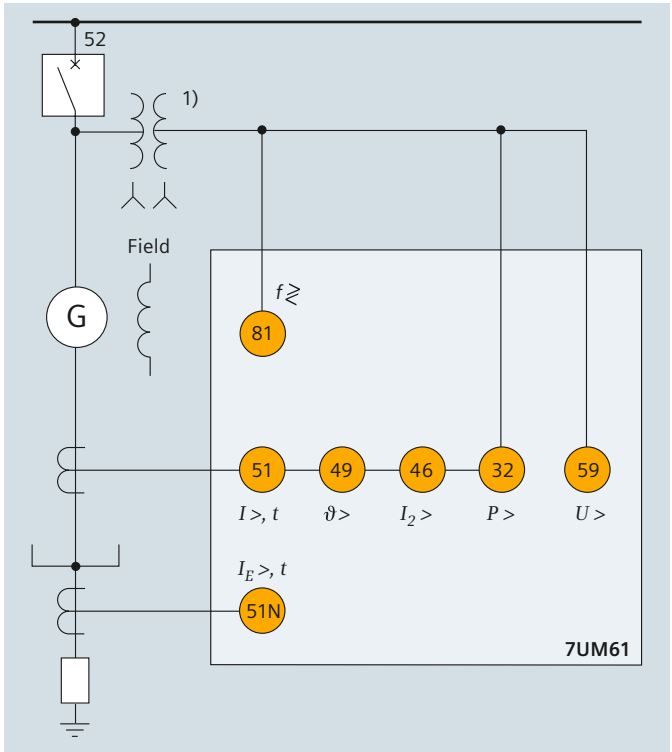


Fig. 6.2-98: **Protection for generators 1–3 MW**

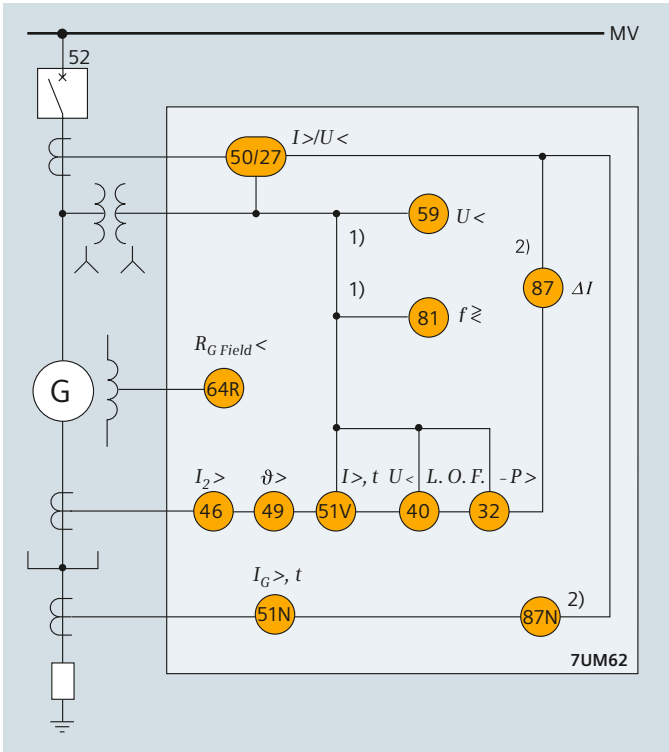


Fig. 6.2-99: **Protection for generators >1–3 MW**

Generators > 5 –10 MW feeding into a system with isolated neutral
(fig. 6.2-100)

General notes:

- The setting range of the directional earth-fault protection (67N) in the 7UM6 relay is 2–1,000 mA. Depending on the current transformer accuracy, a certain minimum setting is required to avoid false operation on load or transient currents.
- In practice, efforts are generally made to protect about 90 % of the machine winding, measured from the machine terminals. The full earth current for a terminal fault must then be ten times the setting value, which corresponds to the fault current of a fault at 10 % distance from the machine neutral.

Relay earth-current input connected to:	Minimum relay setting:	Comments:
Core-balance CT 60 / 1 A: 1 single CT 2 parallel CTs 3 parallel Cts 4 parallel CTs	 2 mA 5 mA 8 mA 12 mA	
Three-phase CTs in residual (Holmgreen) connection	1 A CT: 50 mA 5 A CT: 200 mA	In general not suitable for sensitive earth-fault protection
Three-phase CTs in residual (Holmgreen) connection with special factory calibration to minimum residual false currents (≤ 2 mA)	2–3 ‰ of secondary rated CT current $I_{n\,SEC}$ 10–15 mA with 5 A CTs	1 A CTs are not recommended in this case

For the most sensitive setting of 2 mA, we therefore need 20 mA secondary earth current, corresponding to (60 / 1) × 20 mA = 1.2 A primary.

If sufficient capacitive earth current is not available, an earthing transformer with resistive zero-sequence load can be installed as earth-current source at the station busbar. The smallest standard earthing transformer TGAG 3541 has a 20 s short-time rating of input connected to: S_G = 27 kVA

In a 5 kV system, it would deliver:

$$I_{G\,20\,s} = \frac{\sqrt{3} \cdot S_G}{U_N} = \frac{\sqrt{3} \cdot 27{,}000\ \text{VA}}{5{,}000\ \text{V}} = 9.4\ \text{A}$$

corresponding to a relay input current of 9.4 A × 1 / 60 A = 156 mA. This would provide a 90 % protection range with a setting of about 15 mA, allowing the use of 4 parallel connected core-balance CTs. The resistance at the 500 V open-delta winding of the earthing transformer would then have to be designed for

$R_B = U^2_{SEC}/S_G$ = 500 U^2 / 27,000 VA = 9.26 Ω (27 kW, 20 s)

For a 5 MVA machine and 600 / 5 A CTs with special calibration for minimum residual false current, we would get a secondary current of $I_{G\,SEC}$ = 9.4 A / (600 / 5) = 78 mA.

With a relay setting of 12 mA, the protection range would in this case be 100 $\left(1 - \frac{12}{78}\right)$ = 85 %.

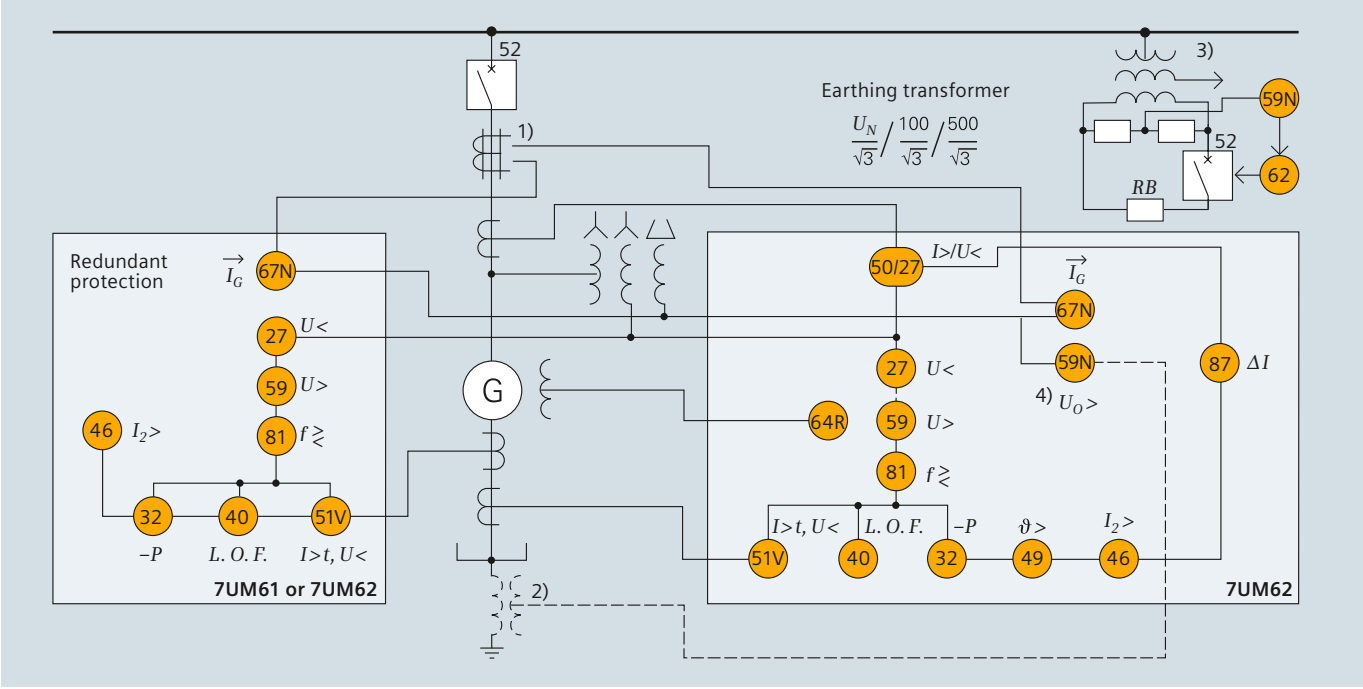


Fig. 6.2-100: **Protections for generators > 5 –10 MW**

Notes (fig. 6.2-100):

1) The standard core-balance CT 7XR96 has a transformation ratio of 60 / 1 A.
2) Instead of an open-delta winding at the terminal VT, a 1-phase VT at the machine neutral could be used as zero-sequence polarizing voltage.
3) The earthing transformer is designed for a short-time rating of 20 s. To prevent overloading, the load resistor is automatically switched off by a time-delayed zero-sequence voltage relay (59N + 62) and a contactor (52).
4) During the startup time of the generator with the open circuit-breaker, the earthing source is not available. To ensure earth-fault protection during this time interval, an auxiliary contact of the circuit-breaker can be used to change over the directional earth-fault relay function (67N) to a zero-sequence voltage detection function via binary input.

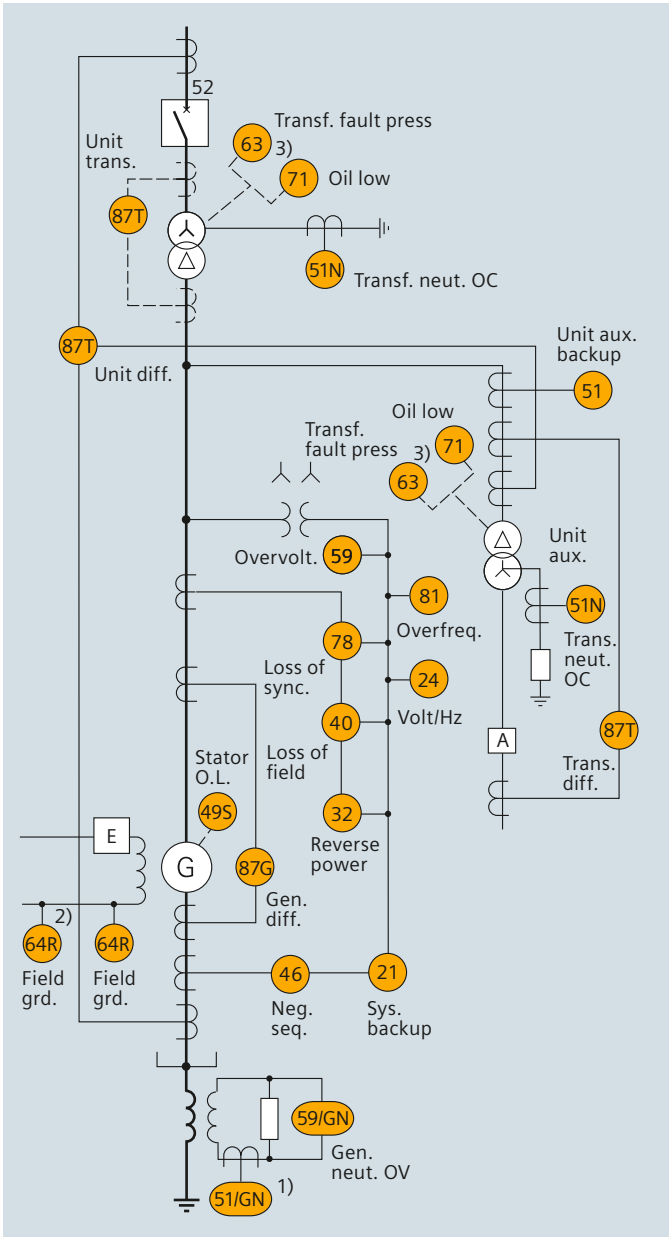


Fig. 6.2-101: **Protections for generators > 50 MW**

Generators > 50 –100 MW in generator transformer unit connection
(fig. 6.2-101)

Notes:

1) 100 % stator earth-fault protection based on 20 Hz voltage injection
2) Sensitive rotor earth-fault protection based on 1–3 Hz voltage injection
3) Non-electrical signals can be incoupled in the protection via binary inputs (BI)
4) Only used functions shown; further integrated functions available in each relay type.

Relay type	Functions[4]	Number of relays required
7UM62	21, 24, 32, 40, 46, 49, 51GN[1], 59GN[1], 59, 64R, 64R[2], 78, 81, 87G, via BI: 71, 63	2
7UM61 or 7UM62	51, 51N, optionally 21, 59, 81, via BI: 71, 63	1
7UT612	87T, 51N, optionally	1 2
7UT613	87T	1

Fig. 6.2-102: **Assignment for functions to relay type**

Synchronization of a generator

Fig. 6.2-103 shows a typical connection for synchronizing a generator. Paralleling device 7VE6 acquires the line and generator voltage, and calculates the differential voltage, frequency and phase angle. If these values are within a permitted range, a CLOSE command is issued after a specified circuit-breaker make time. If these variables are out of range, the paralleling device automatically sends a command to the voltage and speed controller. For example, if the frequency is outside the range, an actuation command is sent to the speed controller. If the voltage is outside the range, the voltage controller is activated.

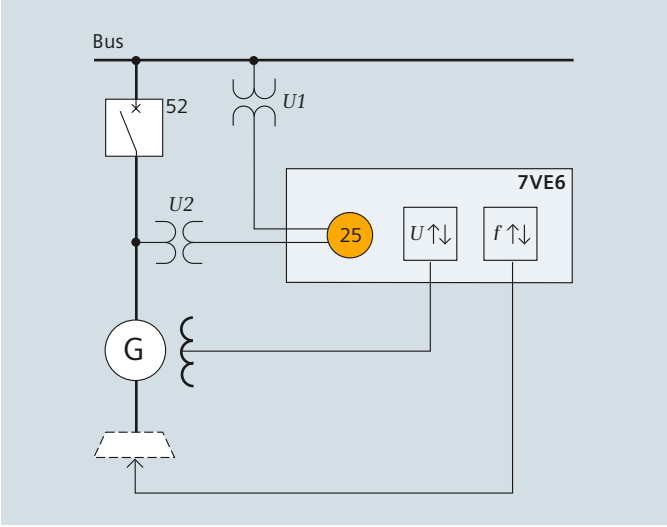


Fig. 6.2-103: **Synchronization of a generator**

6

5. Busbars

Busbar protection by overcurrent relays with reverse interlocking

General note:

- Applicable to distribution busbars without substantial (< 0.25 × I_N) backfeed from the outgoing feeders.

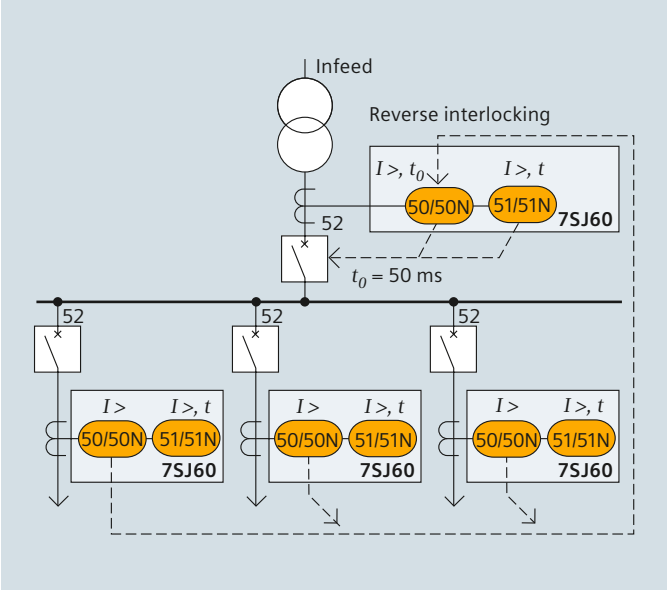


Fig. 6.2-104: **Busbar protection by O/C relays with reverse interlocking**

High-impedance busbar protection

General notes:

- Normally used with single busbar, and one-breaker-and-a-half schemes.
- Requires separate class X current transformer cores. All CTs must have the same transformation ratio.

Note:

A varistor is normally applied across the relay input terminals to limit the voltage to a value safely below the insulation voltage of the secondary circuits.

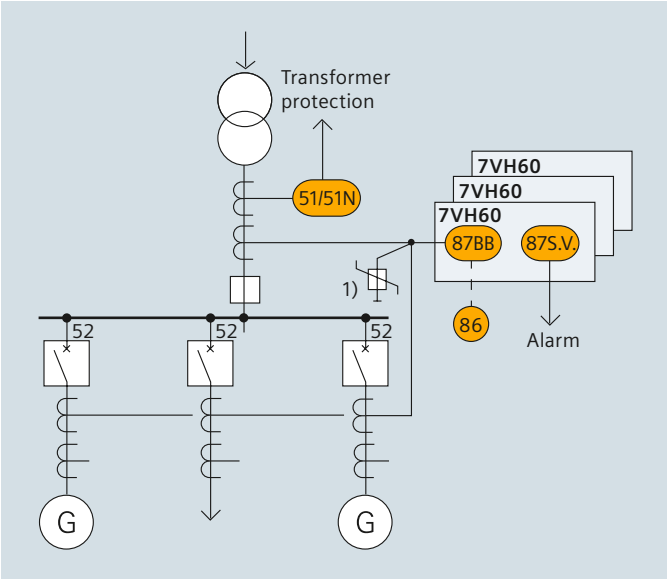


Fig. 6.2-105: **High-impedance busbar protection**

Low-impedance busbar protection 7SS60

General notes:

- Normally used with single busbar, one-breaker-and-a-half, and double busbar schemes, different transformation ratios can be adapted by matching transformers.
- Unlimited number of feeders.
- Feeder protection can be connected to the same CT core.

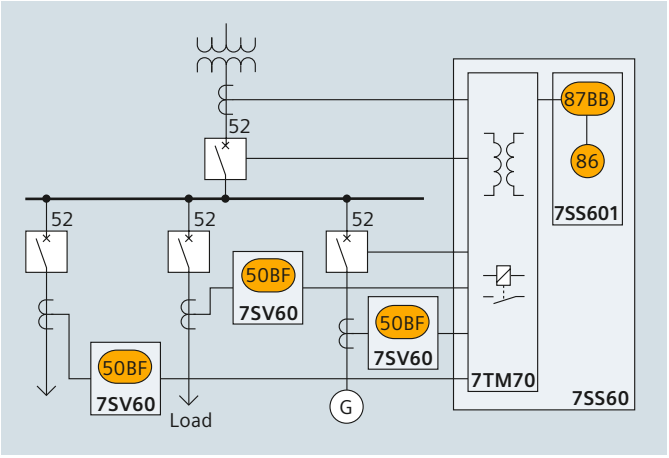


Fig. 6.2-106: **Low-impedance busbar protection 7SS60**

Distributed busbar protection 7SS52

General notes:

- Suitable for all types of busbar schemes.
- Preferably used for multiple busbar schemes where a disconnector (isolator) replica is necessary.
- The numerical busbar protection 7SS52 provides additional breaker failure protection.
- Different CT transformation ratios can be adapted numerically.
- The protection system and the disconnector (isolator) replica are continuously self-monitored by the 7SS52.
- Feeder protection can be connected to the same CT core.

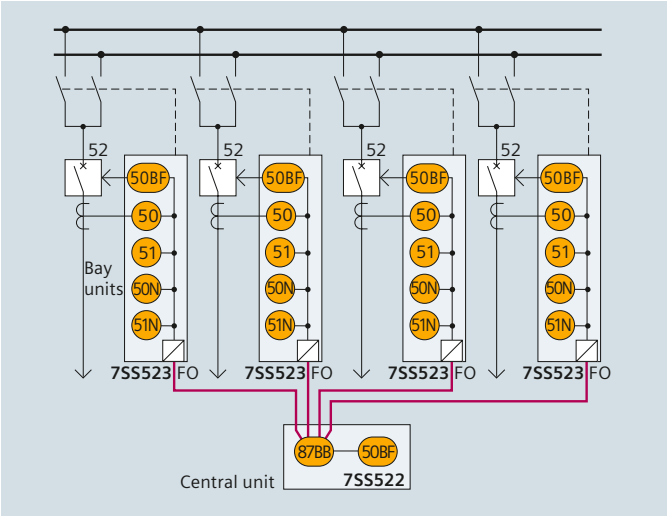


Fig. 6.2-107: **Distributed busbar protection 7SS52**

6. Power systems

Load shedding

In unstable power systems (e.g., isolated systems, emergency power supply in hospitals), it may be necessary to isolate selected loads from the power system to prevent overload of the overall system. The overcurrent-time protection functions are effective only in the case of a short-circuit.

Overloading of the generator can be measured as a frequency or voltage drop.

(Protection functions 27 and 81 available in 7RW600, 7SJ6 and 7SJ8.)

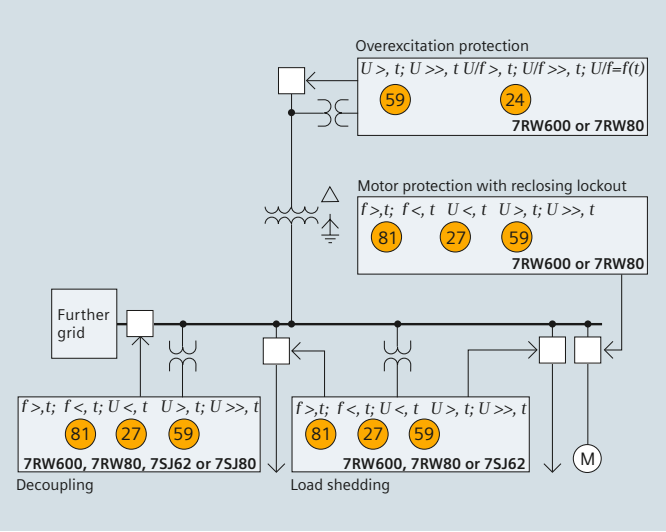


Fig. 6.2-108: **Load shedding**

Load shedding with rate-of-frequency-change protection

The rate-of-frequency-change protection calculates, from the measured frequency, the gradient or frequency change df / dt. It is thus possible to detect and record any major active power loss in the power system, to disconnect certain consumers accordingly and to restore the system to stability. Unlike frequency protection, rate-of-frequency-change protection reacts before the frequency threshold is undershot. To ensure effective protection settings, it is recommended to consider requirements throughout the power system as a whole. The rate-of-frequency-change protection function can also be used for the purposes of system decoupling.

Rate-of-frequency-change protection can also be enabled by an underfrequency state.

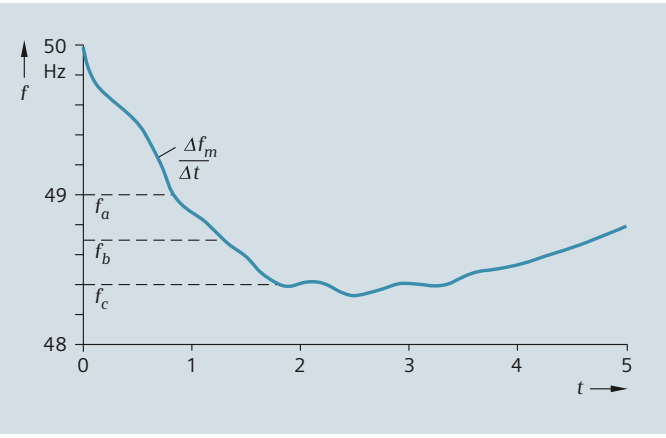


Fig. 6.2-109: **Load shedding with rate-of-frequency-change protection**

Trip circuit supervision (ANSI 74TC)

One or two binary inputs can be used for the trip circuit supervision.

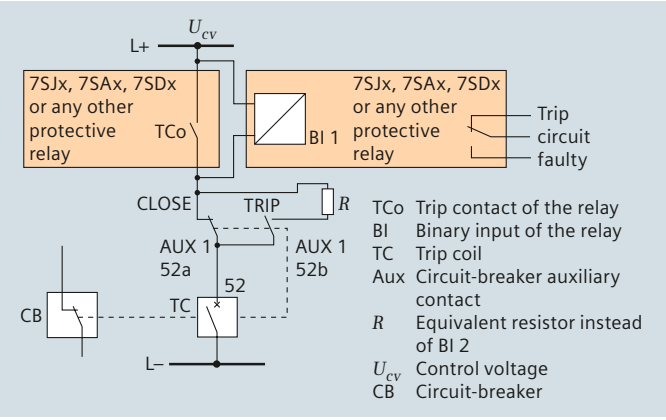


Fig. 6.2-110: **Trip circuit supervision (ANSI 74TC)**

Disconnecting facility with flexible protection function

General note:
The SIPROTEC protection relay 7SJ64 disconnects the switchgear from the utility power system if the generator feeds energy back into the power system (protection function $P_{reverse}>$). This functionality is achieved by using flexible protection. Disconnection also takes place in the event of frequency or voltage fluctuations in the utility power system (protection functions $f<$, $f>$, $U<$, $U>$, $I_{dir}>$, $I_{Edir}>$/ 81, 27, 59, 67, 67N).

Notes:
1) The transformer is protected by differential protection and inverse or definite-time overcurrent protection functions for the phase currents. In the event of a fault, the circuit-breaker CB1 on the utility side is tripped by a remote link. Circuit-breaker CB2 is also tripped.
2) Overcurrent-time protection functions protect feeders 1 and 2 against short-circuits and overload caused by the connected loads. Both the phase currents and the zero currents of the feeders can be protected by inverse and definite-time overcurrent stages. The circuit-breakers CB4 and CB5 are tripped in the event of a fault.

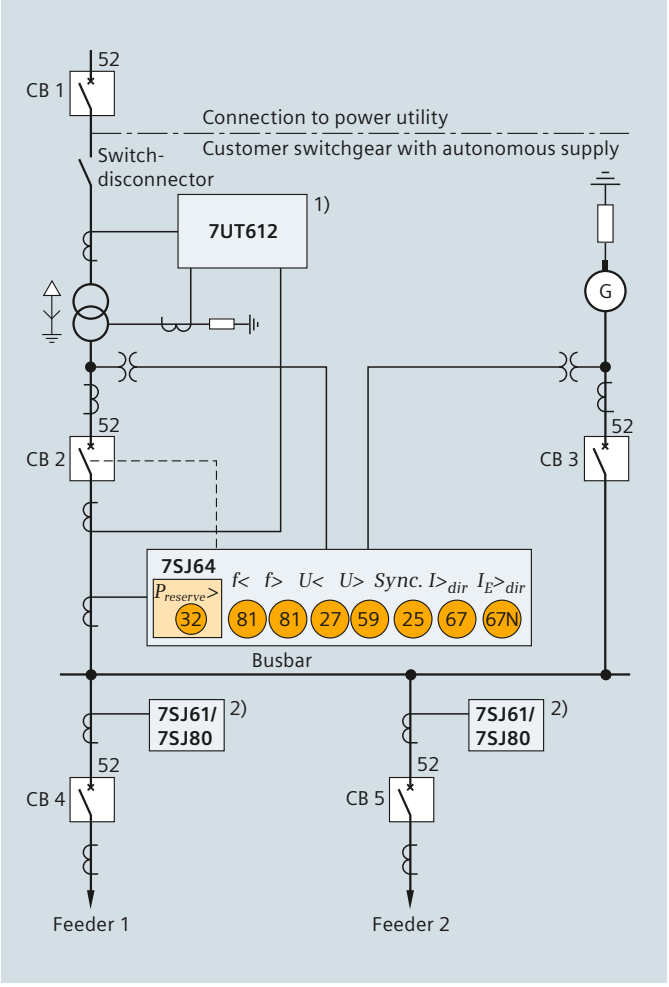


Fig. 6.2-111: **Example of a switchgear with autonomous generator supply**

6.2.5 Protection Coordination

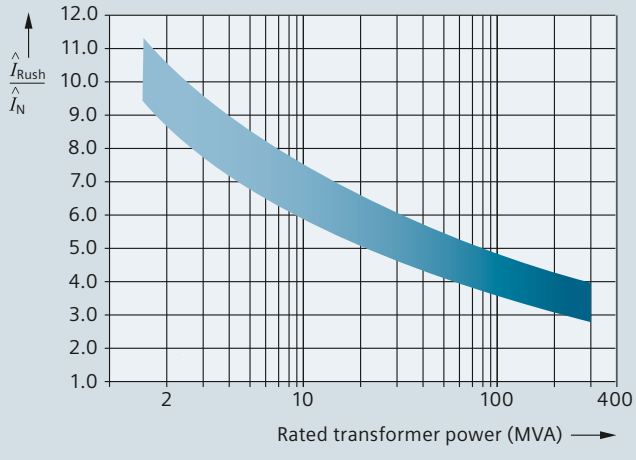
Typical applications and functions
Relay operating characteristics and their settings must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulty component and to leave the rest of the power system in service in order to minimize supply interruptions and to ensure stability.

Sensitivity
Protection should be as sensitive as possible in order to detect faults at the lowest possible current level. At the same time, however, it should remain stable under all permissible load, overload and through-fault conditions. For more information: http://www.siemens.com/systemplanning. The Siemens engineering programs SINCAL and SIGRADE are especially designed for selective protection grading of protection relay systems. They provide short-circuit calculations, international standard characteristics of relays, fuses and circuit-breakers for easy protection grading with respect to motor starting, inrush phenomena, and equipment damage curves.

Phase-fault overcurrent relays
The pickup values of phase overcurrent relays are normally set 30 % above the maximum load current, provided that sufficient short-circuit current is available. This practice is recommended particularly for mechanical relays with reset ratios of 0.8 to 0.85. Numerical relays have high reset ratios near 0.95 and allow, therefore, about a10 % lower setting. Feeders with high transformer and/or motor load require special consideration.

Transformer feeders
The energizing of transformers causes inrush currents that may last for seconds, depending on their size (fig. 6.2-112). Selection of the pickup current and assigned time delay have to be coordinated so that the inrush current decreases below the relay overcurrent reset value before the set operating time has elapsed. The inrush current typically contains only about a 50 % fundamental frequency component. Numerical relays that filter out harmonics and the DC component of the inrush current can therefore be set to be more sensitive. The inrush current peak values of fig. 6.2-112 will be reduced to more than one half in this case. Some digital relay types have an inrush detection function that may block the trip of the overcurrent protection resulting from inrush currents.

Ground-fault protection relays
Earth-current relays enable a much more sensitive setting, because load currents do not have to be considered (except 4-wire circuits with 1-phase load). In solidly and low-resistance earthed systems, a setting of 10 to 20 % rated load current can generally be applied. High-resistance earthing requires a much more sensitive setting, on the order of some amperes primary. The earth-fault current of motors and generators, for example, should be limited to values below 10 A in order to avoid iron burning. In this case, residual-current relays in the start point connection of CTs cannot be used; in particular, with rated CT primary currents higher than 200 A. The pickup value of the zero-sequence relay would be on the order of the error currents of the CTs. A special core-balance CT is therefore used as the earth-current sensor. The core-balance CT 7XR96 is designed for a ratio of 60/1 A. The detection of 6 A primary would then require a relay pickup setting of 0.1 A secondary. An even more sensitive setting is applied in isolated or Petersen coil earthed systems where very low earth currents occur with 1-phase-to-earth faults. Settings of 20 mA and lower may then be required depending on the minimum earth-fault current. Sensitive directional earth-fault relays (integrated into the relays 7SJ62, 63, 64, 7SJ80, 7SK80, 7SA6) allow settings as low as 5 mA.



Time constant of inrush current

Nominal power (MVA)	0.5 ... 1.0	1.0 ... 10	> 10
Time constant (s)	0.16 ... 0.2	0.2 ... 1.2	1.2 ... 720

Fig. 6.2-112: **Peak value of inrush current**

Motor feeders
The energization of motors causes a starting current of initially 5 to 6 times the rated current (locked rotor current).

A typical time-current curve for an induction motor is shown in fig. 6.2-113.

In the first 100 ms, a fast-decaying asymmetrical inrush current also appears. With conventional relays, it was common practice to set the instantaneous overcurrent stage of the short-circuit protection 20 to 30 % above the locked rotor current with a short-time delay of 50 to 100 ms to override the asymmetrical inrush period.

Numerical relays are able to filter out the asymmetrical current component very rapidly so that the setting of an additional time delay is no longer applicable.

The overload protection characteristic should follow the thermal motor characteristic as closely as possible. The adaptation is made by setting the pickup value and the thermal time constant, using the data supplied by the motor manufacturer. Furthermore, the locked-rotor protection timer has to be set according to the characteristic motor value.

Time grading of overcurrent relays (51)
The selectivity of overcurrent protection is based on time grading of the relay operating characteristics. The relay closer to the infeed (upstream relay) is time-delayed against the relay further away from the infeed (downstream relay). The calculation of necessary grading times is shown in fig. 6.2-113 by an example for definite-time overcurrent relays.

The overshoot times take into account the fact that the measuring relay continues to operate due to its inertia, even if when the fault current is interrupted. This may be high for mechanical relays (about 0.1 s) and negligible for numerical relays (20 ms).

Inverse-time relays (51)
For the time grading of inverse-time relays, in principle the same rules apply as for the definite-time relays. The time grading is first calculated for the maximum fault level and then checked for lower current levels (fig. 6.2-114).

If the same characteristic is used for all relays, or if when the upstream relay has a steeper characteristic (e.g., very much over normal inverse), then selectivity is automatically fulfilled at lower currents.

Differential relay (87)
Transformer differential relays are normally set to pickup values between 20 and 30 % of the rated current. The higher value has to be chosen when the transformer is fitted with a tap changer.

Restricted earth-fault relays and high-resistance motor / generator differential relays are, as a rule, set to about 10 % of the rated current.

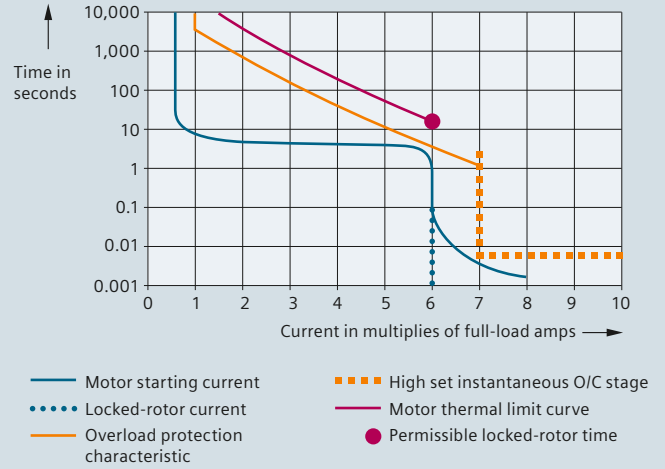


Fig. 6.2-113: **Typical motor current-time characteristics**

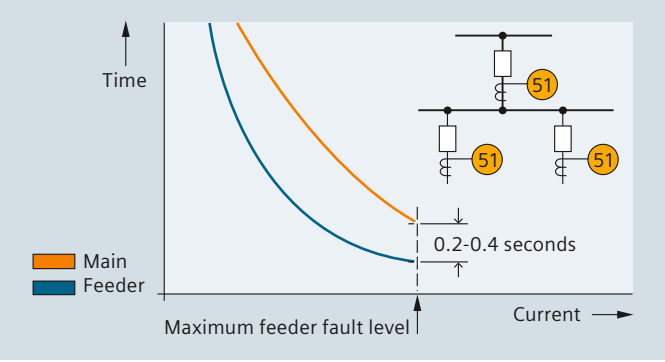


Fig. 6.2-114: **Coordination of inverse-time relays**

Instantaneous overcurrent protection (50)
This is typically applied on the final supply load or on any protection relay with sufficient circuit impedance between itself and the next downstream protection relay. The setting at transformers, for example, must be chosen about 20 to 30 % higher than the maximum through-fault current. The relay must remain stable during energization of the transformer.

Calculation example
The feeder configuration of fig. 6.2-116 and the associated load and short-circuit currents are given. Numerical overcurrent relays 7SJ60 with normal inverse-time characteristics are applied.

The relay operating times, depending on the current, can be derived from the diagram or calculated with the formula given in fig. 6.2-117.

The I_p/I_N settings shown in fig. 6.2-116 have been chosen to get pickup values safely above maximum load current.

This current setting should be lowest for the relay farthest downstream. The relays further upstream should each have equal or higher current settings.

The time multiplier settings can now be calculated as follows:

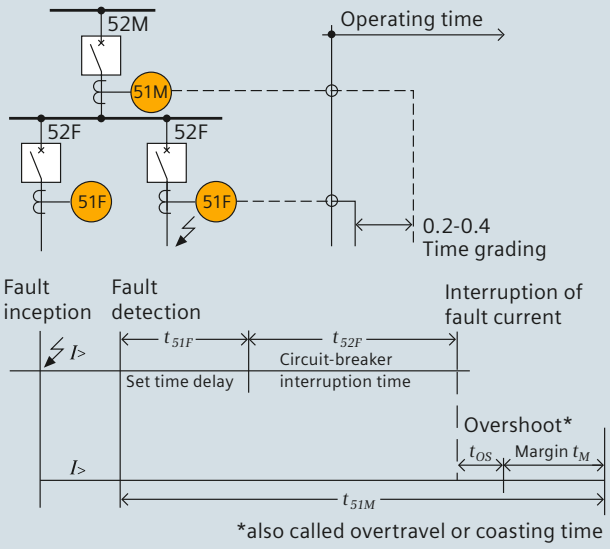
Station C:
- For coordination with the fuses, we consider the fault in location F1.
  The short-circuit current $I_{scc.}$ max. related to 13.8 kV is 523 A.
  This results in 7.47 for I/I_p at the overcurrent relay in location C.
- With this value and $T_p = 0.05$, an operating time of $t_A = 0.17$ s can be derived from fig 6.2-114.

This setting was selected for the overcurrent relay to get a safe grading time over the fuse on the transformer low-voltage side. Safety margin for the setting values for the relay at station C are therefore:
- Pickup current: $I_p/I_N = 0.7$
- Time multiplier: $T_p = 0.05$

Station B:
The relay in B has a primary protection function for line B-C and a backup function for the relay in C. The maximum through-fault current of 1.395 A becomes effective for a fault in location F2. For the relay in C, an operating time time of 0.11 s ($I/I_p = 19.93$) is obtained.

It is assumed that no special requirements for short operating times exist and therefore an average time grading interval of 0.3 s can be chosen. The operating time of the relay in B can then be calculated.

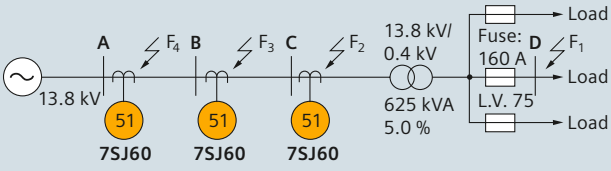
- $t_B = 0.11 + 0.3 = 0.41$ s
- Value of $I_p/I_N = \dfrac{1{,}395\ \text{A}}{220\ \text{A}} = 6.34$ (fig. 6.2-116)
- With the operating time 0.41 s and $I_p/I_N = 6.34$, $T_p = 0.11$ can be derived from fig. 6.2-117.



Time grading

$t_{rs} = t_{51M} - t_{51F} = t_{52F} + t_{OS} + t_M$	
Example 1	t_{TG} =0.10 s + 0.15 s + 0.15 s = 0.40 s
Oil circuit-breaker	$t_{52F} = 0.10$ s
Mechanical relays	$t_{OS} = 0.15$ s
Safety margin for measuring errors, etc.	$t_M = 0.15$ s
Example 2	$t_{TG} = 0.08 + 0.02 + 0.10 = 0.20$ s
Vacuum circuit-breaker	$t_{52F} = 0.08$ s
Numerical relays	$t_{OS} = 0.02$ s
Safety margin	$t_M = 0.10$ s

Fig. 6.2-115: **Time grading of overcurrent-time relays**



Station	Max. load A	$I_{SCC.\ max}$* A	CT ratio	I_p/I_N**	I_{prim}*** A	$I/I_p = \dfrac{I_{scc.\ max}}{I_{prim}}$
A	300	4,500	400/5	1.0	400	11.25
B	170	2,690	200/5	1.1	220	12.23
C	50	1,395	100/5	0.7	70	19.93
D	–	523	–	–	–	–

*) $I_{SCC.\ max}$ = Maximum short-circuit current
**) I_p/I_N = Relay current multiplier setting
***) I_{prim} = Primary setting current corresponding to I_p/I_N

Fig. 6.2-116: **Time grading of inverse-time relays for a radial feeder**

The setting values for the relay at station B are:

- Pickup current: $I_p/I_N = 1.1$
- Time multiplier $T_p = 0.11$

Given these settings, the operating time of the relay in B for a close fault in F3 can also be checked: The short-circuit current increases to 2,690 A in this case (fig. 6.2-116). The corresponding I/I_p value is 12.23.

- With this value and the set value of $T_p = 0.11$, an operating time of 0.3 s is obtained again (fig. 6.2-117).

Station A:
- Adding the time grading interval of 0.3 s, the desired operating itme is $t_A = 0.3 + 0.3 = 0.6$ s.

Following the same procedure as for the relay in station B, the following values are obtained for the relay in station A:
- Pickup current: $I_p/I_N = 1.0$
- Time multiplier $T_p = 0.17$
- For the close-in fault at location F4, an operating time of 0.48 s is obtained.

The normal way
To prove the selectivity over the whole range of possible short-circuit currents, it is normal practice to draw the set of operating curves in a common diagram with double log scales. These diagrams can be calculated manually and drawn point-by-point or constructed by using templates.

Today, computer programs are also available for this purpose. Fig. 6.2-118 shows the relay coordination diagram for the selected example, as calculated by the Siemens program SIGRADE (Siemens Grading Program).

Note:
To simplify calculations, only inverse-time characteristics have been used for this example. About 0.1 s shorter operating times could have been reached for high-current faults by additionally applying the instantaneous zones I>> of the 7SJ60 relays.

Coordination of overcurrent relays with fuses and low-voltage trip devices
The procedure is similar to the above-described grading of overcurrent relays. A time interval of between 0.1 and 0.2 s is usually sufficient for a safe time coordination.

Strong and extremely inverse characteristics are often more suitable than normal inverse characteristics in this case. Fig. 6.2-119 shows typical examples.

Simple distribution substations use a power fuse on the secondary side of the supply transformers (fig. 6.2-119a).

In this case, the operating characteristic of the overcurrent relay at the infeed has to be coordinated with the fuse curve.

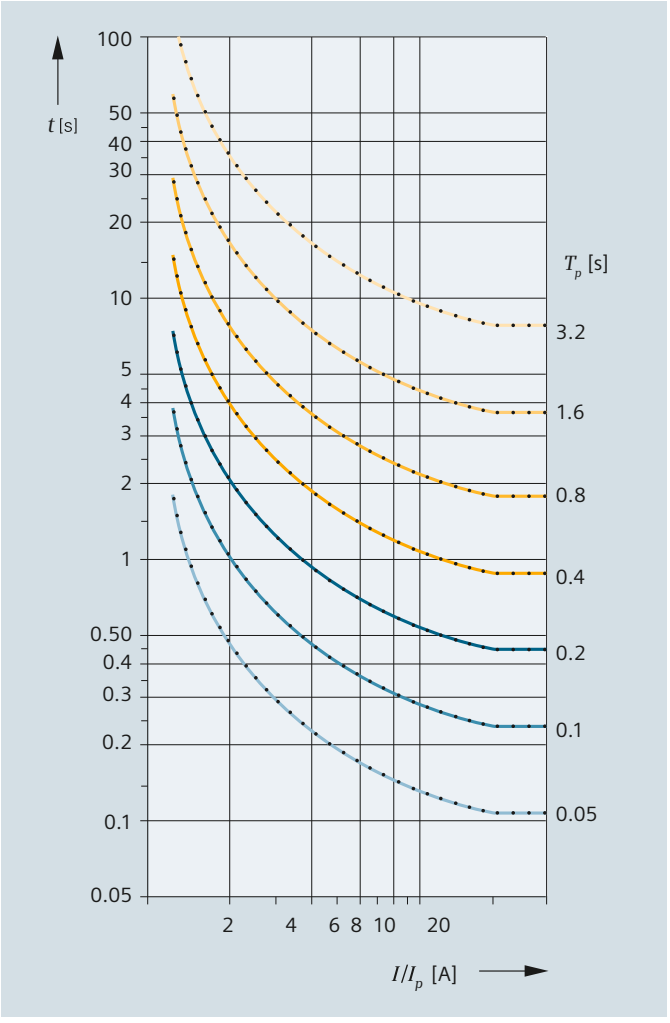


Fig. 6.2-117: **Normal inverse-time characteristic of the 7SJ60 relay**

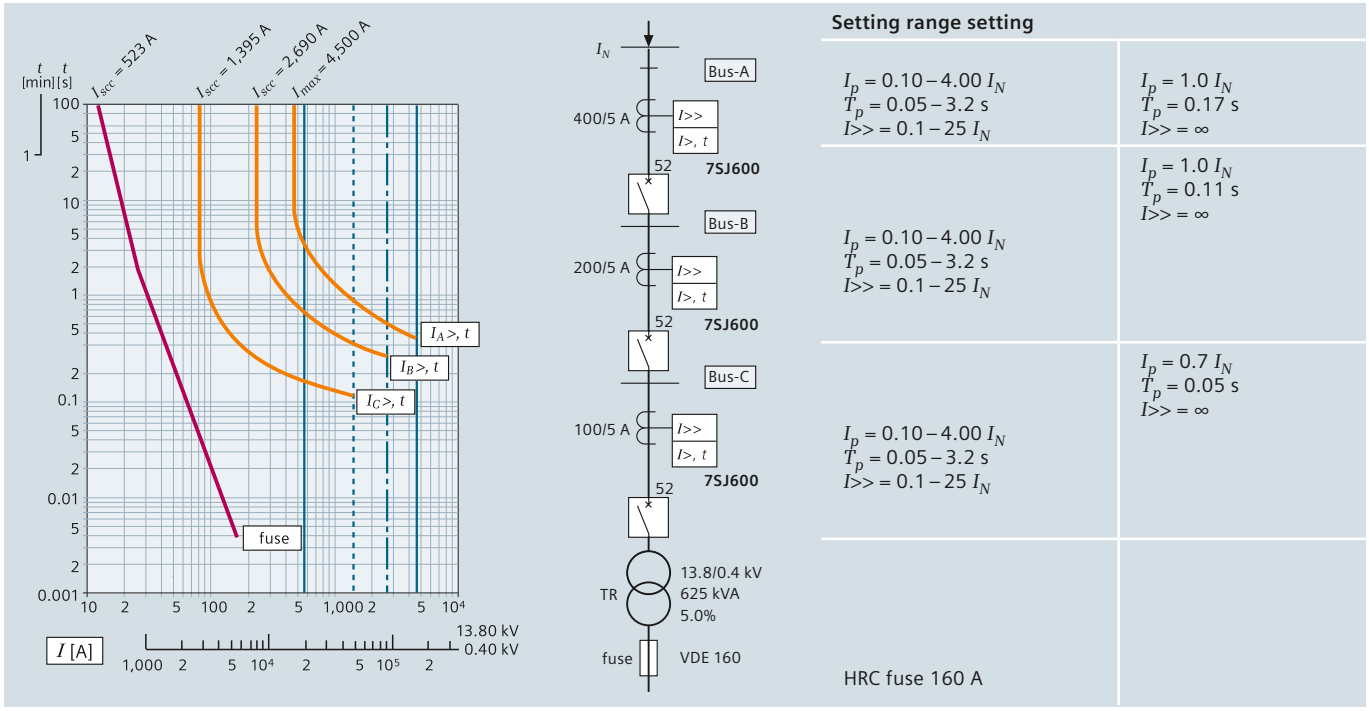
Normalinverse

$$t = \frac{0.14}{(I/I_p)^{0.02} - 1} \cdot T_p(\text{s})$$

Strong inverse characteristics may be used with expulsion-type fuses (fuse cutouts), while extremely inverse versions adapt better to current limiting fuses.

In any case, the final decision should be made by plotting the curves in the log-log coordination diagram.

Electronic trip devices of LV breakers have long-delay, short-delay and instantaneous zones. Numerical overcurrent relays with one inverse-time and two definite-time zones can closely be adapted to this (fig. 6.2-119b).



Setting range setting	
$I_p = 0.10 - 4.00\ I_N$ $T_p = 0.05 - 3.2$ s $I>> = 0.1 - 25\ I_N$	$I_p = 1.0\ I_N$ $T_p = 0.17$ s $I>> = \infty$
$I_p = 0.10 - 4.00\ I_N$ $T_p = 0.05 - 3.2$ s $I>> = 0.1 - 25\ I_N$	$I_p = 1.0\ I_N$ $T_p = 0.11$ s $I>> = \infty$
$I_p = 0.10 - 4.00\ I_N$ $T_p = 0.05 - 3.2$ s $I>> = 0.1 - 25\ I_N$	$I_p = 0.7\ I_N$ $T_p = 0.05$ s $I>> = \infty$
HRC fuse 160 A	

Fig. 6.2-118: **Overcurrent-time grading diagram**

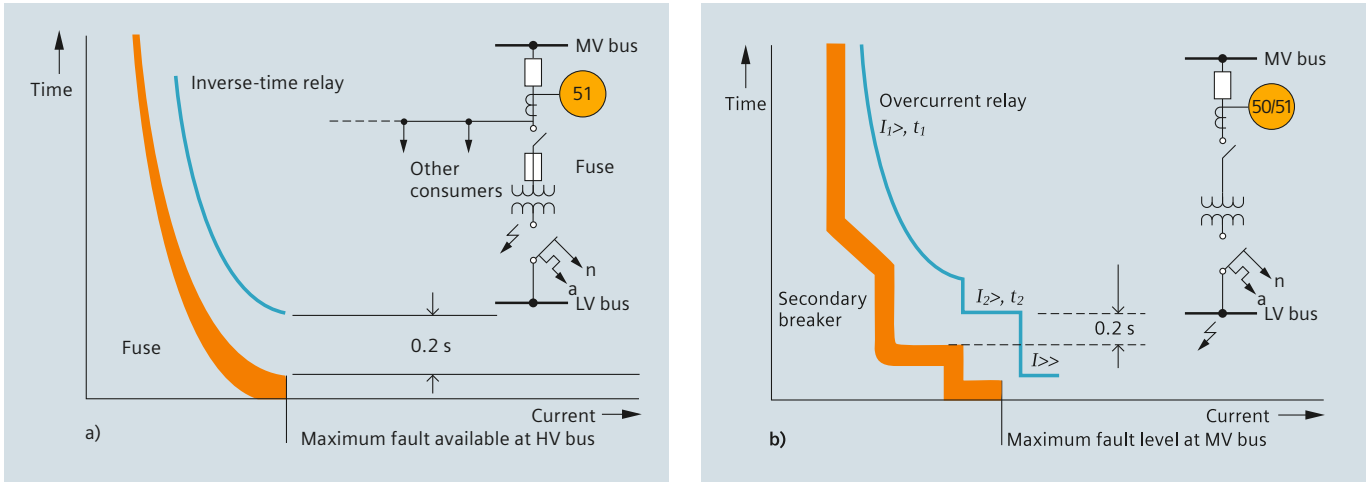


Fig. 6.2-119: **Coordination of an overcurrent relay with an MV fuse and low-voltage breaker trip device**

Coordination of distance relays

The distance relay setting must take into account the limited relay accuracy, including transient overreach (5 %, according to IEC 60255-6), the CT error (1 % for class 5P and 3 % for class 10P) and a security margin of about 5 %. Furthermore, the line parameters are often only calculated, not measured. This is a further source of errors. A setting of 80 to 85 % is therefore common practice; 80 % is used for mechanical relays, while 85 % can be used for the more accurate numerical relays.

Where measured line or cable impedances are available, the protected zone setting may be extended to 90 %. The second and third zones have to keep a safety margin of about 15 to 20 % to the corresponding zones of the following lines. The shortest following line always has to be considered (fig. 6.2-120).

As a general rule, the second zone should at least reach 20 % over the next station to ensure backup for busbar faults, and the third zone should cover the longest following line as backup for the line protection.

Grading of zone times

The first zone normally operates undelayed. For the grading of the time delays of the second and third zones, the same rules as for overcurrent relays apply (fig. 6.2-115, page 308). For the quadrilateral characteristics (relays 7SA6 and 7SA5), only the reactance values (X values) have to be considered for the protected zone setting. The setting of the R values should cover the line resistance and possible arc or fault resistances. The arc resistance can be roughly estimated as follows:

$$R_{Arc} = \frac{2.5 \cdot l_{arc}}{I_{SCC\ Min}}\ [\Omega]$$

l_{arc} = Arc length in mm

$I_{SCC\ Min}$ = Minimum short-circuit current in kA

- Typical settings of the ratio R/X are:
  - Short lines and cables (≤ 10 km): R/X =2 to 6
  - Medium line lengths < 25 km: R/X =2
  - Longer lines 25 to 50 km: R/X =1

Shortest feeder protectable by distance relays

The shortest feeder that can be protected by underreaching distance zones without the need for signaling links depends on the shortest settable relay reactance.

$$X_{Prim\ Min} = X_{Relay\ Min} \cdot \frac{VT_{ratio}}{CT_{ratio}}$$

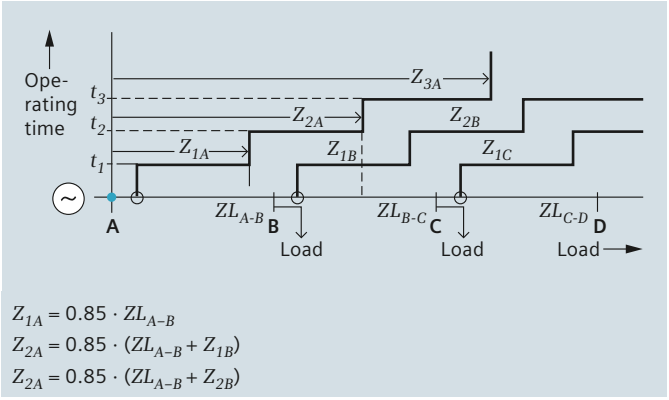
$$l_{min} = \frac{X_{Prim\ Min}}{X'_{Line}}$$

The shortest setting of the numerical Siemens relays is 0.05 Ω for 1 A relays, corresponding to 0.01 Ω for 5 A relays. This allows distance protection of distribution cables down to the range of some 500 meters.

Breaker failure protection setting

Most numerical relays in this guide provide breaker failure (BF) protection as an integral function. The initiation of the BF protection by the internal protection functions then takes place via software logic. However, the BF protection function may also be initiated externally via binary inputs by an alternate protection. In this case, the operating time of intermediate relays (BFI time) may have to be considered. Finally, the tripping of the infeeding breakers requires auxiliary relays, which add a small time delay (BFI) to the overall fault clearing time. This is particularly the case with one-breaker-and-a-half or ring bus arrangements where a separate breaker failure relay (7SV600 or 7VK61) is used per breaker (fig. 6.2-82, fig. 6.2-83).

The decisive criterion of BF protection time coordination is the reset time of the current detector (50BF), which must not be exceeded under any condition during normal current interruption. The reset times specified in the Siemens numerical relay manuals are valid for the worst-case condition: interruption of a fully offset short-circuit current and low current pickup setting (0.1 to 0.2 times rated CT current).



$Z_{1A} = 0.85 \cdot ZL_{A-B}$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{1B})$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{2B})$

Fig. 6.2-120: **Grading of distance zones**

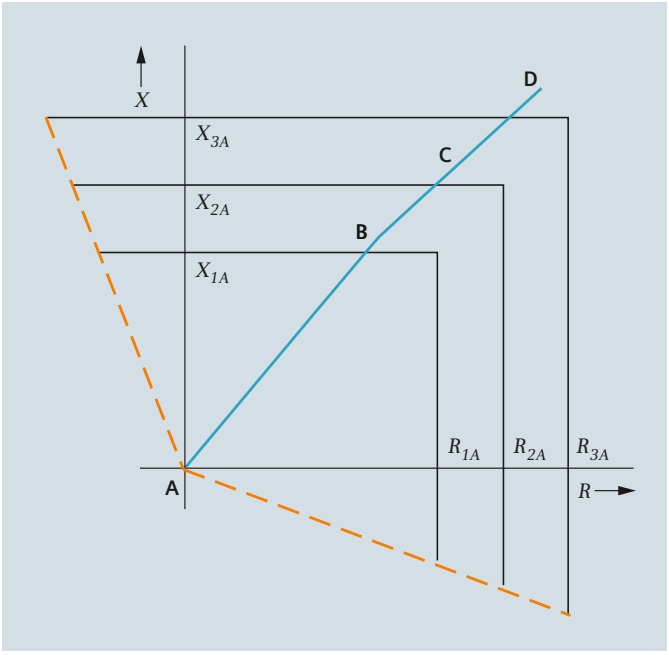


Fig. 6.2-121: **Operating characteristics of Siemens distance relays**

The reset time is 1 cycle for EHV relays (7SA6/52, 7VK61) and 1.5 to 2 cycles for distribution type relays (7SJ**).

Fig. 6.2-122 (next page) shows the time chart for a typical breaker failure protection scheme. The stated times in parentheses apply for transmission system protection and the times in square brackets for distribution system protection.

High-impedance differential protection – verification of design

The following design data must be established:

CT data

The prerequisite for a high-impedance scheme is that all CTs used for that scheme must have the same ratio. They should also be of low leakage flux design according to Class PX of IEC 60044-1 (former Class X of BS 3938) or TPS of IEC 60044-6, when used for high-impedance busbar protection schemes. When used for restricted earth-fault differential protection of, e.g., a transformer winding especially in solidly earthed systems, CTs of Class 5P according to IEC 60044-1 can be used as well. In each case the excitation characteristic and the secondary winding resistance are to be provided by the manufacturer. The knee-point voltage of the CT must be at least twice the relay pickup voltage to ensure operation on internal faults.

Relay

The relay can be either:

a) a dedicated design high-impedance relay, e.g., designed as a sensitive current relay 7VH60 or 7SG12 (DAD-N) with external series resistor R_{stab}. If the series resistor is integrated into the relay, the setting values may be directly applied in volts, as with the relay 7VH60 (6 to 60V or 24 to 240 V); or

b) a numerical overcurrent protection relay with sensitive current input, like 7SJ6 or 7SR1 (Argus-C). To the input of the relay a series stabilizing resistor R_{stab} will be then connected as a rule in order to obtain enough stabilization for the high-impedance scheme. Typically, a non-linear resistor V (varistor) will be also connected to protect the relay, as well as wiring against overvoltages.

Sensitivity of the scheme

For the relay to operate in the event of an internal fault, the primary current must reach a minimum value to supply the relay pickup current (I_{set}), the varistor leakage current (I_{var}) and the magnetizing currents of all parallel-connected CTs at the set pickup voltage. A low relay voltage setting and CTs with low magnetizing current therefore increase the protection sensitivity.

Stability during external faults

This check is made by assuming an external fault with maximum through-fault current and full saturation of the CT in the faulty feeder. The saturated CT is then substituted with its secondary winding resistance R_{CT}, and the appearing relay voltage V_R corresponds to the voltage drop of the infeeding currents (through-fault current) across R_{CT} and R_{lead}. The current (voltage) at the relay must, under this condition, stay reliably below the relay pickup value.

In practice, the wiring resistances R_{lead} may not be equal. In this case, the worst condition with the highest relay voltage (corresponding to the highest through-fault current) must be sought by considering all possible external feeder faults.

Setting

The setting is always a trade-off between sensitivity and stability. A higher voltage setting leads not only to enhanced

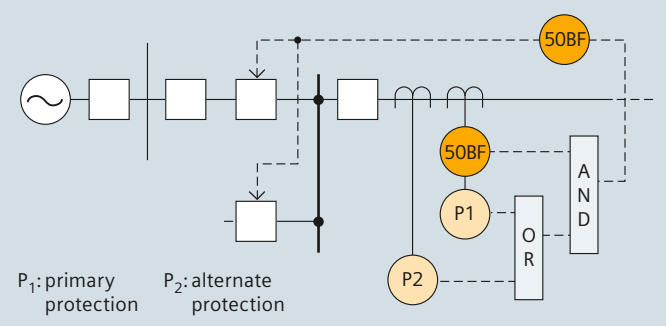


Fig. 6.2-122: **Breaker failure protection, logic circuit**

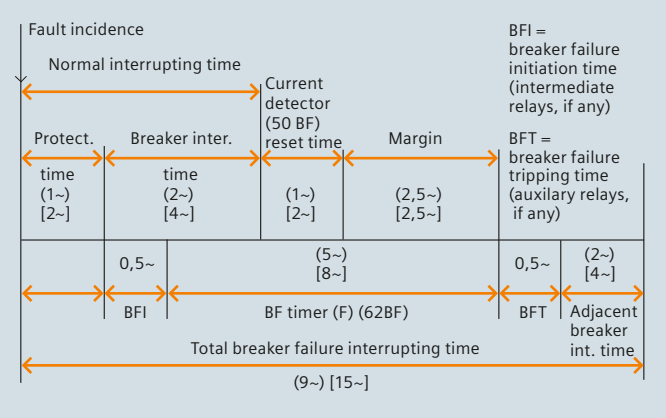


Fig. 6.2-123: **Time coordination of BF time setting**

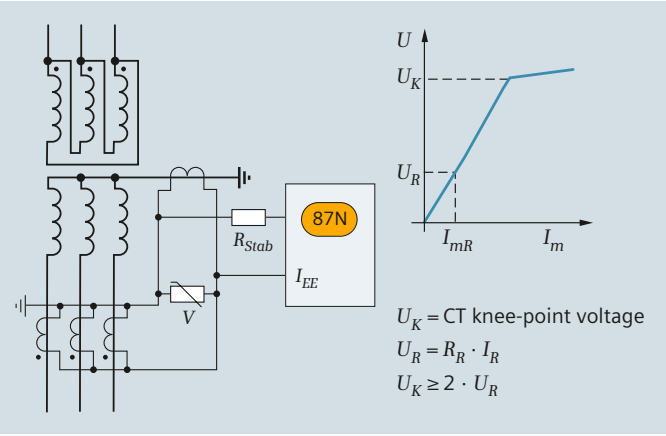


Fig. 6.2-124: **Principle connection diagram for high-impedance restricted ground-fault protection of a winding of the transformer using SIPROTEC digital overcurrent relay (e.g. 7SJ61)**

Relay setting U_{rms}	C	ß	Varistor type
≤ 125	450	0.25	600 A /S1/S256
125 – 240	900	0.25	600 A /S1/S1088

Calculation example:

Restricted earth-fault protection for the 400 kV winding of 400 MVA power transformer with $I_{r,400\,kV}$ = 577 A installed in a switchgear with a rated short-time withstand current of 40 kA.
Given:
N = 4 CTs connected in parallel; I_{pn}/I_{sn} = 800 A / 1 A – CT ratio;
U_k = 400 V – CT knee-point voltage;
I_m = 20 mA – CT magnetizing current at U_k;
R_{CT} = 3 Ω – CT internal resistance;
R_{lead} = 2 Ω – secondary wiring (lead) resistance
Relay: 7SJ612; time-overcurrent 1-phase input used with setting range I_{set} = 0.003 A to 1.5 A in steps of 0.001 A; relay internal burden R_{relay} = 50 mΩ

Stability calculation

$$U_{s,min} = I_{k,max,thr}\frac{I_{sn}}{I_{pn}}(R_{CT}+R_{lead}) = 10{,}000\,\frac{1}{800}\,(3+2) = 62.6\ \text{V}$$

with $I_{k,max,thr}$ taken as $16 \cdot I_{r,400kV} = 16 \cdot 577\ \text{A} = 9{,}232$ A, rounded up to 10 kA.
The actual stability voltage for the scheme U_s can be taken with enough safety margin as $\boldsymbol{U_s = 130\,V}$ (remembering that $2U_s < U_k$).

Fault setting calculation

For the desired primary fault sensitivity of 125 A, which is approx. 22 % of the rated current of the protected winding $I_{r,400\,kV}$ (i.e., $I_{p,des}$ = 125 A) the following current setting can be calculated:

$$I_{set} = I_{p,des}\frac{I_{sn}}{I_{pn}} - N \,.\, I_m\frac{U_s}{U_k} = 125\,\frac{1}{800} - 4\,.\,0.02\,\frac{130}{400} = 0.13\ \text{A}$$

Stabilizing resistor calculation

From the $\boldsymbol{U_s}$ and $\boldsymbol{I_{set}}$ values calculated above the value of the stabilizing resistor $\boldsymbol{R_{stab}}$ can be calculated:

$$R_{stab} = \frac{U_s}{I_{set}} - R_{relay} = \frac{130}{0.13} - 0.05 = \approx 1{,}000\ \Omega$$

where the relay resistance can be neglected.

The stabilizing resistor R_{stab} can be chosen with a necessary minimum continuous power rating $P_{stab,cont}$ of:

$$P_{stab,cont} \geq \frac{{U_s}^2}{R_{stab}} = \frac{130^2}{1{,}000} = 16.9\ \text{W}$$

Moreover, R_{stab} must have a short-time rating large enough to withstand the fault current levels before the fault is cleared. The time duration of 0.5 seconds can be typically considered ($P_{stab,\,0.5s}$) to take into account longer fault clearance times of back-up protection. The r.m.s. voltage developed across the stabilizing resistor is decisive for the thermal stress of the stabilizing resistor. It is calculated according to formula:

$$U_{rms,relay} = 1.3\cdot\sqrt[4]{U_{k3}\cdot R_{stab}\cdot I_{k,max,int}\frac{I_{sn}}{I_{pn}}} = 1.3\cdot\sqrt[4]{400^3\cdot 1000\cdot 50} = 1738.7\ \text{V}$$

The resulting short-time rating $P_{stab,\,0.5s}$ equals to:

$$P_{stab,\,0.5s} = \frac{{U_{rms,relay}}^2}{R_{stab}} = \frac{1{,}739^2}{1{,}000} = 3023\ \text{W}$$

Check whether the voltage limitation by a varistor is required

The relay should normally be applied with an external varistor which should be connected across the relay and stabilizing resistor input terminals. The varistor limits the voltage across the terminals under maximum internal fault conditions. The theoretical voltage which may occur at the terminals can be determined according to following equation:

$$U_{k,max,int} = I_{k,max,int}\frac{I_{sn}}{I_{pn}}(R_{relay}+R_{stab}) = 40{,}000\,\frac{1}{800}\,(0.05+1{,}000) = 50{,}003\ \text{V}$$

with $I_{k,max,int}$ taken as the rated short-circuit current of the switchgear = 40 kA.

The resulting maximum peak voltage across the panel terminals (i.e., tie with relay and R_{stab} connected in series):

$$\hat{U}_{max,relay} = 2\sqrt{2U_k\left(U_{k,max,int}\right)} = 2\sqrt{2\cdot 400(50003-400)} = 12600\ \text{V}$$

Since $U_{max,\,relay} > 1.5$ kV, the varistor is necessary.

Exemplarily, a METROSIL of type 600A / S1 / Spec.1088 can be used (β = 0.25, C = 900).
This Metrosil leakage current at voltage setting U_s =130 V equals to

$$I_{rms} = 0.52\left(\frac{U_{set,rms}\cdot\sqrt{2}}{C}\right)^{1/\beta} = 0.91\ \text{mA}$$

and can be neglected by the calculations, since its influence on the proposed fault setting is negligible.

through-fault stability but also to higher CT magnetizing and varistor leakage currents, resulting consequently in a higher primary pickup current.

A higher voltage setting also requires a higher knee-point voltage of the CTs and therefore greater size of the CTs. A sensitivity of 10 to 20 % of I_r (rated current) is typical for restricted earth-fault protection. With busbar protection, a pickup value ≥ I_r is normally applied. In systems with neutral earthing via impedance, the fault setting shall be revised against the minimum earth-fault conditions.

Non-linear resistor (varistor)

Voltage limitation by a varistor is needed if peak voltages near or above the insulation voltage (2 kV ... 3 kV) are expected. A limitation to U_{rms} = 1,500 V is then recommended. This can be checked for the maximum internal fault current by applying the formula shown for $U_{max\,relay}$. A restricted earth-fault protection may sometimes not require a varistor, but a busbar protection in general does. However, it is considered a good practice to equip with a varistor all high impedance protection installations. The electrical characteristic of a varistor can be expressed as $U = C\,I^{\beta}$ where C and β are the varistor constants.

CT requirements for protection relays

Instrument transformers

Instrument transformers must comply with the applicable IEC recommendations IEC 60044 and 60186 (PT), ANSI / IEEE C57.13 or other comparable standards.

Voltage transformers (VT)

Voltage transformers (VT) in single-pole design for all primary voltages have typical single or dual secondary windings of 100, 110 or 115 V / √3, with output ratings between 10 and 50 VA suitable from most applications with digital metering and protection equipment, and accuracies of 0.1 % to 6 % to suit the particular application. Primary BIL values are selected to match those of the associated switchgear.

Current transformers

Current transformers (CT) are usually of the single-ratio type with wound or bar-type primaries of adequate thermal rating. Single, double or triple secondary windings of 1 or 5 A are standard. 1 A rating should, however, be preferred, particularly in HV and EHV substations, to reduce the burden of the connected lines. Output power (rated burden in VA), accuracy and

saturation characteristics (rated symmetrical short-circuit current limiting factor) of the cores and secondary windings must meet the requirements of the particular application.The CT classification code of IEC is used in the following:

- Measuring cores
  These are normally specified with 0.2 % or 0.5 % accuracy (class 0.2 or class 0.5), and an rated symmetrical short-circuit current limiting factor FS of 5 or 10.
  The required output power (rated burden) should be higher than the actually connected burden. Typical values are 2.5, 5 or 10 VA. Higher values are normally not necessary when only electronic meters and recorders are connected.
  A typical specification could be: 0.5 FS 10, 5 VA.
- Cores for billing values metering
  In this case, class 0.25 FS is normally required.
- Protection cores
  The size of the protection core depends mainly on the maximum short-circuit current and the total burden (internal CT burden, plus burden of connected lines, plus relay burden). Furthermore, a transient dimensioning factor has to be considered to cover the influence of the DC component in the short-circuit current.

Glossary of used abbreviations (according to IEC 60044-6, as defined)

K_{ssc}	=	Rated symmetrical short-circuit current factor (example: CT cl. 5P20 → K_{ssc} = 20)
K'_{ssc}	=	Effective symmetrical short-circuit current factor
K_{td}	=	Transient dimensioning factor
$I_{ssc\,max}$	=	Maximum symmetrical short-circuit current
I_{pn}	=	CT rated primary current
I_{sn}	=	CT rated secondary current
R_{ct}	=	Secondary winding d.c. resistance at 75 °C / 167 °F (or other specified temperature)
R_b	=	Rated resistive burden
R'_b	=	$R_{lead} + R_{relay}$ = connected resistive burden
T_P	=	Primary time constant (net time constant)
U_K	=	Knee-point voltage (r.m.s.)
R_{relay}	=	Relay burden
R_{lead}	=	$\frac{2 \cdot \rho \cdot l}{A}$
with		
l	=	Single conductor length from CT to relay in m
ρ	=	Specific resistance = 0.0175 Ωmm² / m (copper wires) at 20 °C / 68 °F (or other specified temperature)
A	=	Conductor cross-section in mm²

In general, an ac-curacy of 1 % in the range of 1 to 2 times nominal current (class 5 P) is specified. The rated symmetrical short-circuit current factor K_{SSC} should normally be selected so that at least the maximum short-circuit current can be transmitted without saturation (DC component is not considered).

This results, as a rule, in rated symmetrical short-circuit current factors of 10 or 20 depending on the rated burden of the CT in relation to the connected burden. A typical specification for protection cores for distribution feeders is 5P10, 10 VA or 5P20, 5 VA.

The requirements for protective current transformers for transient performance are specified in IEC 60044-6. In many practical cases, iron-core CTs cannot be designed to avoid saturation under all circumstances because of cost and space reasons, particularly with metal-enclosed switchgear.

CT dimensioning formulae

$$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b} \text{ (effective)}$$

$$\text{with } K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\,max}}{I_{pn}} \text{ (required)}$$

The Siemens relays are therefore designed to tolerate CT saturation to a large extent. The numerical relays proposed in this guide are particularly stable in this case due to their integrated saturation detection function. The effective symmetrical short-circuit current factor K'_{SSC} can be calculated as shown in the table above. The rated transient dimensioning factor K_{td} depends on the type of relay and the primary DC time constant. For relays with a required saturation-free time from ≤ 0.4 cycle, the primary (DC) time constant TP has little influence.

CT design according to BS 3938 / IEC 60044-1 (2000)

IEC Class P can be approximately transfered into the IEC Class PX (BS Class X) standard definition by following formula:

$$U_k = \frac{(R_b + R_{ct}) \cdot I_n \cdot K_{ssc}}{1.3}$$

Example:
IEC 60044: 600 / 1, 5P10, 15 VA, R_{ct} = 4 Ω

IEC PX or BS: $U_K = \frac{(15 + 4) \cdot 1 \cdot 10}{1.3} = 146$ V, $R_{ct} = 4\ \Omega$

For CT design according to ANSI / IEEE C 57.13 please refer to page 331

The CT requirements mentioned in table 6.2-3 are simplified in order to allow fast CT calculations on the safe side. More accurate dimensioning can be done by more intensive calculation with Siemens's CTDIM (www.siemens.com/ctdim) program. Results of CTDIM are released by the relay manufacturer.

Adaption factor for 7UT6, 7UM62 relays in fig 6.2-122 (limited resolution of measurement)

$$F_{Adap} = \frac{I_{pn}}{I_{nO}} \cdot \frac{I_{Nrelay}}{I_{sn}} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}} \rightarrow \text{Request: } ⅛ \leq 8$$

7SD52, 53, 610, when transformer inside protected zone

$$\frac{I_{n\text{-}pri}\text{-}CT_{max}}{I_{n\text{-}pri}\text{-}CT_{min}} \cdot \frac{1}{\text{Transformer ratio}^*} \leq 8$$

* If transformer in protection zone, else 1

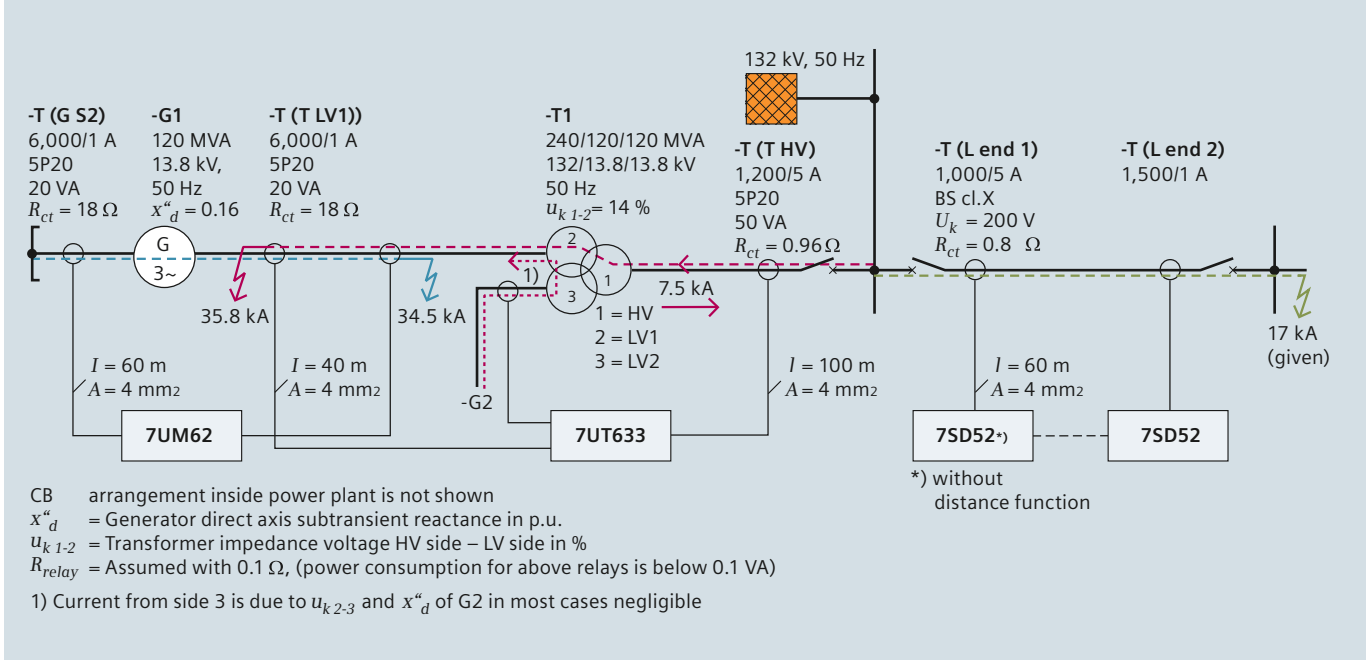
$I_{n\text{-}pri}$-CT-Transf-Site ≤ 2 · I_n-Obj-Transf-Site AND

$I_{n\text{-}pri}$-CT-Transf-Site ≥ I_n-Obj-Transf-Site with

I_{nO}	= Rated current of the protected object
U_{nO}	= Rated voltage of the protected object
I_{Nrelay}	= Rated current of the relay
S_{Nmax}	= Maximun load of the protected object (for transformers: winding with max. load)

Relay type	Transient dimensioning factor K_{td}	Min. required sym. short-circuit current factor K'_{ssc}	Min. required knee-point voltage U_k
Overcurrent-time and motor protection 7SJ511, 512, 531 7SJ45, 46, 60 7SJ61, 62, 63, 64 7SJ80, 7SK80	–	$K'_{ssc} \geq \frac{I_{High\ set\ point}}{I_{pn}}$ at least: 20	$U_k \geq \frac{I_{High\ set\ point}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ at least: $\frac{20}{1.3} \cdot (R_{ct} + R'_b) \cdot I_{sn}$
Line differential protection (pilot wire) 7SD600	–	$K'_{ssc} \geq \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ and: $\frac{3}{4} \leq \frac{(K'_{ssc} \cdot I_{pn})_{end1}}{(K'_{ssc} \cdot I_{pn})_{end2}} \leq \frac{4}{3}$	$U_k \geq \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ and: $\frac{3}{4} \leq \frac{(U_k/(R_{ct} + R'_b) \cdot I_{pn}/I_{sn})_{end1}}{(U_k/(R_{ct} + R'_b) \cdot I_{pn}/I_{sn})_{end2}} \leq \frac{4}{3}$
Line differential protection (without distance function) 7SD52x, 53x, 610 (50/60 Hz)	Transformer 1.2 / Busbar/Line 1.2 / Gen./Motor 1.2	$K'_{ssc} \geq$ $K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ and (only for 7SS): $\frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}} \leq 100$ (measuring range)	$U_K \geq$ $K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ and (only for 7SS): $\frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}} \leq 100$ (measuring range)
Tranformer/generator differential protection 7UT612, 7UT612 V4.0 7UT613, 633, 635, 7UT612 V4.6 7UM62	Transformer / Busbar/Line / Gen./Motor 4 / 4 / 5 3 / 3 / 5 4 / – / 5		
Busbar protection 7SS52, 7SS60	for stabilizing factors k ≥ 0.5 0.5		
Distance protection 7SA522, 7SA6, 7SD5xx (with distance function)	primary DC time constant T_p [ms] ≤ 30 / ≤ 50 / ≤ 100 / ≤ 200 K_{td} (a): 1 / 2 / 4 / 4 K_{td} (b): 4 / 5 / 5 / 5	$K'_{ssc} \geq$ K_{td} (a) $\cdot \frac{I_{scc\ max\ (close-in\ fault)}}{I_{pn}}$ and: K_{td} (b) $\cdot \frac{I_{scc\ max\ (zone\ 1-end\ fault)}}{I_{pn}}$	$U_K \geq$ K_{td} (a) $\cdot \frac{I_{scc\ max\ (close-in\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ and: K_{td} (b) $\cdot \frac{I_{scc\ max\ (zone\ 1-end\ fault)}}{I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$

Table 6.2-3: **CT requirements**



CB arrangement inside power plant is not shown
x''_d = Generator direct axis subtransient reactance in p.u.
$u_{k\ 1-2}$ = Transformer impedance voltage HV side – LV side in %
R_{relay} = Assumed with 0.1 Ω, (power consumption for above relays is below 0.1 VA)

1) Current from side 3 is due to $u_{k\ 2-3}$ and x''_d of G2 in most cases negligible

Fig. 6.2-125: **Example 1 – CT verification for 7UM62, 7UT6, 7SD52 (7SD53, 7SD610)**

-T (G S2), 7UM62	-T (T LV1), 7UT633	-T (T HV), 7UT633	-T (L end 1), 7SD52
$I_{scc\ max\ (ext.\ fault)} = \frac{c \cdot S_{NG}}{\sqrt{3} \cdot U_{NG}\, x"_d}$ $= \frac{1.1 \cdot 120{,}000\ \text{kVA}}{\sqrt{3} \cdot 13.8\ \text{kV} \cdot 0.16} = 34{,}516\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = \frac{S_{NT}}{\sqrt{3} \cdot U_{NT}\, u_k"}$ $= \frac{120{,}000\ \text{kVA}}{\sqrt{3} \cdot 13.8\ \text{kV} \cdot 0.14} = 35{,}860\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = \frac{S_{NT}}{\sqrt{3} \cdot U_{NT}\, u_k"}$ $= \frac{240{,}000\ \text{kVA}}{\sqrt{3} \cdot 132\ \text{kV} \cdot 0.14} = 7{,}498\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = 17\ \text{kA}$ (given)
$K_{td} = 5$ (from table 6.2-3)	$K_{td} = 3$ (from table 6.2-3)	$K_{td} = 3$ (from table 6.2-3)	$K_{td} = 1.2$ (from table 6.2-3)
$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 5 \cdot \frac{31{,}378\ \text{A}}{6{,}000\ \text{A}} = 28.8$	$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 3 \cdot \frac{35{,}860\ \text{A}}{6{,}000\ \text{A}} = 17.9$	$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 3 \cdot \frac{7{,}498\ \text{A}}{1{,}200\ \text{A}} = 18{,}7$	
$R_b = \frac{S_n}{I^2_{sn}} = \frac{20\ \text{VA}}{1\ \text{A}^2} = 20\ \Omega$	$R_b = \frac{S_n}{I^2_{sn}} = \frac{20\ \text{VA}}{1\ \text{A}^2} = 20\ \Omega$	$R_b = \frac{S_n}{I^2_{sn}} = \frac{50\ \text{VA}}{(5\ \text{A})^2} = 2\ \Omega$	
$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot \rho \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 60\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.625\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot \rho \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 640\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.450\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot \rho \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 100\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.975\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot \rho \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 60\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.625\ \Omega$
$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{18\ \Omega + 20\ \Omega}{18\ \Omega + 0.625\ \Omega} = 40.8$	$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{18\ \Omega + 20\ \Omega}{18\ \Omega + 0.450\ \Omega} = 41.2$	$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{0.96\ \Omega + 2\ \Omega}{0.96\ \Omega + 0.975\ \Omega} = 30.6$	$U_K \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ $= 1.2 \cdot \frac{17{,}000\ \text{A}}{1.3 \cdot 1{,}000\ \text{A}} \cdot (0.8\ \Omega + 0.625\ \Omega) \cdot 5\ \text{A}$ $= 111.8\ \text{V}$
K'_{ssc} required = 28.8, K_{ssc} effective = 40.8 28.8 < 40.8 ➞ CT dimensioning is ok	K'_{ssc} required = 17.9, K_{ssc} effective = 41.2 17.9 < 41.2 ➞ CT dimensioning is ok	K'_{ssc} required = 18.7, K_{ssc} effective = 30.6 18.7 < 30.6 ➞ CT dimensioning is ok	U_K required = 111.8 V, U_K effective = 200 V 111.8 V < 200 V ➞ CT dimensioning is ok
$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{6{,}000\ \text{A} \cdot \sqrt{3} \cdot 13.8\ \text{kV}}{120{,}000\ \text{kVA}} \cdot \frac{1\ \text{A}}{1\ \text{A}}$ $= 1.195$ $1/8 \leq 1.195 \leq 8$ ➞ ok!	$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{6{,}000\ \text{A} \cdot \sqrt{3} \cdot 13.8\ \text{kV}}{240{,}000\ \text{kVA}} \cdot \frac{1\ \text{A}}{1\ \text{A}}$ $= 0.598$ $1/8 \leq 0.598 \leq 8$ ➞ ok!	$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{1{,}200\ \text{A} \cdot \sqrt{3} \cdot 132\ \text{kV}}{240{,}000\ \text{kVA}} \cdot \frac{5\ \text{A}}{5\ \text{A}}$ $= 1.143$ $1/8 \leq 1.143 \leq 8$ ➞ ok!	$\frac{I_{pn\ max}}{I_{pn\ min}} \leq 8$ $\frac{1{,}500\ \text{A}}{1{,}000\ \text{A}} = 1.5 \leq 8$ ➞ ok!

Table 6.2-4: **Example 1 (continued) – verfication of the numerical differential protection**

Attention (only for 7UT6 V4.0): When low-impedance REF is used, the request for the REF side (3-phase) is:
$^1/_4 \leq F_{Adap} \leq 4$, (for the neutral CT: $^1/_8 \leq F_{Adap} \leq 8$)

Further condition for 7SD52x, 53x, 610 relays (when used as line differential protection without transformer inside protected zone): Maximum ratio between primary currents of CTs at the end of the protected line:

$$\frac{I_{pn\ max}}{I_{pn\ min}} \leq 8$$

Example 2: Stability verification of the numerical busbar protection relay 7SS52

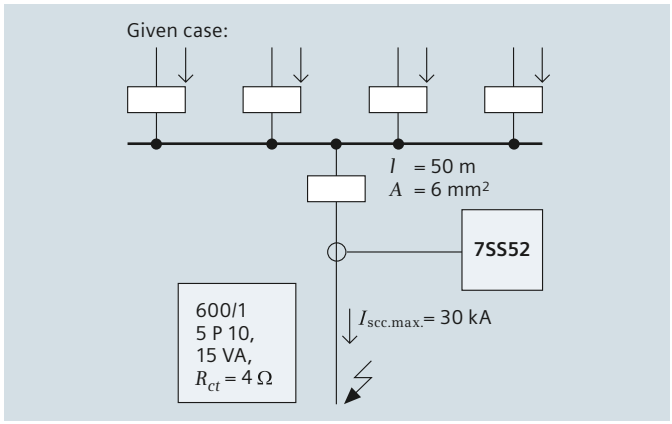


Fig. 6.2-126: **Example 2**

$$\frac{I_{scc\,max}}{I_{pn}} = \frac{30{,}000\ \text{A}}{600\ \text{A}} = 50$$

According to table 6.2-5, page 313 $K_{td} = {}^1/_2$

$$K'_{ssc} \geq \frac{1}{2} \cdot 50 = 25$$

$$R_b = \frac{15\ \text{VA}}{1\ \text{A}^2} = 15\ \Omega$$

$$R_{relay} = 0.1\ \Omega$$

$$R_{lead} = \frac{2 \cdot 0.0175 \cdot 50}{6} = 0.3\ \Omega$$

$$R'_b = R_{lead} + R_{relay} = 0.3\ \Omega + 0.1\ \Omega = 0.4\ \Omega$$

$$K'_{ssc} = \frac{R_{ct} + R_b}{R_{ct} + R'_b} \cdot K_{ssc} = \frac{4\ \Omega + 15\ \Omega}{4\ \Omega + 0.4\ \Omega} \cdot 10 = 43.2$$

Result:
The effective K'_{ssc} is 43.2, the required K'_{ssc} is 25. Therefore the stability criterion is fulfilled.

Relay burden
The CT burdens of the numerical relays of Siemens are below 0.1 VA and can therefore be neglected for a practical estimation. Exceptions are the busbar protection 7SS60 and the pilot-wire relays 7SD600.

Intermediate CTs are normally no longer necessary, because the ratio adaptation for busbar protection 7SS52 and transformer protection is numerically performed in the relay.

Analog static relays in general have burdens below about 1 VA.

Mechanical relays, however, have a much higher burden, up to the order of 10 VA. This has to be considered when older relays are connected to the same CT circuit.

In any case, the relevant relay manuals should always be consulted for the actual burden values.

Burden of the connection leads
The resistance of the current loop from the CT to the relay has to be considered:

R_{lead}	$= \frac{2 \cdot \rho \cdot l}{A}$
l	= Single conductor length from the CT to the relay in m
Specific resistance:	
ρ	$= 0.0175 \frac{\Omega \cdot \text{mm}^2}{\text{m}}$ (copper wires) at 20 °C/68 °F
A	= Conductor cross-section in mm²

CT design according to ANSI/IEEE C 57.13

Class C of this standard defines the CT by ist secondary terminal voltage at 20 times rated current, for which the ratio error shall not exceed 10 %. Standard classes are C100, C200, C400 and C800 for 5 A rated secondary current.

This terminal voltage can be approximately calculated from the IEC data as follows:

ANSI CT definition

$$U_{s.t.max} = 20 \cdot 5\ \text{A} \cdot R_b \cdot \frac{K_{ssc}}{20}$$

with
$R_b = \frac{P_b}{I_{sn}^2}$ and I_{Nsn} = 5 A, the result is

$$U_{s.t.max} = \frac{P_b \cdot K_{ssc}}{5\ \text{A}}$$

Example:
IEC 60044: 600/5, 5P20, 25 VA,

ANSI C57.13: $U_{s.t.max} = \frac{(25\ \text{VA} \cdot 20)}{5\ \text{A}} = 100$ V, acc. to class C100

For further information:
www.siemens.com/protection

6.2.6 Relay Selection Guide

Device applications			Distance protection									Line differential protection								
		Device series	SIPROTEC 4				SIPROTEC 5			Reyrolle		SIPROTEC 600er	SIPROTEC Compact	SIPROTEC 4		SIPROTEC 5			Reyrolle	
ANSI	Function	Abbr.	7SA522	7SA61	7SA63	7SA64	7SA84	7SA86	7SA87	7SG163	7SG164	7SD60	7SD80	7SD610	7SD5	7SD84	7SD86	7SD87	7PG2111	7SG18
	Protection functions for 3-pole tripping	3-pole	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Protection functions for 1-pole tripping	1-pole	●	●	●	●	–	–	■	–	●	–	–	●	●	–	–	■	–	–
14	Locked rotor protection	$I> + V<$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
21	Distance protection	$Z<$	■	■	■	■	■	■	■	■	■	–	–	–	●	–	–	–	–	–
FL	Fault locator	FL	■	■	■	■	■	■	■	■	■	–	–	■	■	■	■	■	–	–
24	Overexcitation protection	V/f	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
25	Synchrocheck, synchronizing function	Sync	●	●	●	●	●	●	●	●	●	–	–	–	●	●	●	●	–	–
27	Undervoltage protection	$V<$	●	●	●	●	●	●	●	●	●	–	●	●	●	●	●	●	–	–
27TN/59TN	Stator ground fault 3rd harmonics	$V0<,>$ (3rd harm.)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
32	Directional power supervision	$P>, P<$	■	■	■	■	●	●	●	–	–	–	–	●	■	●	●	●	–	–
37	Undercurrent, underpower	$I<, P<$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38	Temperature supervision	$\Theta>$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
40	Underexcitation protection	$1/X_D$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
46	Unbalanced-load protection	$I2>$	–	–	–	–	●	●	●	–	–	–	–	–	–	●	●	●	–	–
46	Negative-sequence system overcurrent	$I2>, I2/I1>$	–	–	–	–	●	●	●	–	–	–	–	–	–	●	●	●	–	–
47	Phase-sequence-voltage supervision	LA, LB, LC	■	■	■	■	■	■	■	■	■	–	–	■	■	■	■	■	–	–
48	Start-time supervision	I^2_{start}	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
49	Thermal overload protection	θ, I^2t	–	■	■	■	●	●	●	–	●	–	■	■	■	●	●	●	–	–
50/50N	Definite time-overcurrent protection	$I>$	■	■	■	■	■	■	■	■	■	●	■	■	■	■	■	■	●	■
50Ns	Sensitive ground-current protection	$I_{Ns}>$	●	●	●	●	●	●	●	●	–	–	–	–	●	●	●	●	–	–
50Ns	Intermittent ground fault protection	Iie	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
50L	Load-jam protection	$I>_L$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
50BF	Circuit-breaker failure protection	CBFP	●	●	●	●	●	●	●	●	–	●	■	●	■	●	●	●	–	■
51 /51N	Inverse time-overcurrent protection	I_P, I_{Np}	■	■	■	■	■	■	■	–	–	–	■	■	■	■	■	■	–	■
51V	Overcurrent protection, voltage controlled	$t=f(I)+V<$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

More functions next page

Combined line differential and distance protection		High impedance protection			Overcurrent and feeder protection/ feeder automation *(Further devices on page 324)*																
SIPROTEC 5		Reyrolle			SIPROTEC easy		SIPROTEC 600er		SIPROTEC Compact			SIPROTEC 4				SIPROTEC 5		Reyrolle				
7SL86	7SL87	7SR23 [1]	7PG23	7SG12	7SJ45	7SJ46	7SJ600	7SJ602	7SJ80	7SJ81	7SC80	7SJ61	7SJ62	7SJ63	7SJ64	7SJ85 [1]	7SJ86	7SR11	7SR12	7SR210	7SR220	7SR224
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
–	■	■	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	●
–	–	–	–	–	–	–	–	–	–	–	–	●	●	●	●	–	–	–	–	–	–	–
■	■	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
■	■	–	–	–	–	–	–	–	●	●	●	–	●	●	●	●	●	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
●	●	–	–	–	–	–	–	–	●	–	● [1]	–	●	–	●	●	●	–	–	–	–	●
●	●	–	–	–	–	–	–	–	●	●	●	–	●	●	●	●	●	–	■	–	■	■
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
●	●	–	–	–	–	–	–	–	●	●	●	–	●	–	●	●	●	–	–	–	–	–
–	–	–	–	–	–	–	–	■	■	■	■	■	■	■ [2]	■	●	●	■	■	■	■	–
–	–	–	–	–	–	–	–	●	–	–	–	●	●	●	●	●	● [1]	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
●	●	–	–	–	–	–	■	■	■	■	■	■	■	■	■	■	■	●	●	■	■	■
●	●	–	–	–	–	–	■	■	■	■	■	■	■	■	■	■	■	●	●	■	■	■
■	■	–	–	–	–	–	–	–	●	●	●	■	■	■	■	■	■	–	■	–	■	■
–	–	–	–	–	–	–	–	–	–	–	–	●	●	●	●	–	–	–	–	–	–	–
●	●	–	–	–	–	–	■	■	■	■	■	■	■	■	■	■	■	●	●	■	■	■
■	■	–	–	–	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
●	●	■	■	–	–	–	–	●	●	●	■ [1]	●	●	●	●	●	● [1]	●	●	■	■	■
–	–	–	–	–	–	–	–	–	■ [1]	–	–	●	●	–	●	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	●	●	●	●	–	–	–	–	–	–	–
●	●	–	–	–	–	–	■	■	■	■	■	■	■	■	■	●	●	■	■	■	■	■
■	■	–	–	–	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
–	–	–	–	–	–	–	–	–	● [1]	–	–	–	■	–	■	–	–	–	■	–	■	■

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

Device applications			Distance protection									Line differential protection								
		Device series	SIPROTEC 4				SIPROTEC 5			Reyrolle		SIPROTEC 600er	SIPROTEC Compact	SIPROTEC 4		SIPROTEC 5			Reyrolle	
ANSI	Function	Abbr.	7SA522	7SA61	7SA63	7SA64	7SA84	7SA86	7SA87	7SG163	7SG164	7SD60	7SD80	7SD610	7SD5	7SD84	7SD86	7SD87	7PG2111	7SG18
55	Power factor	cos φ	■	■	■	■	■	■	■	–	–	–	–	■	■	■	■	■	–	–
59	Overvoltage protection	$V>$	●	●	●	●	●	●	●	●	●	–	●	●	●	●	●	●	–	–
59R, 27R	Rate-of-voltage-change protection	dV/dt	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
64	Sensitive ground-fault protection (machine)		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
66	Restart inhibit	I^2t	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
67	Directional time-overcurrent protection, phase	$I>$, $I_P \angle (V, I)$	■	■	■	■	●	●	●	–	–	–	●	●	–	●	●	●	–	–
67N	Directional time-overcurrent protection for ground-faults	$I_N>$, $I_{NP} \angle (V, I)$	●	●	●	●	●	●	●	–	–	–	●	●	●	●	●	●	–	–
67Ns	Sensitive ground-fault detection for systems with resonant or isolated neutral	$I_N>$, $\angle (V, I)$	●	●	●	●	● [1]	● [1]	● [1]	–	–	–	–	–	●	● [1]	● [1]	● [1]	–	–
68	Power-swing blocking	$\Delta Z/\Delta t$	●	●	●	●	●	●	●	■	■	–	–	–	●	–	–	–	–	–
74TC	Trip-circuit supervision	TCS	■	■	■	■	■	■	■	■	■	–	■	■	■	■	■	■	–	■
78	Out-of-step protection	$\Delta Z/\Delta t$	●	●	●	●	●	●	●	–	–	–	–	–	●	–	–	–	–	–
79	Automatic reclosing	AR	●	●	●	●	●	●	●	●	●	–	●	●	●	●	●	●	–	–
81	Frequency protection	$f<$, $f>$	●	●	●	●	●	●	●	–	–	–	●	●	●	●	●	●	–	–
81R	Rate of change of frequency	df/dt	–	–	–	–	–	–	–	–	–	–	●	–	–	–	–	–	–	–
	Vector-jump protection	$\Delta\varphi_U>$	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
81LR	Load restoration	LR	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
85	Teleprotection		■	■	■	■	■	■	■	●	●	■	■	■	■	–	–	–	●	■
86	Lockout		■	■	■	■	■	■	■	■	■	–	■	■	■	■	■	■	–	■
87	Differential protection	ΔI	–	–	–	–	–	–	–	–	–	■	■	■	■	■	■	■	■	■
87N	Differential ground-fault protection	ΔI_N	–	–	–	–	–	–	–	–	–	■	■	●	●	–	–	–	–	–
	Broken-wire detection for differential protection		–	–	–	–	–	–	–	–	–	–	–	■	■	■	■	■	–	–
90V	Automatic Voltage Control		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PMU	Synchrophasor measurement	PMU	–	–	–	–	●	●	●	–	–	–	–	–	–	●	●	●	–	–

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

Further functions next page

Combined line differential and distance protection		High impedance protection			Overcurrent and feeder protection/ feeder automation																
SIPROTEC 5		Reyrolle			SIPROTEC easy		SIPROTEC 600er		SIPROTEC Compact			SIPROTEC 4				SIPROTEC 5		Reyrolle			
7SL86	7SL87	7SR23 [1]	7PG23	7SG12	7SJ45	7SJ46	7SJ600	7SJ602	7SJ80	7SJ81	7SC80	7SJ61	7SJ62	7SJ63	7SJ64	7SJ85 [1]	7SJ86	7SR11	7SR12	7SR210	7SR220	7SR224
■	■	–	–	–	–	–	–	–	●	●	●	–	●	■ 2)	●	■ 2)	■ 2)	–	–	–	–	–
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■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

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Device applications			Distance protection									Line differential protection								
		Device series	SIPROTEC 4				SIPROTEC 5			Reyrolle		SIPROTEC 600er	SIPROTEC Compact	SIPROTEC 4		SIPROTEC 5			Reyrolle	
ANSI	Function	Abbr.	7SA522	7SA61	7SA63	7SA64	7SA84	7SA86	7SA87	7SG163	7SG164	7SD60	7SD80	7SD610	7SD5	7SD84	7SD86	7SD87	7PG2111	7SG18
	Further functions																			
	Measured values		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■
	Switching-statistic counters		■	■	■	■	■	■	■	■	■	–	■	■	■	■	■	■	–	■
	Logic editor		■	■	■	■	■	■	■	–	–	–	■	■	■	■	■	■	–	–
	Inrush-current detection		–	–	–	–	■	■	■	–	–	●	■	■	■	■	■	■	–	–
	External trip initiation		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■
	Control		■	■	■	■	■	■	■	■	■	–	■	■	■	■	■	■	–	■
	Fault recording of analog and binary signals		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■
	Extended fault recording		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Fast-scan recorder		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Slow-scan recorder		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Continuous recorder		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Power quality recorder (class S)		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	GOOSE recorder		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Sequence-of-events recorder		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Extended trigger functions		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Monitoring and supervision		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■
	Protection interface, serial		●	●	●	●	●	●	●	■	■	–	■	■	■	■	■	■	–	■
	No. Setting groups		4	4	4	4	8	8	8	8	8	–	4	4	4	8	8	8	–	8

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

Combined line differential and distance protection		High impedance protection			Overcurrent and feeder protection/ feeder automation																	
SIPROTEC 5		Reyrolle			SIPROTEC easy		SIPROTEC 600er		SIPROTEC Compact			SIPROTEC 4				SIPROTEC 5		Reyrolle				
7SL86	7SL87	7SR23 1)	7PG23	7SG12	7SJ45	7SJ46	7SJ600	7SJ602	7SJ80	7SJ81	7SC80	7SJ61	7SJ62	7SJ63	7SJ64	7SJ85 1)	7SJ86	7SR11	7SR12	7SR210	7SR220	7SR224
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8	8	8	–	8	1	1	1	1	4	4	4	4	4	4	4	8	8	4	4	8	8	8

■ = basic ● = optional (aditional price) – = not available 1) in preparation 2) via CFC

Device applications			Generator and motor protection						Bay controller				
Device series			SIPROTEC Compact		SIPROTEC 5	SIPROTEC 4		Reyrolle	SIPROTEC 4			SIPROTEC 5	
ANSI	Function	Abbr.	7SK80	7SK81	7SK85 [1]	7UM61	7UM62	7SG17	6MD61	6MD63	6MD66	6MD85	6MD86
	Protection functions for 3-pole tripping	3-pole	■	■	■	■	■	■	–	–	–	●	●
	Protection functions for 1-pole tripping	1-pole	–	–	–	–	–	–	–	–	–	–	–
14	Locked rotor protection	$I> + V<$	■	■	–	●	●	■	–	–	–	–	–
21	Distance protection	$Z<$	–	–	–	–	●	–	–	–	–	–	–
FL	Fault locator	FL	–	–	●	–	–	–	–	–	–	–	–
24	Overexcitation protection	V/f	–	–	–	■	■	–	–	–	–	–	–
25	Synchrocheck, synchronizing function	Sync	–	–	●	–	–	–	–	–	●	●	■
27	Undervoltage protection	$V<$	●	●	●	■	■	–	–	–	–	● [1]	● [1]
27TN/59TN	Stator ground fault 3rd harmonics	$V0<, > _{(3rd\ harm.)}$	–	–	–	–	●	–	–	–	–	–	–
32	Directional power supervision	$P>, P<$	●	●	●	■	■	–	–	–	–	● [1]	● [1]
37	Undercurrent, underpower	$I<, P<$	■	■	●	●	●	■	–	–	–	–	–
38	Temperature supervision	$\Theta>$	■	■	●	●	●	●	–	–	–	–	–
40	Underexcitation protection	$1/X_D$	–	–	–	●	●	–	–	–	–	–	–
46	Unbalanced-load protection	$I2>$	■	■	■	●	●	■	–	–	–	●	●
46	Negative-sequence system overcurrent	$I2>, I2/I1>$	■	■	■	■	■	■	–	–	–	●	●
47	Phase-sequence-voltage supervision	LA, LB, LC	●	●	■	■	■	–	–	–	–	–	–
48	Start-time supervision	I^2_{start}	■	■	■	●	●	■	–	–	–	–	–
49	Thermal overload protection	θ, I^2t	■	■	■	■	■	■	–	–	–	■	■
50/50N	Definite time-overcurrent protection	$I>$	■	■	■	■	■	■	–	–	–	●	●
50Ns	Sensitive ground-current protection	$I_{Ns}>$	●	●	●	■	■	–	–	–	–	–	–
50Ns	Intermittent ground fault protection	lie	■ [1]	–	–	–	–	–	–	–	–	–	–
50L	Load-jam protection	$I>_L$	■	■	■	–	–	■	–	–	–	–	–
50BF	Circuit-breaker failure protection	CBFP	■	■	●	●	■	■	–	–	●	–	●
51 /51N	Inverse time-overcurrent protection	I_P, I_{Np}	■	■	■	■	■	–	–	–	–	●	●
51V	Overcurrent protection, voltage controlled	$t=f(I)+V<$	● [1]	–	–	■	■	–	–	–	–	–	–

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

More functions next page

Busbar protection		Transformer protection								Breaker management		Synchronizing		Voltage and frequency protection				Fault recorder
SIPROTEC 600er	SIPROTEC 4	SIPROTEC 4			SIPROTEC 5			Reyrolle		SIPROTEC 4	SIPROTEC 5	SIPROTEC 4	Reyrolle	SIPROTEC 600er	SIPROTEC Compact	Reyrolle		SIPROTEC 5
7SS60	7SS52	7UT612	7UT613	7UT63	7UT85 [1]	7UT86 [1]	7UT87 [1]	7SG14	7SR24	7VK61	7VK87	7VE6	7SG117	7RW60	7RW80	7SG118	7SG15	7KE85 [1]
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■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

Device applications			Generator and motor protection						Bay controller				
Device series			SIPROTEC Compact		SIPROTEC 5	SIPROTEC 4		Reyrolle	SIPROTEC 4			SIPROTEC 5	
ANSI	Function	Abbr.	7SK80	7SK81	7SK85 [1]	7UM61	7UM62	7SG17	6MD61	6MD63	6MD66	6MD85	6MD86
55	Power factor	cos φ	●	●	■ [2]	●	●	–	–	–	–	–	–
59	Overvoltage protection	$V>$	●	●	●	■	■	–	–	–	–	●	●
59R, 27R	Rate-of-voltage-change protection	dV/dt	● [1]	–	–	–	–	–	–	–	–	–	–
64	Sensitive ground-fault protection (machine)		–	–	–	■	■	–	–	–	–	–	–
66	Restart inhibit	I^2t	■	■	■	●	●	–	–	–	–	–	–
67	Directional time-overcurrent protection, phase	$I>$, $I_P \angle (V, I)$	–	–	●	■	■	–	–	–	–	–	–
67N	Directional time-overcurrent protection for ground-faults	$I_N>$, $I_{NP} \angle (V, I)$	●	●	●	■	■	–	–	–	–	–	–
67Ns	Sensitive ground-fault detection for systems with resonant or isolated neutral	$I_N>$, $\angle (V, I)$	●	●	●	■	■	–	–	–	–	–	–
68	Power-swing blocking	$\Delta Z/\Delta t$	–	–	–	–	●	–	–	–	–	–	–
74TC	Trip-circuit supervision	TCS	■	■	■	■	■	■	–	–	–	■	■
78	Out-of-step protection	$\Delta Z/\Delta t$	–	–	–	–	●	–	–	–	–	–	–
79	Automatic reclosing	AR	–	–	●	–	–	–	–	–	●	–	●
81	Frequency protection	$f<$, $f>$	●	●	●	■	■	–	–	–	–	●	●
81R	Rate of change of frequency	df/dt	●	●	–	■	■	–	–	–	–	–	–
	Vector-jump protection	$\Delta\varphi_U>$	–	–	–	●	●	–	–	–	–	–	–
81LR	Load restoration	LR	–	–	–	–	–	–	–	–	–	–	–
85	Teleprotection		–	–	–	–	–	–	–	–	–	–	–
86	Lockout		■	■	■	■	■	■	–	–	–	–	–
87	Differential protection	ΔI	–	–	–	–	■	–	–	–	–	–	–
87N	Differential ground-fault protection	ΔI_N	–	–	–	●	●	–	–	–	–	–	–
	Broken-wire detection for differential protection		–	–	–	–	–	–	–	–	–	–	–
90V	Automatic Voltage Control		–	–	–	–	–	–	–	–	–	–	–
PMU	Synchrophasor measurement	PMU	–	–	●	–	–		–	–	–	●	●

■ = basic ● = optional (aditional price) – = not available

[1] in preparation [2] via CFC

Further functions next page

Busbar protection		Transformer protection								Breaker management		Synchronizing		Voltage and frequency protection				Fault recorder
SIPROTEC 600er	SIPROTEC 4	SIPROTEC 4			SIPROTEC 5			Reyrolle		SIPROTEC 4	SIPROTEC 5	SIPROTEC 4	Reyrolle	SIPROTEC 600er	SIPROTEC Compact	Reyrolle		SIPROTEC 5
7SS60	7SS52	7UT612	7UT613	7UT63	7UT85 [1]	7UT86 [1]	7UT87 [1]	7SG14	7SR24	7VK61	7VK87	7VE6	7SG117	7RW60	7RW80	7SG118	7SG15	7KE85 [1]
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■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

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Device applications			Generator and motor protection						Bay controller				
		Device series	SIPROTEC Compact		SIPROTEC 5	SIPROTEC 4		Reyrolle	SIPROTEC 4			SIPROTEC 5	
ANSI	Function	Abbr.	7SK80	7SK81	7SK85 [1]	7UM61	7UM62	7SG17	6MD61	6MD63	6MD66	6MD85	6MD86
	Further functions												
	Measured values		■	■	■	■	■	■	●	■	■	■	■
	Switching-statistic counters		■	■	■	■	■	■	■	■	■	■	■
	Logic editor		■	■	■	■	■	–	–	■	■	■	■
	Inrush-current detection		■	■	■	–	●	–	–	–	–	●	●
	External trip initiation		■	■	■	■	■	–	–	–	–	–	–
	Control		■	■	■	■	■	–	■	■	■	■	■
	Fault recording of analog and binary signals		■	■	■	■	■	■	–	–	●	■	■
	Extended fault recording		–	–	–	–	–	–	–	–	–	–	–
	Fast-scan recorder		–	–	–	–	–	–	–	–	–	–	–
	Slow-scan recorder		–	–	–	–	–	–	–	–	–	–	–
	Continuous recorder		–	–	–	–	–	–	–	–	–	–	–
	Power quality recorder (class S)		–	–	–	–	–	–	–	–	–	–	–
	GOOSE recorder		–	–	–	–	–	–	–	–	–	–	–
	Sequence-of-events recorder		–	–	–	–	–	–	–	–	–	–	–
	Extended trigger functions		–	–	–	–	–	–	–	–	–	–	–
	Monitoring and supervision		■	■	■	■	■	■	■	■	■	■	■
	Protection interface, serial		–	–	●	–	–	■	–	–	–	● [1]	● [1]
	No. Setting groups		4	4	8	2	2	8	4	4	4	8	8

■ = basic ● = optional (aditional price) – = not available [1] in preparation [2] via CFC

Busbar protection		Transformer protection								Breaker management		Synchronizing		Voltage and frequency protection				Fault recorder
SIPROTEC 600er	SIPROTEC 4	SIPROTEC 4			SIPROTEC 5			Reyrolle		SIPROTEC 4	SIPROTEC 5	SIPROTEC 4	Reyrolle	SIPROTEC 600er	SIPROTEC Compact	Reyrolle		SIPROTEC 5
7SS60	7SS52	7UT612	7UT613	7UT63	7UT85 [1]	7UT86 [1]	7UT87 [1]	7SG14	7SR24	7VK61	7VK87	7VE6	7SG117	7RW60	7RW80	7SG118	7SG15	7KE85 [1]
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–
–	–	■	■	■	■	■	■	■	■	■	■	■	■	–	■	■	■	–
–	■	■	■	■	■	■	■	–	■	■	■	■	–	–	■	–	–	–
–	–	■	■	■	■	■	■	■	■	–	■	–	–	–	–	–	–	–
–	■	■	■	■	■	■	■	■	■	■	■	●	■	●	■	■	–	–
–	–	■	■	■	■	■	■	■	■	■	■	■	■	–	■	■	■	–
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■
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–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	● 1)
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	● 1)
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	● 1)
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	●
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–
–	–	–	–	–	■	■	■	■	■	–	●	–	■	–	–	■	■	–
1	1	4	4	4	8	8	8	8	8	4	8	4	8	1	4	8	8	–

■ = basic ● = optional (aditional price) – = not available 1) in preparation 2) via CFC

6.3 Substation Automation

6.3.1 Introduction

In the past, the operation and monitoring of energy automation and substation equipment was expensive, as it required staff on site. Modern station automation solutions enable the remote monitoring and control of all assets based on a consistent communication platform that integrates all elements from bay level all the way to the control center. Siemens substation automation products can be precisely customized to meet user requirements for utilities, as well as for industrial plants and bulk consumers. A variety of services from analysis to the operation of an entire system round out Siemens's range of supply, and ensure complete asset monitoring. By acquiring and transmitting all relevant data and information, substation automation and telecontrol technologies from Siemens are the key to stable grid operation. New applications, such as online monitoring, can easily be integrated in existing IT architectures. This is how Siemens enables provident asset management, and makes it possible to have all equipment optimally automated throughout its entire life cycle.

6.3.2 Overview and Solutions

During the last years, the influences on the business of the power supply companies have changed a lot. The approach to power grid operation has changed from a static quasi-stable interpretation to a dynamic operational management of the electric power grid. Enhanced requirements regarding the economy of lifetime for all assets in the grid are gaining importance.

As a result, the significance of automation systems has increased a lot, and the requirements for control, protection and remote control have undergone severe changes of paradigm:

- Flexible and tailor-made solutions for manifold applications
- Secure and reliable operation management
- Cost-effective investment and economic operation
- Efficient project management
- Long-term concepts, future-proof and open for new requirements

Siemens energy automation solutions offer an answer to all current issues of today's utilities. Based on a versatile product portfolio and many years of experience, Siemens plans and delivers solutions for all voltage levels and all kinds of substations (fig. 6.3-1).

Siemens energy automation solutions are available both for refurbishment and new turnkey substations, and can be used in classic centralized or distributed concepts. All automation functions can be performed where they are needed.

Flexible and tailor-made solutions for manifold applications
Siemens energy automation solutions offer a variety of standardized default configurations and functions for many typical tasks. Whereas these defaults facilitate the use of the flexible products, they are open for more sophisticated and tailor-made applications. Acquisition of all kinds of data, calculation and automation functions, as well as versatile communication can be combined in a very flexible way to form specific solutions, and fit into the existing surrounding system environment.

The classical interface to the primary equipment is centralized with many parallel cables sorted by a marshalling rack. In such an environment, central protection panels and centralized RTUs are standard. Data interfaces can make use of high density I/O – elements in the rack, or of intelligent terminal modules, which are even available with DC 220 V for digital inputs and direct CT/VT interfaces.

Fig. 6.3-1: **Siemens energy automation products**

Even in such configurations, the user can benefit from full automation and communication capabilities. This means that classical RTU solution, interfaces to other IEDs are included, and HMIs for station operation and supervision can be added as an option. Also, the protection relays are connected to the RTU, so that data from the relays are available both at the station operation terminal and in the control centers.

All members of the SICAM AK, TM, BC, EMIC and MIC family can be equipped with different combinations of communication, both serial and Ethernet (TCP/IP). Different protocols are available, mainly IEC standards, e.g., IEC 60870-5-101/103/104 IEC 61850, IEC 62056-21, but also a lot of other well-known protocols from different vendors.

Fig. 6.3-2 shows an example of refurbishment and centralized data acquisition in an MV substation. The interface to the primary equipment is connected via a marshalling rack, but can use any peripheral voltage (DC 24–220 V). The electronic terminal blocks are designed to substitute conventional terminal blocks, thereby realizing a very economic design. Existing protection relays can be connected either by IEC 60870-5-103 or by the more enhanced IEC 61850.

In new substations, the amount of cabling can be reduced by decentralizing the automation system. Both protection relays and bay controllers are situated as near as possible to the primary switchgear. Typically they are located in relay houses (EHV) or in control cabinets directly beneath HV GIS feeders. The rugged design with maximum EMC provides high security and availability.

For station control, two different products are available: SICAM PAS is a software-oriented product based on standard industrial hardware, whereas SICAM AK, TM, BC, EMIC and MIC represents the modular hardware-oriented design which bridges the gap between remote terminal units (RTUs) and substation automation (SA) (fig. 6.3-3).

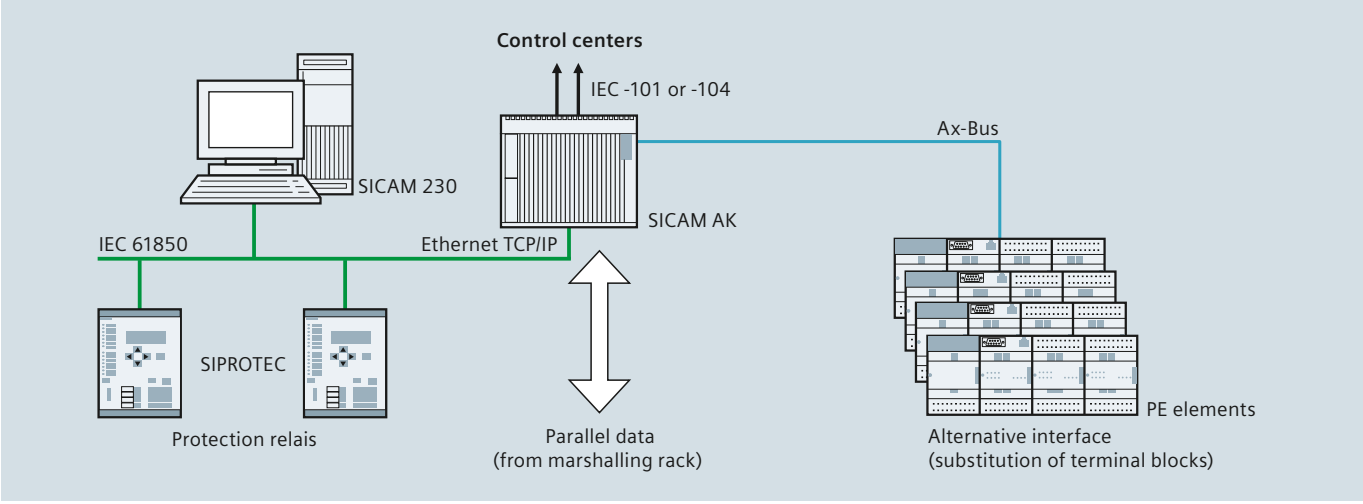


Fig. 6.3-2: **Example of refurbishment and centralized data acquisition in an MV substation**

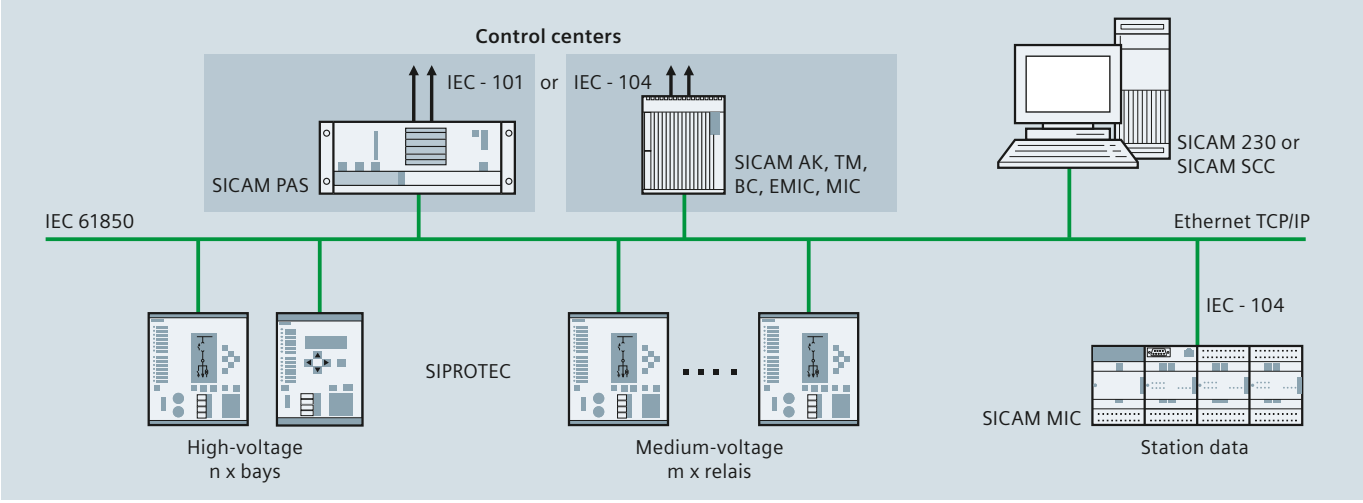


Fig. 6.3-3: **Basic principle of a SICAM station automation solution with alternative station controllers**

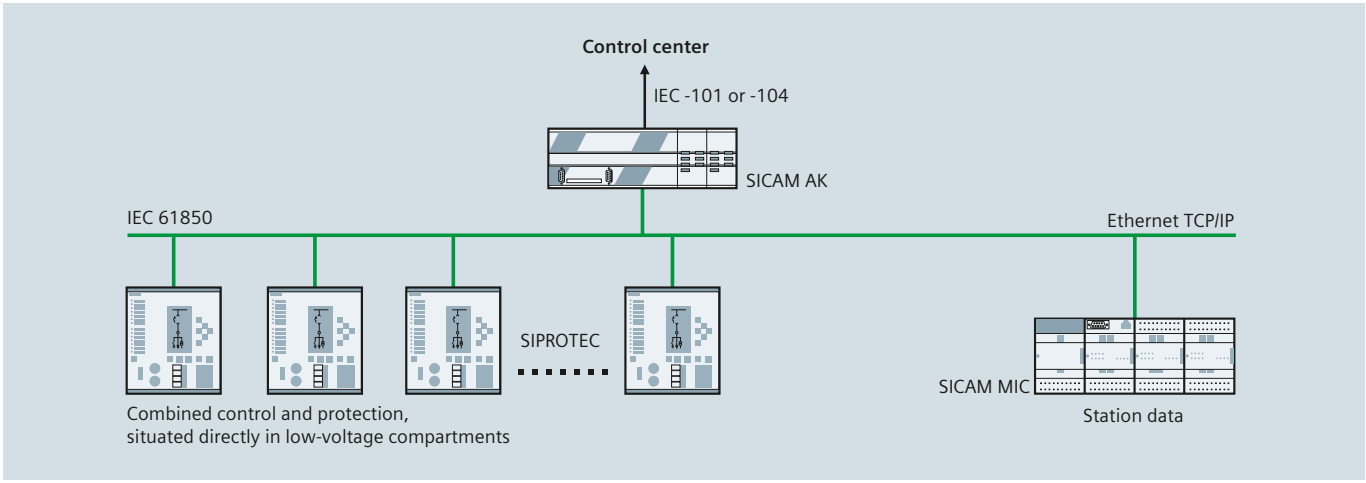


Fig. 6.3-4: **Combined control and protection, situated directly in low-voltage compartments**

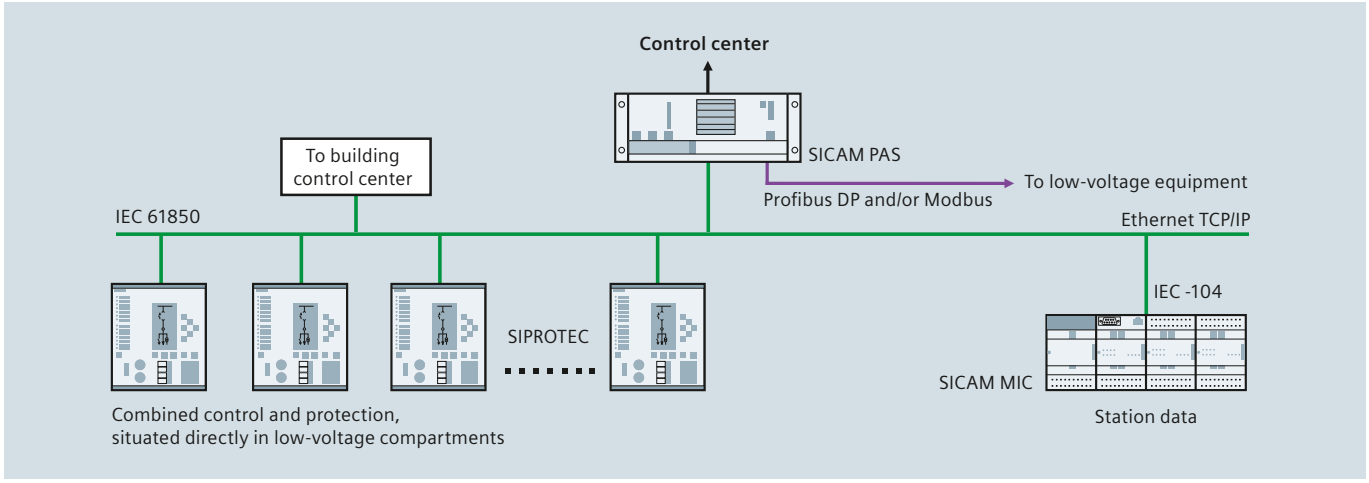


Fig. 6.3-5: **Example of a distribution substation in industry supply**

The flexible Siemens solutions are available for every kind of substation:

- For different voltage levels, from ring main unit to transmission substation
- For new substations or refurbishment
- For gas-insulated or air-insulated switchgear
- For indoor or outdoor design
- For manned or unmanned substations

Communication is the backbone of every automation system. Therefore, Siemens solutions are designed to collect the data from the high-voltage equipment and present them to the different users: the right information for the right users at the right place and time with the required quality and security.

Here are some default examples for typical configurations. They are like elements which can be combined according to the respective requirements. The products, which are the bricks of the configurations, are an integral part of the harmonized system behavior, and support according to the principle of single-point data input. This means that multiple data input is avoided. Even if different engineering tools are necessary for certain configurations, these tools exchange their data for more efficient engineering.

Example of a small medium-voltage substation: Typically it consists of 4 to 16 MV feeders and is unmanned. In most cases, combined bay control and protection devices are located directly in the low-voltage compartments of the switchgear panels.

A station operation terminal is usually not required, because such substations are normally remote-controlled, and in case of local service / maintenance they are easy to control at the front side of the switchgear panels (fig. 6.3-4).

Example of a distribution substation in industry supply: In principle they are similar to the configuration above, but they are often connected to a control center via local area network (LAN). A distinctive feature is the interface to low-voltage distribution boards and sometimes even to the industrial auto-

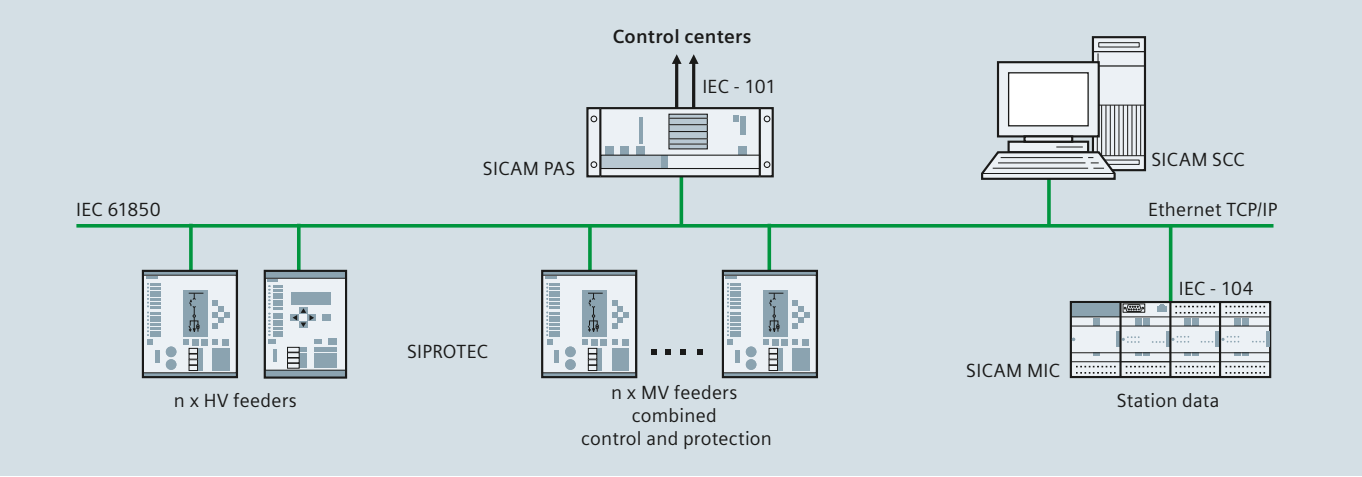


Fig. 6.3-6: **Example for subtransmission**

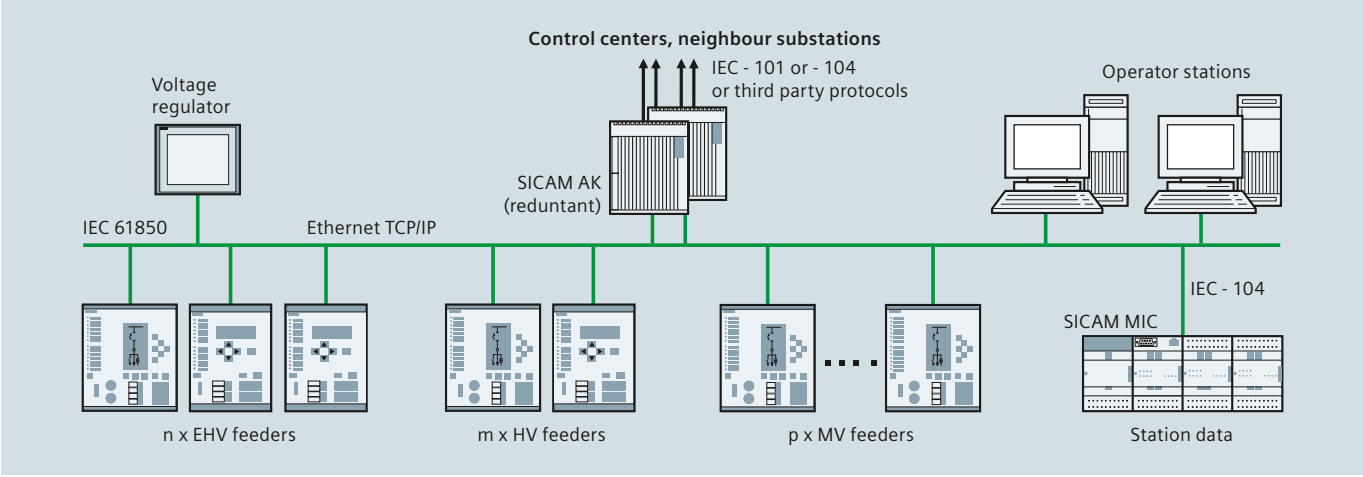


Fig. 6.3-7: **Example for a transmission substation**

mation system for data exchange. Here, the compatibility with SIMATIC products simplifies system integration (fig. 6.3-5).

A subtransmission substation requires even more complexity: 2 or 3 voltage levels have to be equipped; a station operation terminal is usually required; more communication interfaces to external locations, separated control and protection devices on HV level, powerful LAN based on IEC 61850, and remote maintenance access are typical features of such applications (fig. 6.3-6).

In transmission substations, typically two to four voltage levels are to be automated. According to the high importance of such substations, availability is of the highest priority. Therefore, redundancy at substation level is generally required, both for station control units and station operation. Multiple operator stations are often required, multiple communication links to different control centers or neighboring substations are standard. Although most standard applications are IEC protocols, specific protocols also have to be offered for interfacing existing third-party devices. Complex automation functions support the operation and maintenance of such substations, such as voltage regulation by controlling on-load tap changers, synchrocheck, automatic command sequences, etc. (fig. 6.3-7).

The devices are as flexible as the configurations: Bay controllers, protection relays, station control units, station operation units and RTUs can be configured from small to very large. The well-known products of the SICAM and SIPROTEC series are a well proven base for the Siemens solutions.

Secure and reliable operation

Siemens solutions provide human machine interfaces (HMI) for every control level and support the operators with reliable information and secure, easy-to-use control features.

At feeder level:

- Conventional panels with pushbuttons and instruments for refurbishment
- Electronic front panels combined with bay control units (default)

- Access points for remote terminals connected to the station operation units
- Portable touch panels with wireless access in defined areas

At substation level:
- Single or redundant HMI
- Distributed server / client architectures with multiple and / or remote terminals
- Interface to office automation

All images and pictures of the HMIs are designed according to ergonomic requirements, so as to give the operators clear information that is easy to use. Control commands are only accepted if access rights are met, the local / remote switches are in the right position and the multi-step command sequence is actively handled. Care is taken that only commands which are intended and explicitly given are processed and sent to the switchgear.

Automation functions support operation:
- Interlocking
- Feeder or remote blocking (option)
- Command sequences (option)
- Automatic recloser (option)
- Automatic switchover (option)
- etc.

All images and pictures of the HMI are organized hierarchically and, for easy access, they guide the user to the required information and to fast alarm recognition. In addition, alarm and event logs, measurement curves, fault records, archives and flexible reports support the analysis of any situation in the power grid (fig. 6.3-8).

For security reasons only specially authorized personnel is granted access to operation and engineering tools. Flexible access rights are defined for operators, design engineers and service personnel, and differentiate between engineering access and operation rights.

Security of data transmission is catered for by secure protocols and secure network design. Especially, easy remote access to substations creates the need for such complex measures. The experienced Siemens engineers provide all the necessary knowledge for network security concepts.

Cost-effective investment and economic operation
The customized solutions from Siemens cater for effective investment. Tailor-made configurations and functions make sure that only required items are offered. The efficient tools cater for fast and easy engineering and support all project phases of an automation system, from collection of the substation data to deployment of all needed functions, and finally to reporting and archiving. The long lifetime of the involved future-proof products extend the time period between investments into automation systems.

Siemens solutions ensure low cost of ownership, thus taking into account all costs during lifetime. The automation systems are maintenance free and easy to expand at a later date. Last but not least, the powerful services for remote maintenance (diagnosis, settings, updates, test, etc.) provide a very economic way to keep any substation up-to-date and running.

Simple handling of the solutions is provided by:

- Same look and feel of all HMI on different levels.
- Vertical and horizontal interoperability of the involved products.
- Plug and play for spare parts by simple exchange of flash cards.

Reduction of engineering effort by
- Seamless data management, only single data input for whole project.
- Easy up and downloads, even remote.
- Integrated test tools.

Reduction of service expenses during lifetime by
- Integrated self-supervision in all components
- Powerful diagnosis in clear text
- Remote access for diagnosis, settings, test, expansions, etc.

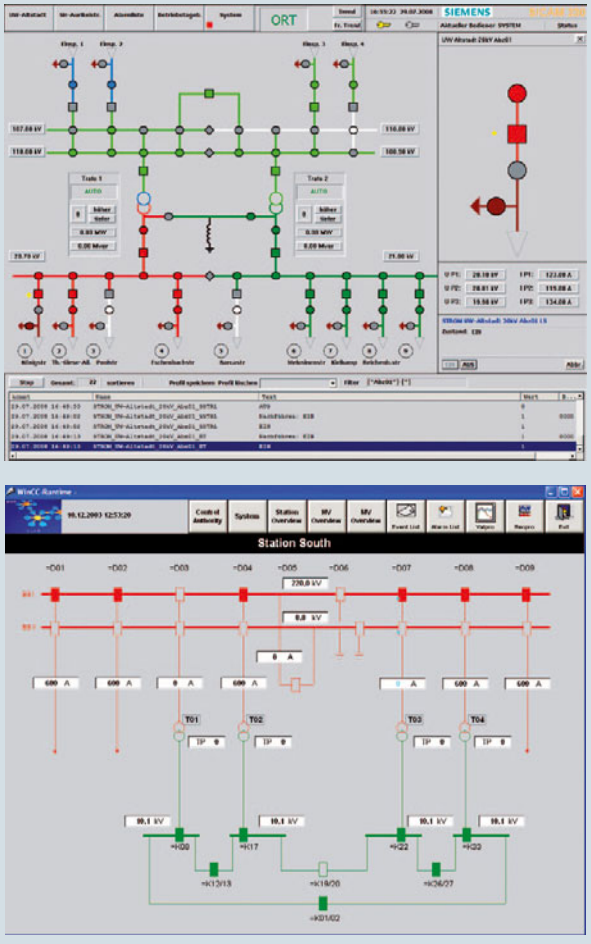


Fig. 6.3-8: **Human machine interface for every control level**

Reduction of complexity by seamless communication
- Worldwide standard IEC 61850 promoted by Siemens
- Integrated IT security concepts
- Latest technology integrated

Efficient and state-of-the-art projects

The solutions for energy automation are part of the extensive programme, "Siemens One". This means that energy automation solutions are integrated in different applications of the vast activity and expertise of Siemens:
- Power grids in transmission and distribution
- Complete building automation
- Solutions for pipelines and infrastructure
- Turnkey railway systems

They all make use of the energy automation solutions and the associated transfer of expertise for efficient project and order execution. Our worldwide engineering centers are always close to the system operators (fig. 6.3-9).

Long-term stability and trendsetting features for new requirements

With Siemens energy automation systems every user benefits from more than 70 years of experience in remote control and substation automation. The energy automation systems are designed for a long lifetime. Innovation is based on existing products, and compatibility of different product generations is part of the Siemens development philosophy.

The extensive use of available IEC standards strongly supports long-term stability and expandability. Examples are communication protocols like IEC 61850 in the substation, IEC 61970 for control centers, and IEC 60870-5 for remote communication. They form the strong backbone for the seamless solutions in energy automation. Additionally, the systems are tested in rugged environmental conditions and certified according to applicable IEC standards.

Investments in our solutions are secured by the "evergreen concept", which defines migration methods when a new generation of products is introduced to the markets, e.g., the migration solution for SICAM LSA 678 from the early 90ies: By substituting the station control device with today's SICAM PAS, it is possible to retain the installed feeder devices and import the existing

Fig. 6.3-9: **The worldwide engineering centers of Siemens**

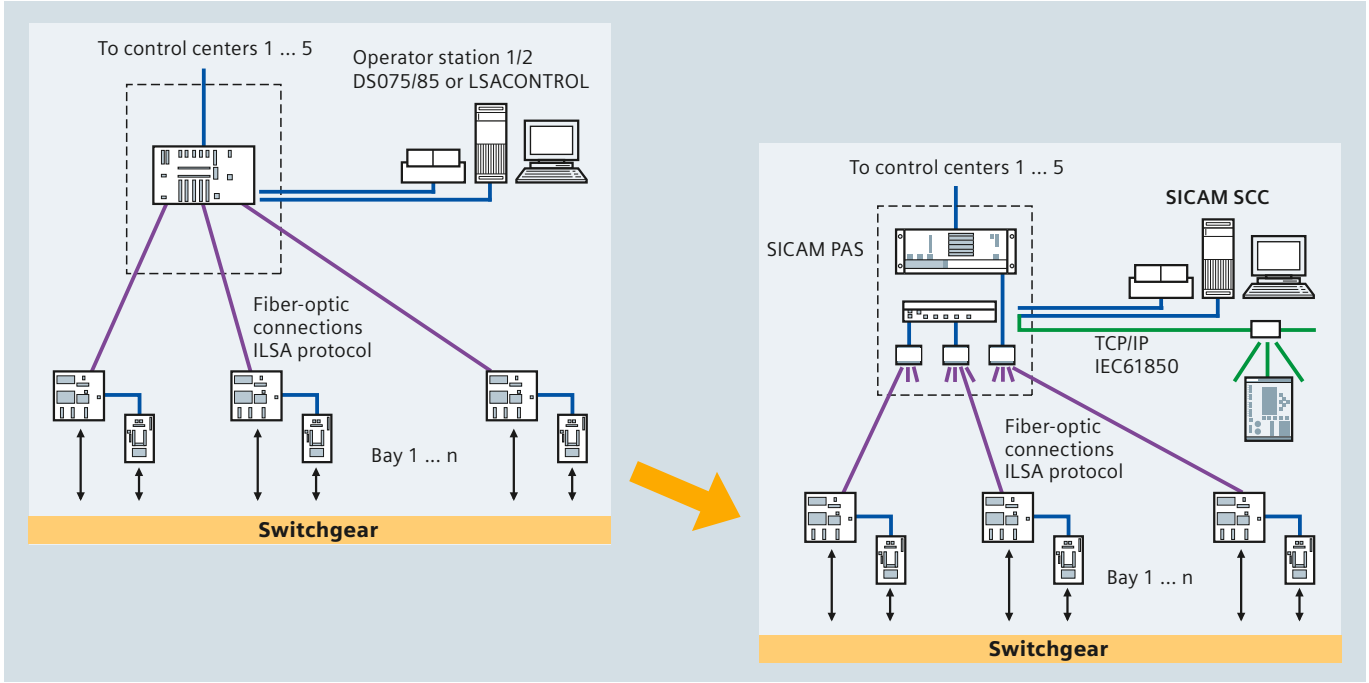


Fig. 6.3-10: **Migration from LSA to PAS**

database with the settings into the new tool SICAM PAS UI. This method reduces the refurbishment work significantly and adds new features to the system: In the next years the substation can be expanded with new feeder devices through the use of IEC 61850, even though some parts of the system might already be older than 15 years (fig. 6.3-10).

Our solutions are not only compatible with older devices, they are also very innovative. The Frost&Sullivan Technology Leadership Award 2006 was presented to Siemens for pioneering in the development of an innovative technology, the IEC 61850.

With Siemens energy automation solutions, every user is on the safe side: The combination of long-term experience and the newest innovation supplies safety for many years to come.

6.3.3 SICAM PAS

SICAM PAS (Power Automation System) meets all the demands placed on a distributed substation control system – both now and in the future. Amongst many other standardized communication protocols, SICAM PAS particularly supports the IEC 61850 standard for communication between substations and IEDs. SICAM PAS is an open system and – in addition to standardized data transfer processes – it features user interfaces for the integration of system-specific tasks and offers multiple automation options. SICAM PAS can thus be easily included in existing systems and used for system integration, too. With modern diagnostics, it optimally supports commissioning and maintenance. SICAM PAS is clearly structured and reliable, thanks to its open, fully documented and tested system (fig. 6.3-11).

System overview, application and functionality of SICAM PAS

- SICAM PAS is an energy automation solution; its system architecture makes it scalable.
- SICAM PAS is suitable for operating a substation not only from one single station level computer, but also in combination with further SICAM PAS or other station control units. Communication in this network is based on a powerful Ethernet LAN.
- With its features and its modular expandability, SICAM PAS covers a broad range of applications and supports distributed system configurations. A distributed SICAM PAS system operates simultaneously on several computers.
- SICAM PAS can use existing hardware components and communication standards as well as their connections.
- SICAM PAS controls and registers the process data for all devices of a substation, within the scope of the data transfer protocols supported.
- SICAM PAS is a communication gateway. This is why only one single data connection to a higher-level system control center is required.
- SICAM PAS enables integration of a fully graphical process visualization system directly in the substation.
- SICAM PAS simplifies installation and parameterization of new devices, thanks to its intuitive user interface.
- SICAM PAS is notable for its online parameter setting features, particularly when the system has to be expanded. There are no generation times; loading into a target system is not required at all or only required if configuration is performed on a separate engineering PC.
- SICAM PAS features integrated testing and diagnostic functions.
- Its user-friendliness, its operator control logic, its orientation to the Windows world and its open structure ideally suit users' requirements.
- SICAM PAS is developed in accordance with selected security standards and meets modern demands placed on safe communication.

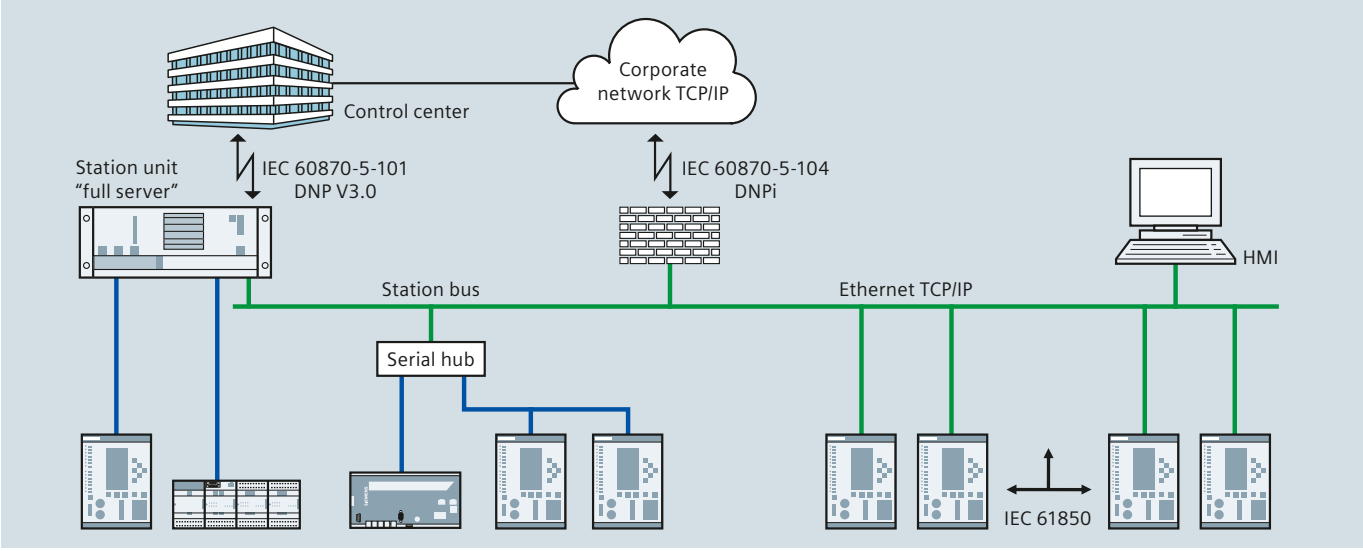


Fig. 6.3-11: **Typical SICAM PAS configuration; IEDs are connected to the station unit with IEC 61850 and various other protocols (IEC 60870-5-103,DNPV3.00, etc.). The station unit communicates with the higher-level system control center by means of IEC 60870-5-101 and / or 104**

System architecture
SICAM PAS works on industrial-standard hardware with the Microsoft Windows operating systems. The advantages of this platform are low hardware and software costs, ease of operation, scalability, flexibility and constantly available support. With the powerful real-time data distribution system, applications can be allocated among several computers, thus boosting performance, connectivity and availability.

A database system stores and organizes the data basis (e.g. configuration data, administrative status data, etc.). The device master function for communication with Intelligent Electronic Devices (IEDs) supports a large number of well-established protocols.

The SICAM PAS data normalization function allows conversions such as measured-value filtering, threshold value calculation and linear characteristics.

SICAM SCC is used for process visualization. Specifically designed for energy applications, it assists the operating personnel in optimizing the operations management. It provides a quick introduction to the subject matter and a clearly arranged display of the system's operating states. SICAM SCC is based on SIMATIC WinCC, one of the leading process visualization processes that is used in industrial automation worldwide.

To facilitate incident analysis, the fault recordings from protection relays are retrieved and archived automatically during operation. This is particularly supported for the standard protocols IEC 61850 and IEC 60870-5-103, but also for PROFIBUS FMS (SIPROTEC 4) and SINAUT LSAS ILSA. Furthermore, SIMEAS R fault recorders can also be connected to the system, and their detailed fault recordings can be retrieved and archived as well.

To manage the fault recording archive, the program SICAM PQ Analyzer with its program part Incident Explorer is used. Fault recordings are visualized and evaluated with the program Comtrade View as standard. Alternatively, SIGRA 4 with its additional functions can also be used.

Communication
Device interfaces and communication protocols
In a substation configured and operated with SICAM PAS, various types of protection relays, IEDs, bay control units, measured-value recorders and telecontrol units from a wide range of manufacturers can be used. SICAM PAS offers a large number of commercially available communication protocols for recording data from various devices and through differing communication channels. Subsequent expansion is easy.

Fig. 6.3-12: **SIPROTEC 4 bay controllers and protection devices**

Fig. 6.3-13: **SIPROTEC 4 bay controllers with local control**

Protocols
SICAM PAS supports the following communication protocols (optionally available):
- Control center connection IEC 60870-5-101, IEC 60870-5-104, DNP V3.00, MODBUS, TG 8979, CDT
- Open data exchange OPC server, OPC XML DA server, OPC client
- IED and substation connection IEC 61850, IEC 60870-5-101, IEC 60870-5-103, IEC 60870-5-104, DNP V3.00, PROFIBUS FMS (SIPROTEC 4), PROFIBUS DP, MODBUS, SINAUT LSA-ILSA

Fig. 6.3-14: **Versatile communication with SICAM PAS**

Available protocols:
These communication protocols and device drivers can be obtained as optional additions to the standard scope of SICAM PAS.

- IEC 61850 (Client):
  IEC 61850 is the communication standard for interconnecting the devices at the feeder and station control levels on the basis of Ethernet. IEC 61850 supports the direct exchange of data between IEDs, thus enabling switching interlocks across feeders independently of the station control unit, for example.
- IEC 60870-5-103 (Master):
  Protection relays, IEDs, bay control units, measured value recorders and transformer controllers from many manufacturers support the IEC 60870-5-103 protocol and can therefore be connected directly to SICAM PAS.
- IEC 60870-5-101 (Master):
  The IEC 60870-5-101 protocol is generally used to connect telecontrol units. The "balanced" and "unbalanced" traffic modes are supported.
- Automatic dialing is also supported for the connection of substations with this protocol. SICAM PAS can establish the dial-up connection to the substation either cyclically or as required (e.g., for command output). By contrast, the substation can also establish a connection cyclically or in event-triggered mode.
- IEC 60870-5-104 (Master):
  Furthermore, connection of substations is also supported by the TCP/IP-based IEC 60870-5-104 protocol.
- DNP V3.0 (Master) – Level 3:
  Apart from the IEC protocols -101 and -104, DNP 3.0 is another standardized telecontrol protocol used by many IEDs and RTUs and applied worldwide. The units can be connected both serially and with TCP/IP (DNPi). TCP/IP-based communication can operate with an asymmetrical encryption procedure, thus meeting security requirements.
- PROFIBUS DP (Master):
  PROFIBUS DP is a highly powerful field bus protocol. For example, it is used for industrial automation and for automating the supply of electricity and gas. PROFIBUS DP serves to interface multifunctional measuring instruments such as SICAM P (I, V, P, Q, $p.f.$ ($cos\varphi$) or, for example, to connect ET200 components for gathering messages and for simple commands. Messages, for example, can be derived from the signaling contacts of fuse switch-disconnectors.
- MODBUS (Master)
  Besides PROFIBUS DP, the MODBUS protocol is also well-known in industrial applications. SICAM PAS allows to connect IEDs und RTUs with this protocol, both via serial and TCP/IPbased connections.
- PROFIBUS FMS (SIPROTEC 4)
  Most SIPROTEC 4 bay controllers and protection relays can be connected to the SICAM PAS station unit via PROFIBUS FMS.
- SINAUT LSA ILSA (Master)
  Communication via the SINAUT LSA ILSA protocol is a special advantage of SICAM PAS. Existing LSA central units can be replaced without changing the configuration on bay level.

System control center connections, distributed process connection and process visualization

- SICAM PAS operates on the basis of Microsoft Windows operating systems. This means that the extensive support which Windows offers for modern communication protocols is also available with SICAM PAS.
- SICAM PAS was conceived for easy and fast integration of conventional protocols. Please contact Siemens in case of questions about integration of user-specific protocols.
- For the purpose of linking up to higher-level system control centers, the standardized telecontrol protocols IEC 60870-5-101, IEC 60870-5-104 and DNP V3.00 (Level 3) serially and over IP (DNPi), as well as MODBUS (serially and over IP), TG 8979 (serially) and CDT (serially) are supported. Security or "safe communication" are gaining more and more importance. Asymmetric encryption enables tap-proof communication connection to higher-level control centers with IEC 60870-5-104 and DNP V3.00 via TCP/IP. For DNP V3.00, authentication can be used as an additional security mechanism.
- Distributed process connection in the substation is possible thanks to the SICAM PAS Device Interface Processor (DIP).
- SICAM PAS can also be set up on computers networked with TCP/IP. Here, one computer performs the task of the so-called "full server". Up to six other computers can be used as DIPs. With this architecture, the system can be adapted to the topological situation and its performance also boosted.
- SICAM PAS allows use of the SICAM SCC process visualization system for central process control and monitoring. For industrial applications, it is easy to configure an interface to process visualization systems via OPC (object linking and embedding for process control).
- SICAM PAS can be configured as an OPC server or as an OPC client. The SICAM PAS process variables – available with the OPC server – can be read and written with OPC clients working either on the same device or on one networked by TCP/IP. This mechanism enables, for example, communication with another process visualization system. The OPC server is included in the basic system. Optionally, this server functionality is also available as OPC XML DA for communication with clients based on other operating systems as well as beyond firewall limits. The OPC client can read and write data from other OPC servers. A typical application could be the connection of SIMATIC programmable controllers. The OPC client is available as an optional package.
- SICAM Diamond can be used to monitor the system interfaces, to indicate switching device states and up-to-date measured values, and also for further diagnostic purposes. Apart from these configuration-free diagnostic views, SICAM Diamond also supports message logging in event and alarm lists as well as process visualization in single-line diagrams, and can thus be used as a simple human-machine interface. Messages and measured values can be archived in files (monthly). On the one hand, SICAM Diamond consists of the Diamond Server, which is directly connected with SICAM PAS and prepares the data for access with a Web browser, and on the other hand, the SICAM Diamond Client as operator interface in the context of the Microsoft Internet Explorer. Except for the Microsoft Internet Explorer, no additional software has to be installed on

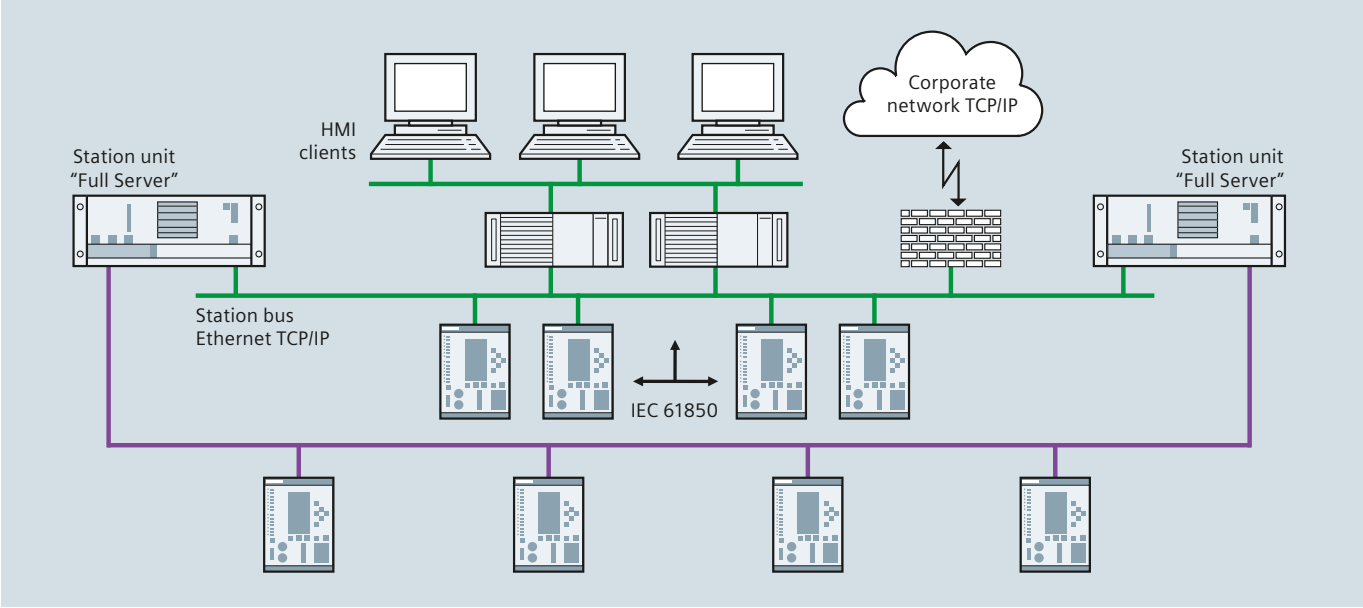


Fig. 6.3-15: **Typical redundant configuration: The station unit and the HMI server are based on a redundant structure to boost availiability**

the Web clients. SICAM Diamond allows access to archive files and fault recordings through the World Wide Web. The archive files can be saved on the Web client for evaluation, e.g. with Microsoft Excel. Fault recordings can be visualized directly in the Internet Explorer.

Further station control aspects

During, e.g., maintenance work or for other operational reasons, information exchange with the control centers or the substation itself can be blocked with the telecontrol blocking and bay blocking functions. The telecontrol blocking function can also be configured for specific channels so as to prevent the transfer of information to one particular control center during operation, while transfer continues with other control centers. The bay blocking and telecontrol blocking functions act in both the signaling and the command directions. Channel-specific switching authority also makes it possible to distinguish between local control (SICAM SCC) and remote control for the switching direction, but also between control center connections. For these three functions, information-specific exceptions can be declared additionally, so that, e.g., certain messages are transmitted despite an activated block, or special commands are processed and issued despite of a defined switching authority. While a 1-out-of-n check is normally effective in IEDs, i.e. only one command is accepted and issued at the same time, an m-out-of-n check is supported on the side of the substation control system with SICAM PAS. This helps to define how many commands can be processed at the same time for all IEDs. Circuit-breakers can be controlled in synchronized/unsynchronized mode.

Automation tasks

can be configured in SICAM PAS with the CFC (Continuous Function Chart), which conforms to IEC 61131. In this editor, tasks are configured graphically by wiring function blocks. SICAM PAS comes with an extensive library of CFC function blocks, developed and system-tested specially for energy automation.

Applications range from generation of simple group indications through switching interlocks to complex operating sequences. Creation of operating sequences is supported by the SFC Editor (Sequential Function Chart).

In this context, additionally pre-configured and system-tested applications such as frequency-based load shedding, transformer monitoring and SF6 gas monitoring can be optionally licensed. Besides special functional components and CFCs, the scope of supply also covers operating images for SICAM SCC.

Redundancy

SICAM PAS features comprehensive redundancy functions to boost the availability of the station automation system:

- The substation control unit can be used in a duplicate configuration ("system redundancy")
- The communication to IEDs and RTUs can be redundant ("interface redundancy")
- Subordinate units can be duplicated (redundancy at the bay control level)
- Subunits that are only designed for communication with one master (e.g., with only one serial interface) can be supported.

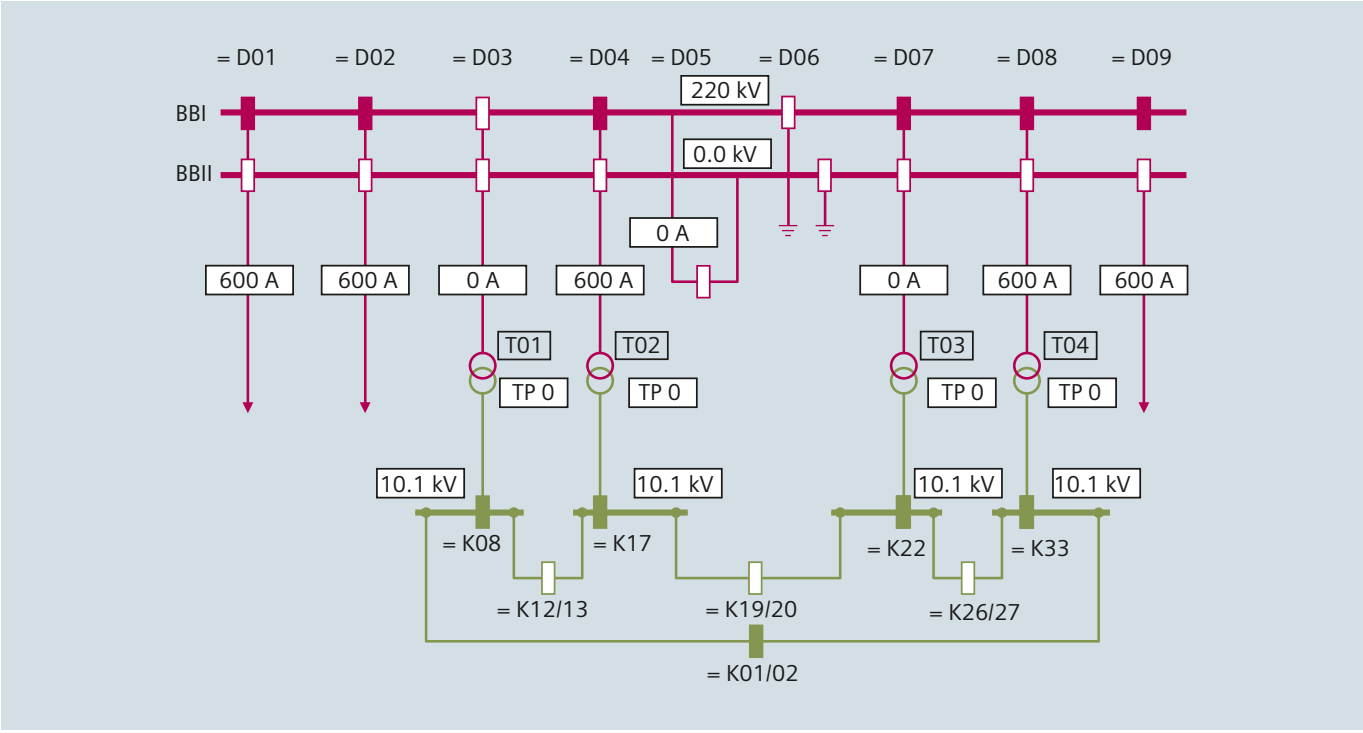


Fig. 6.3-16: **Process visualization with SICAM SCC**

6

The individual applications (communication protocols) operate independently of each other in a hot/standby connection, i.e. a changeover, e.g., of the IEC 61850 client from one station control unit to the other due to a disturbance has no effects on the communication connection to the control center, which remains on the first station control unit without interruption. Apart from a higher stability in unaffected communication connections, the redundancy changeover of affected components takes place within a very short time (depending on application and configuration, between 250 ms and max. 3 sec). Adjustments during operation such as bay/telecontrol blocking, switching authority, but also marking commands to the SoftPLC for operational control of the automation functions, are kept synchronous in both station control units during redundancy operation. The current adjustments are also valid after a redundancy changeover. SICAM SCC communicates simultaneously with both redundant station control units. A redundant structure is also possible for process visualization with SICAM SCC and fault-record archiving with SICAM PQ Analyzer as shown in fig. 6.3-15.

Scope of information

The amount of information to be processed by SICAM PAS is essentially determined by the following factors:

- Computer network concept (multiple-computer network or single-station system)
- Performance data of the hardware used
- Performance data of the network
- Size of the database (RDBMS)
- Rate of change of values

With a distributed PAS system using a full server and up to 6 DIPs, a maximum of 350 IEDs and 20,000 data points can be supported.

Process visualization with SICAM SCC

In the operation of a substation, SICAM PAS is used for configuration purposes and as a powerful data concentrator.
SICAM SCC serves as the process visualization system. Several independent SICAM SCC servers can be connected to one SICAM PAS. Connection of redundant servers is also possible. SICAM SCC supports the connection of several SICAM PAS systems. In the signal lists, the original time stamps are logged in ms resolution as they occur in the devices. With every signal, a series of additional data is also presented to provide information about causes (spontaneous, command), event sources (close range, local, remote), etc. Besides process signals, command signals are also logged. IndustrialX controls are used to control and monitor switchgear. These switching-device objects support four different forms of presentation (IEC, DIN, SINAUT LSA, SICAM) for circuit-breakers and disconnectors. It is also possible to create bitmaps (defined for a specific project) to represent switching devices, and to link them to the objects. For informative visualization, not only nominal and spontaneous flashing are supported, but also the display of various device and communication states (e.g., up-to-date / not up-to-date, feeder and telecontrol blocking, etc.). Measured values and switching device states that are not continuously updated due to, e.g., device or communication failure or feeder blocking, may be updated directly via the operation panel with SICAM SCC (fig. 6.3-16).

In conjunction with the SICAM PAS station unit, the switching devices can be controlled either directly or with "select before operate". When visualizing the process by single-line diagrams, topological coloring can be used. The WinCC add-on SIMATIC Web navigator can be used for control and monitoring via the Internet. SICAM Valpro can be used to evaluate measured and metered values. It not only allows a graphical and a tabular display of archived values, but also enables subsequent evaluation functions such as minimum, maximum and averages values (on an hourly or daily basis). For protection devices connected with the protocols IEC 61850, IEC 60870-5-103 as well as PROFIBUS FMS (SIPROTEC 4) or SINAUT LSA ILSA, fault recordings can be retrieved and archived automatically. SICAM PQ Analyzer with its component Incident Explorer is used for management and evaluation of the fault recordings.

SICAM SCC V7.0 SP1 can also be used as a process visualization system for

- SICAM AK, TM, BC, EMIC and MIC
- IEC 61850 devices (for example, SIPROTEC 4)

SICAM SCC for SICAM AK, TM, BC, EMIC and MIC
For communication with SICAM AK, TM, BC, EMIC and MIC, the protocol IEC 60870-5-104 or IEC 61850 can be used. Both SICAM TOOLBOX II V5.0 and SICAM SCC V7.0 SP1 support exchange of configuration data.

SICAM SCC for devices with communication standard IEC 61850
Devices communicating via IEC 61850 can be connected directly to SICAM SCC. For this usage, SCL files (SCD, ICD, CID) are imported. The files are created, for example, with the DIGSI 4 system configurator.

SICAM SCC for SICAM PAS, SICAM AK, TM, BC, EMIC and MIC and IEC 61850 devices
With SICAM SCC V7.0 SP1, a common control and monitoring system for the systems SICAM PAS, SICAM AK, TM, BC, EMIC and MIC and for IEC 61850 devices can be realized.

SICAM SCC is based on SIMATIC WinCC, which has advanced to become both the industrial standard and the market leader in Europe. It features:

- Multilingual capability
- All operation and monitoring functions on board. These include not only the graphics system for plant displays and the signaling and archiving system for alarms and measured values, but also a reporting and logging system. Further advantages are integrated user administration, along with the granting and checking of access rights for configuration and runtime operations.
- Easy and efficient configuration
  Configuration is assisted by dialogs, wizards and extensive libraries.
- Consistently scalable, even via the Web
  In conformity with requirements, the bandwidth ranges from small single-user stations up to client/server solutions with user stations on the Web as well as support of the server redundancy.
- WinCC/Redundancy – increases system availability by redundant WinCC stations or servers monitoring each other mutually, ensuring the operability of the system and enabling complete data acquisition.
- Open standards for easy integration
  - Using any external tools, archived data can be accessed through a series of open interfaces (such as SQL and ODBC) for further editing.
  - Manufacturer-independent communication with lower-level controllers (or with applications such as MS Excel) is supported with OPC (OLE for Process Control).
- Visual Basic for Applications (VBA), VBScript or ANSI-C create an ideal scope for project-specific solutions.
- Expandable with options and add-ons such as
  - WinCC/Dat@Monitor serves to display and evaluate current process states and historical data on office PCs, using standard tools such as the Microsoft Internet Explorer or Microsoft Excel
  - WinCC/Web Navigator is an option with SIMATIC WinCC for controlling and monitoring systems over the Internet, a company Intranet or a LAN
  - WINCC/Connectivity Pack
    The functions of the two OPC servers HDA and A&E, and of the WinCC OLE-DB provider, are ensured by the WinCC/ Connectivity Pack.
  - Alarm management system ACC
    With the aid of the alarm management system ACC, messages from the WinCC signaling system can be forwarded automatically to radio call receivers.

Overview of the operator control philosophy and user interface

The SICAM PAS user interface is based on customary Windows technology, which allows to navigate in the familiar Windows environment both when configuring the system and during ongoing operation. The system distinguishes between configuration and operation of a substation. In SICAM PAS, these two tasks are firmly separated by two independent programs.

The SICAM PAS UI – configuration program (fig. 6.3-17) is used to create and edit a project-specific configuration. To enhance clarity, four views are distinguished:

- Configuration
- Mapping
- System topology
- Device templates

A common feature of all views is that they have an Explorer window that shows the system configuration in a clearly arranged tree structure. As in the Windows Explorer, it is possible to open individual levels of this tree structure to work in them. Meanwhile, other levels can be closed to improve clarity. Depending on the current navigation level and the chosen component, in the context menu (right mouse button) SICAM PAS offers precisely those program functions that are currently appropriate.

Operation takes place through the necessary steps in the data window on the right. Here, parameters can be set, information selected and assignments defined to form a user-specific, process-oriented system topology. The user interface is uncomplicated and structured according to the task definition, so as to enable intuitive working and to simplify changes. The user interface assists the editing process by displaying parameter descriptions and messages when incorrect parameters are entered. In the tabular views for

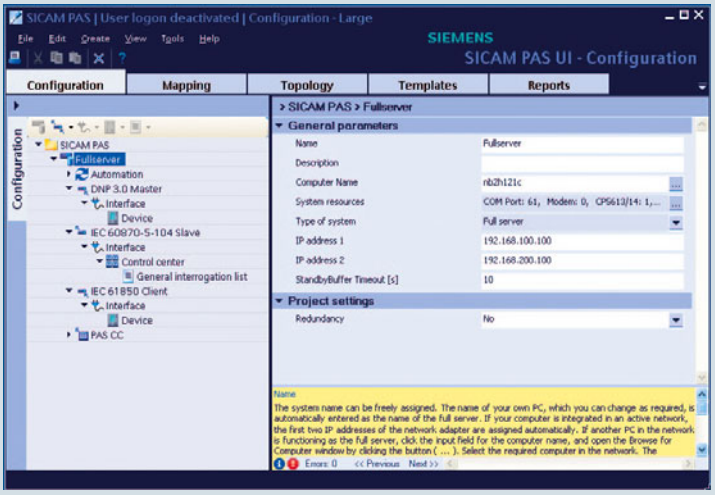


Fig. 6.3-17: **SICAM PAS UI – Configuration**

information assignment and allocation to the system topology, configuration is made easy by extensive sorting and filtering mechanisms, multiple choices and Drag & Drop.

To ensure data consistency and to avoid redundant data input, SICAM PAS UI provides extensive import and export functions for the exchange of configuration data, e.g., with the bay control level and with process visualization. To create new PAS projects and change the structure of existing PAS projects, a configuration license is required for using "SICAM PAS UI – Configuration". For reading access to the parameterizing data as well as parameter changes, the program can also be used on a runtime license basis. In SICAM PAS, everything is on board. Apart from the actual runtime environment, the "SICAM PAS UI – Configuration" program is always installed on the station computer. Thus, the project database and the configuration program always match, and adjustments and expansions are also possible after many years – regardless of separate engineering computers.

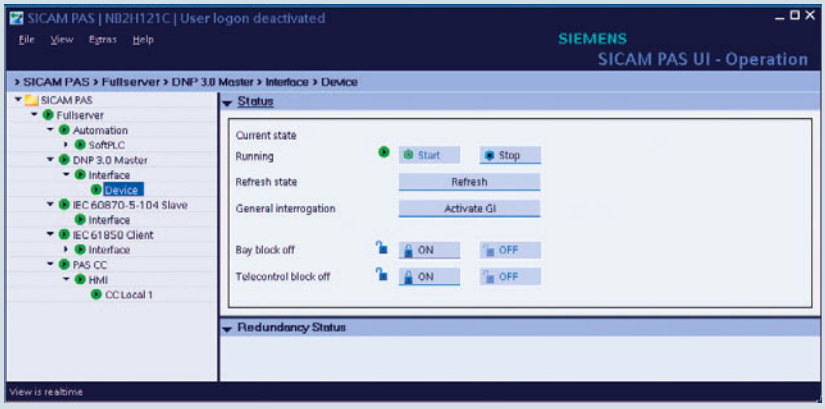


Fig. 6.3-18: **SICAM PAS UI – Operation**

Fig. 6.3-19: **SICAM PAS Value Viewer**

6.3.4 SICAM Station Unit

Hardware components of the SICAM station unit
The industrial standard SICAM station unit represents the robust, embedded hardware platform for the SICAM PAS software product. It is based on the 19" rack technology. The SICAM Station Unit (fig. 6.3-21) consists of the following hardware components:

- Optional extensions must be ordered separately
- Power supply modules as ordered
- Power supply control unit
- 2 USB interfaces (V2.0) on the rear panel (for dongle and memory stick)
- Three different CPU modules
  - Single core CPU – the classic version
    Recommended for use with older versions of SICAM PAS (e.g., V5.11) and standard substation automation configurations
  - Dual core CPU RAID – optimized for power quality
    Recommended for use power quality applications
  - Dual core CPU – best performance for SICAM PAS
- SDRAM, DDR2, 4 GB
- 2 flash cards, 4 GB each
- Graphic feature: 2048 pixels × 1536 pixels, 16.7 million colors
- VGA interface for monitor

Fig. 6.3-21: **SICAM station unit: industrial hardware for high reliability**

- 4 USB interfaces (V2.0) e.g., for keyboard / mouse
- 2 RJ45 interfaces for LAN (10 / 100 / 1000BaseT Gigabit Ethernet)
- 2 COM interfaces
- Connection unit with connections for power supply and ON / OFF switch

SICAM station unit

SICAM PAS station unit V2 based on industrial mobile processor 19" rack system, fanless operation, without moving components.
4 external USB, 2 internal USB, 2 x Gbit Ethernet RJ45, 1 serial port, status LEDs.
Redundant power supplies, switchover without reboot.
Monitored by SNMP, HW Watchdog, Temperature/voltage monitoring, live contact
Windows XP Embedded service pack 2
SICAM PAS software must be ordered separately.

Power supply
Primary power supply
DC 24 – 60 V
AC/DC 110 – 230 V
Secondary power supply
without
DC 24 – 60 V
AC/DC 110 – 230 V no secondary power supply

CPU type
CPU module with single core CPU
(Celeron® M 440, 1.86GHz), 2 x 4GB CF, 2GB RAM, image SU V2 20, backup DVD
CPU module with dual core CPU
(Core Duo T2500, 2GHz), 2 x 4GB CF, 2GB RAM, image SU V2 20, backup DVD
CPU module with dual core CPU with RAID System
(Intel Core 2 Duo L7500 1.6GHz), 2 x 4GB CF, 4GB RAM, Image SU V2 20,
Backup DVD, incl. RAID controller and RAID system level 1 incl. 2x100GByte hard disks

I/O boards
None
One digital I/O module (32 binary contacts)
Two digital I/O modules (64 binary contacts)

PCI adapter
without PCI-adapter
with PCI-adapter

Com port expander
Without com port expander
8 Ports, incl. octopus cable

Guarantee extension
Standard 2 year guarantee
Guarantee for third year

Fig. 6.3-22: **Overview of available packages for the station unit**

Optional extensions:
- External USB-DVD drive for image DVD
- External USB hard disk for backup
- USB memory stick
- PCI adapter for up to 4 PCI cards
- COM-port extension cards
- PROFIBUS card
- GPS / DCF 77 time signal receiver manufactured by Hopf
- Up to 64 binary I/O-contacts

6.3.5 Configuration Examples

Configuration for medium to large applications
If the subsgtation comprises 30 to 150 bay control units, SICAM PAS and SICAM SCC must run on separate PCs. The example below illustrates the connection of the bay control units to a SICAM station unit (fig. 6.3-23).

Configuration for large to extra-large applications
In large to extra-large applications with up to 350 bay devices, SICAM PAS is implemented as a distributed system equipped with a full server and up to 6 DIPs. SICAM SCC is installed on a separate PC (fig. 6.3-24).

Several SICAM PAS full servers connected to a human-machine interface (HMI)
The example illustrates a SICAM SCC human-machine interface (HMI) with 2 SICAM station units to which bay devices are connected. This configuration makes sense in cases where no spatially distributed human-machine interface and no failsafe SICAM SCC are required (fig. 6.3-25).

Redundant human-machine interface (HMI)
The connection of several full servers to a redundant SICAM SCC human-machine interface represents another configuration option. This configuration enhances the system's operational reliability (fig. 6.3-26).

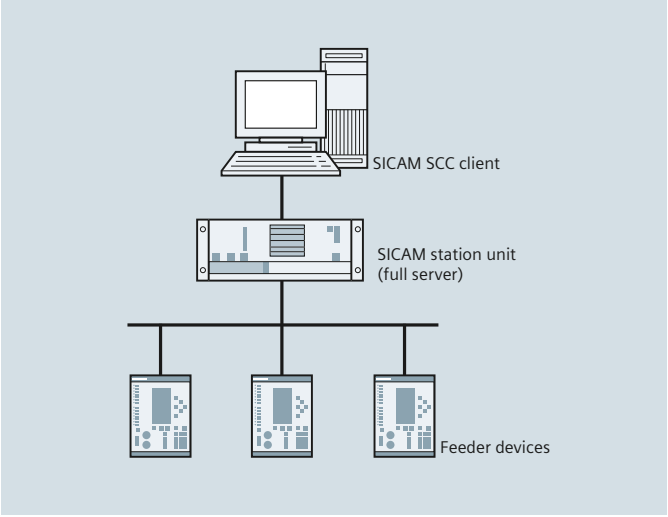


Fig. 6.3-23: **Connection of feeder devices to a SICAM station unit**

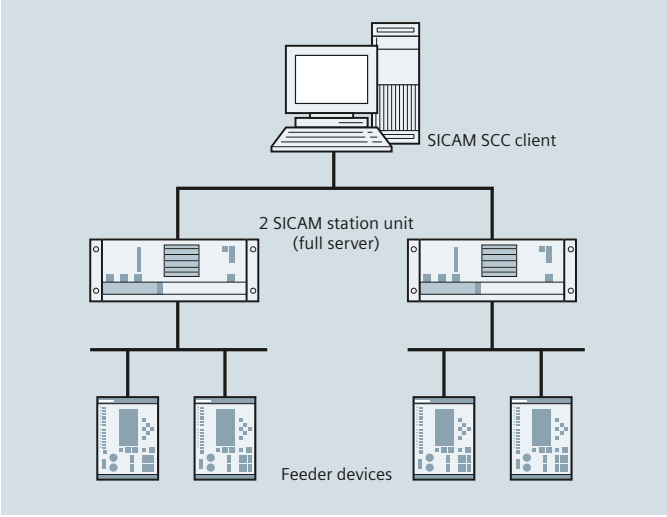


Fig. 6.3-25: **SICAM SCC with several SICAM station units**

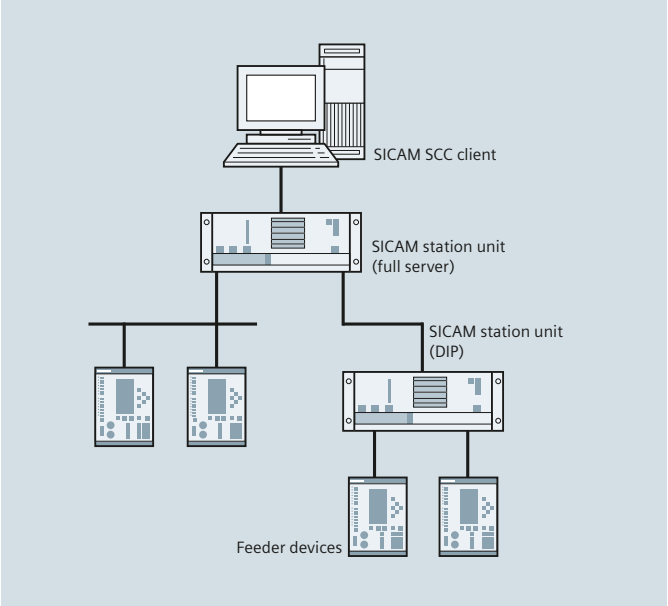


Fig. 6.3-24: **Connection of feeder devices in a distributed system**

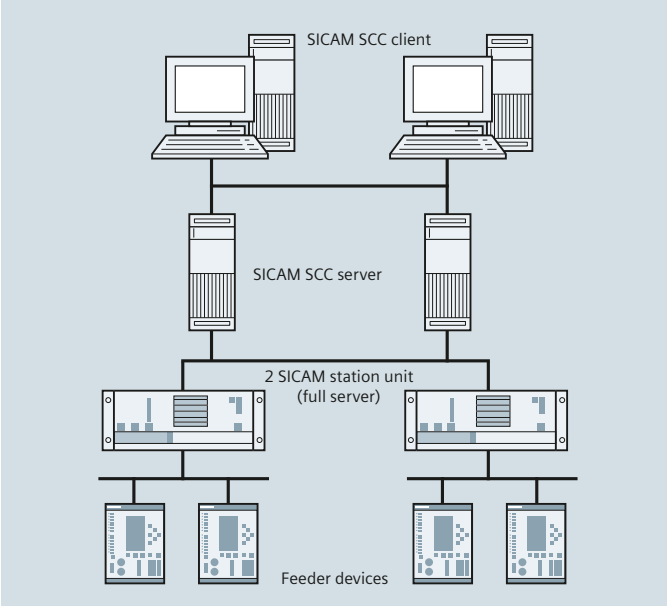


Fig. 6.3-26: **Redundant SICAM PAS in client/server configuration**

Distributed system with full server and DIP
The example shows a distributed SICAM PAS system. It consists of a full server and DIP, and communicates with a control center via TCP/IP. Bay control units and substations are connected to a distributed system via Ethernet and serial interfaces (fig. 6.3-27).

Redundant connection of bay control units and substations
SICAM PAS supports the redundant connection of bay control units and substations. The example illustrates the following configuration:

- Redundant full servers
- Redundant SICAM SCCs implemented in server/client architecture
- Connection of bay control units to 2 SICAM PAS stations

Bay control units with 2 interfaces are required for the redundant connection of bay control units. Alternatively, bay control units equipped with one interface can be connected redundantly via a splitter (fig. 6.3-28).

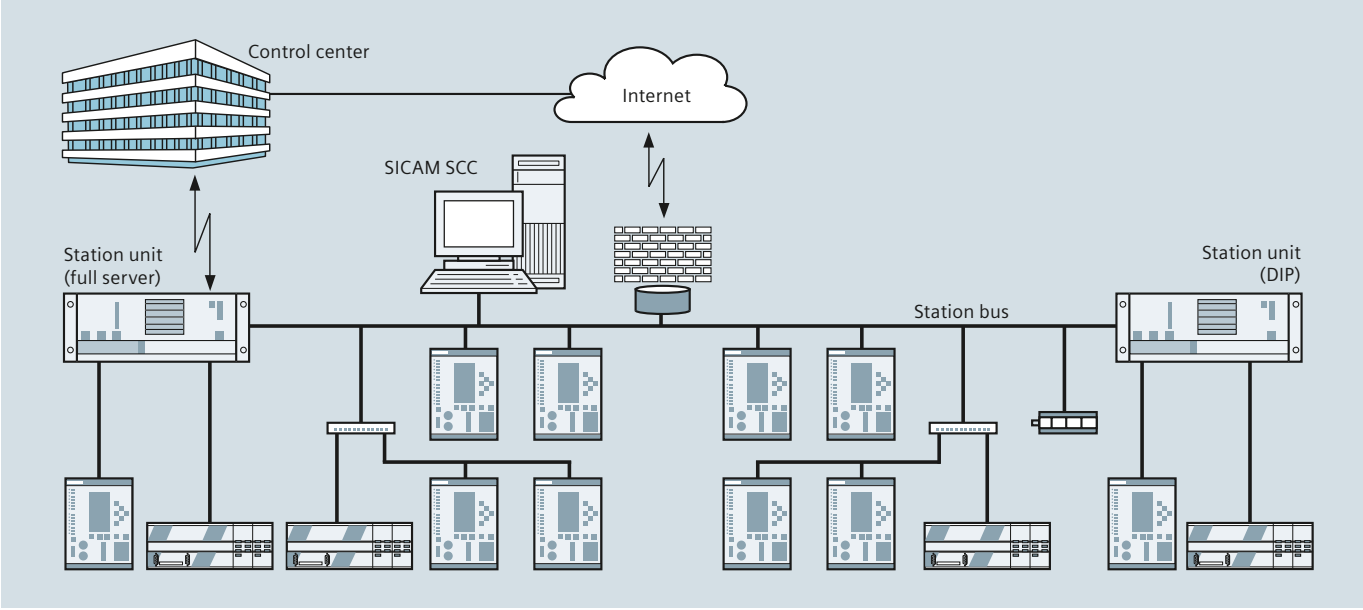


Fig. 6.3-27: **Example of a distributed SICAM PAS system with full server and DIPs**

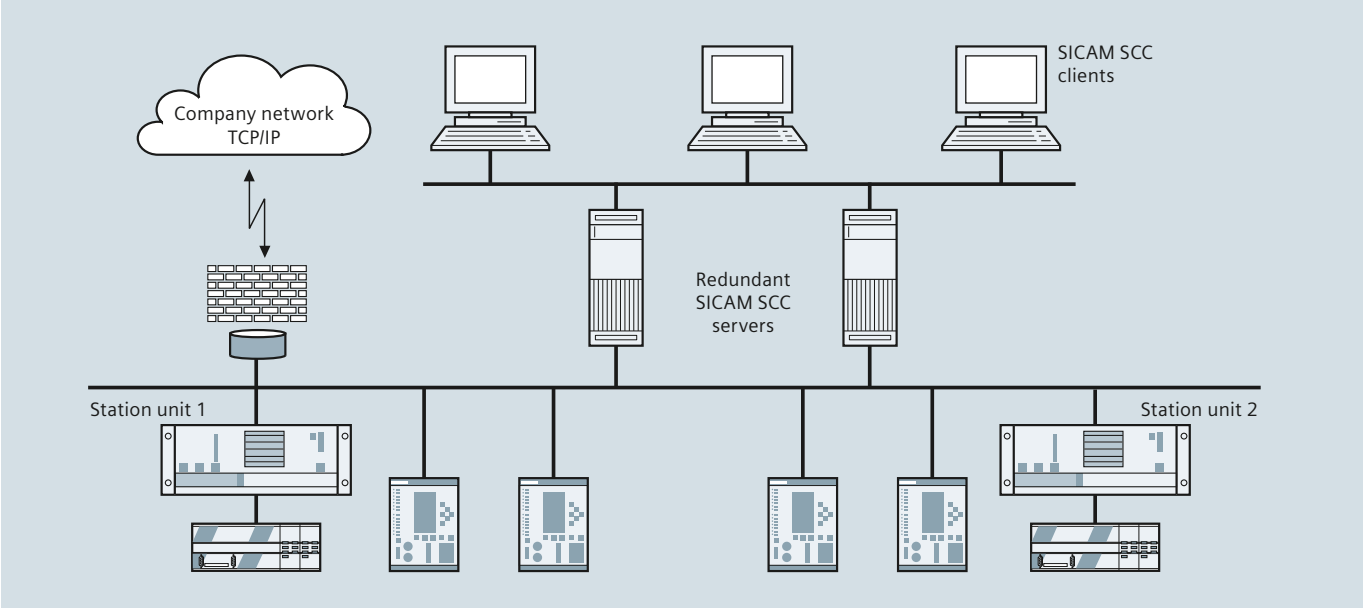


Fig. 6.3-28: **SICAM PAS station bus configuration with redundant connection of the feeder devices and the redundant SICAM SCC station controller**

6.3.6 SICAM AK, TM, BC, EMIC and MIC

Versatile functionality and high flexibility are fundamental for a modern remote control system. SICAM AK, TM, BC, EMIC and MIC adds comprehensive options for communication, automation and process interfaces. The different components of SICAM AK, TM, BC, EMIC and MIC offer optimal scalability regarding the number of interfaces and signals. Nevertheless these components are all based on the same system architecture, the same technology, and are handled with the same engineering tool (SICAM TOOLBOX II).

- SICAM AK is the large automation component for a flexible mix of communication, automation and I/O. It offers optimal support as master controller or RTU, gateway or front-end, with local or distributed I/O. Versatile redundancy concepts are another asset of these components.
- SICAM TM is the solution for compact applications. This component offers up to 4 communication interfaces plus automation function and process interface per distributed terminal modules. All modules are easily mounted to standard DIN rails. The terminal modules can be distributed up to 200 m with fiber-optic cables.
- SICAM BC is the ruggedized component for highest EMC and direct process interface up to DC 220 V. High switching capacity and direct interface for measurement transformers, plus expandability with TM modules provide flexible application in centralized and distributed configurations. Up to 3 communication interfaces and automation functions are integrated.
- SICAM MIC is a small RTU and offers either a serial interface according to IEC 60870-5-101 or an Ethernet interface with IEC 60870-5-104. Up to 8 terminal modules for I/O can be connected. A simplified automation function and a Web server for easy engineering are integrated.
- SICAM EMIC, the new smart automation system. Thanks to its node functionality with 3 interfaces,SICAM EMIC has many different potential applications. It can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn't offer adequate signal scope, it can be connected additional. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.

All components of the ACP family are using the same communication modules, and therefore they can use all available protocols. In addition to standards like IEC 60870-5-101/103/104 and IEC 61850 (client and/or server), also DNP 3.0 and Modbus are available in addition to a lot of legacy and third-party protocols for connecting third-party devices.

Another joint feature of all components is the integrated flash memory card, where all parameters and firmwares are stored. A simple exchange of a component is now possible, just by changing the memory card.

The SICAM TOOLBOX II offers all functions for an integrated, seamless engineering of complete projects, and works with all components of SICAM AK, TM, BC, EMIC and MIC. It supports all phases of an RTU or station automation project. Data exchange with DIGSI and PAS UI means a single entry point for data engineering avoiding multiple manual data inputs for a mixed configuration.

With SICAM AK, TM, BC, EMIC and MIC there is always enough performance at hand: The modular multiprocessor concept grows with every enhancement of the system. The distributed architecture and the principle of "evolutionary development" cater for a future proof system with long lifetime expectation and high security of investment. SICAM AK, TM, BC, EMIC and MIC carries the experience of more than 30 years of remote control and automation; many references are proving the flexible ways of application.

Automation component SICAM AK

Longevity through continuity and innovation
SICAM AK features high functionality and flexibility through the implementation of innovative and reliable technologies, on the stable basis of a reliable product platform.

For this, the system concept ACP (Automation, Control and Protection) creates the technological preconditions. Balanced functionality permits the flexible combination of automation, telecontrol and communication tasks. Complemented with the scalable performance and various redundancy configurations, an optimal adaptation to the respective requirements of the process is achieved (fig. 6.3-29).

SICAM AK is thus perfectly suitable for automation with integrated telecontrol technology as:
- Telecontrol substation or central device
- Automation unit with autonomous functional groups
- Data node, station control device, front-end or gateway
- With local or remote peripherals
- For rear panel installation or 19 inch assembly

SICAM AK – the forward-looking product
Versatile communication:
- Up to 66 serial interfaces according to IEC 60870-5-101 / 103
- LAN / WAN communication according to IEC 60870-5-104
- LAN communication according to IEC 61850
- Various third-party protocols possible

Easy engineering with SICAM TOOLBOX II:
- Object-oriented data model
- Creation of open-loop and closed-loop control application programs according to IEC 61131-3
- All engineering tasks can also be carried out remotely

Plug and play for spare parts:
- Storage of parameters and firmware on a flash card
- Spare part exchange does not require additional loading with SICAM TOOLBOX II

Open system architecture:
- Modular, open and technology-independent system structure
- System-consistent further development and therefore an innovative and future-proof product

Scalable redundancy:
- Component redundancy
- Doubling of processing / communication elements

The intelligent terminal – SICAM TM, EMIC and MIC:
- Direct connection of actuators and sensors with wire cross-sections up to 2.5 mm^2
- Can be located remotely up to 200 m
- Binary input / output also for DC 110 / 220 V
- Assembly on 35 mm DIN rail

Versatile communication capability
With SICAM AK, a variety of media can be utilized for local and remote communication. (wire connections, FO, radio, dial-up traffic, GSM, GPRS, WAN, LAN, field bus etc.)

Through the simple installation of serial interface modules, in total up to 66 communication interfaces are possible in one SICAM AK, whereby a different individual protocol can be used for each interface.

For standard communication protocols according to IEC 60870-5-101 / 103 / 104 and IEC 61850 are implemented.

Besides the standard protocols there are also a variety of third-party protocols available (DNP 3.0, Modbus etc.).

Simple process interfacing
In addition to the central acquisition and output of process signals within an SICAM AK mounting rack, it is possible to use SICAM TM, EMIC and MIC peripheral elements (fig. 6.3-30).

An essential feature of the SICAM TM, EMIC and MIC peripheral elements is the efficient and simple interfacing possibility of the process signals. This takes place on so-called I / O modules, which are distinguished through a robust casing, a secure contact as well as solid electronics. The I / O modules are lined up in rows. The contact takes place during the process of latching together,

Fig. 6.3-29: **SICAM AK**

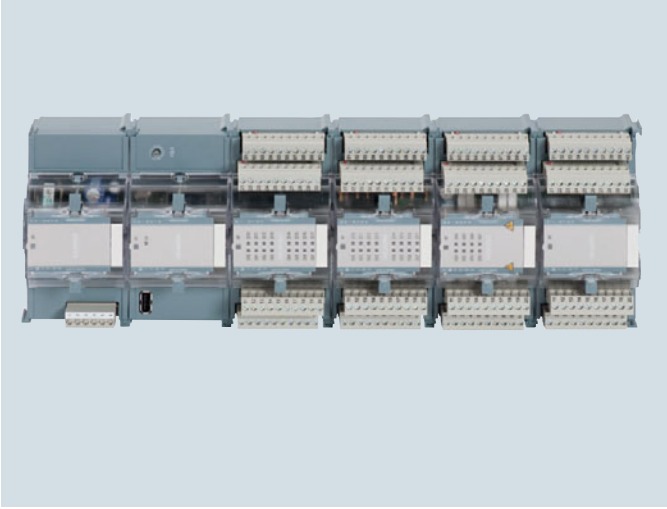


Fig. 6.3-30: **SICAM TM, EMIC and MIC peripheral elements**

without any further manipulation. Thereby each module remains individually exchangeable.

A clearly arranged connection front with LEDs for the status display ensures clarity locally. The structure of the terminals enables a direct sensor / actuator wiring without using intermediate terminal blocks with wire cross-sections up to 2.5 mm^2. Modules for binary inputs and outputs up to DC 220 V open further saving potentials at the interface level.

Depending on the requirements, the I / O modules can be fitted with either an electrical bus or an optical bus, through which the peripheral signals can be acquired as close as possible to the point of origin. In this way, broad cabling can be reduced to a minimum.

Easy engineering
An essential aspect in the overall economical consideration are the costs that occur for the creation, maintenance and service. For this, the reliable SICAM TOOLBOX II is used.

- Object orientation:
  The object orientation makes it possible to also utilize the same characteristics of same-type primary-technology units and operational equipment (e.g., disconnectors, circuit-breakers, feeders etc.) for the configuration. The close coupling with the design tool ensures the consistent, uniform documentation of the entire plant through to circuit diagram. Through this, considerable rationalization results with engineering.
- Open-loop and closed-loop control according to IEC 61131-3:
  Open-loop and closed-loop control application programs are created by means of CAEx plus according to IEC 61131-3, a standard that is generally accepted and recognized in the market. As a result, the training periods are reduced considerably.
- All engineering tasks can also be carried out remotely:
  All engineering tasks, from the system diagnostic through to the online test, can also be performed remotely with the SICAM TOOLBOX II. For this, a separate communication link between SICAM TOOLBOX II and SICAM AK is not necessary: Every available communication interface can be used. Using further automation units of SICAM TM, AK or BC, the SICAM TOOLBOX II can be remotely positioned over an arbitrary number of hierarchies.

The access to the engineering data is fundamentally protected by a password.

Plug and play for spare parts
All data of an automation unit – such as firmware and parameters – are stored non-volatile centrally on an exchangeable flash card. With a restart of the automation unit, and also with a restart of individual modules, all necessary data are automatically transferred from the flash card to all CPUs and modules.

Consequently, with the exchange of modules, new loading is no longer required, since new modules obtain all data from the memory card. With the replacement of spare parts, plug and play becomes a reality: No special tool is required, even loading is no longer necessary.

Thereby, work during a service operation is reduced to a minimum.

Open system architecture
The basis for this automation concept is a modular, open and consequently technology-independent system architecture for processing, communication and peripherals (multi-processor system, firmware).

Standardized interfaces between the individual elements again permit, even with further developments, the latest state of technology to be implemented, without having to modify the existing elements. In this way, a longevity of the product and consequently investment security and continuity can be ensured (fig. 6.3-31).

Every board and every module on which a firmware can run, forms, together with the function-determining firmware, one system element.

The adaptation to the specific requirements of the application is achieved through the individual configuration and through the loading of standard firmware and parameters. Within their defined limits, the parameters thereby not only influence the behavior of the firmware functions, but also that of the hardware functions. With that, for all module types, all mechanical parameter settings are omitted, such as e.g., the changing of jumpers or loads, thus enabling not only the online change, but also a consistent documentation of the set parameters by the SICAM TOOLBOX II as well as a simplified storage.

System overview
Mechanics
Fig. 6.2-32 and fig. 6.2-33 show two types of basic mounting racks: module CM-2832 with 9 slots and module CM-2835 with 17 slots.

Module CM-2833 (not pictured here) is the expansion mounting rack for up to 16 peripheral elements outside the basic mounting rack.

With the mechanics, value has been placed on flexibility and easy handling. Consequently, the mounting rack is available for rear panel installation or for 19" (swing) frame installation.

Almost all necessary external connectors (e.g., communication, peripherals, external periphery bus) can be connected with the help of standard cables or prefabricated cables without any additional tools (fig. 6.3-34, fig. 6.3-35, fig. 6.3-36).

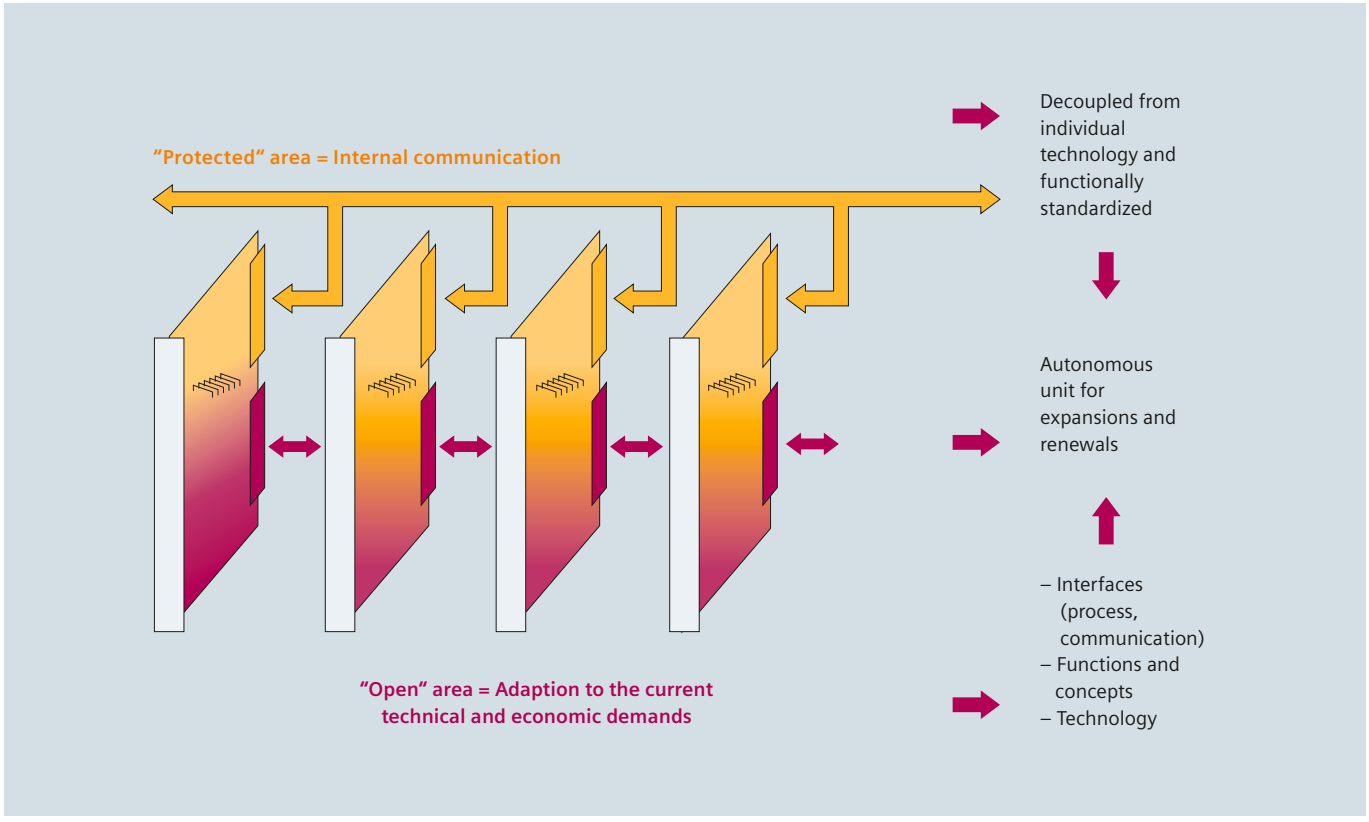


Fig. 6.3-31: **Open system architecture**

Fig. 6.3-32: **CM-2832 – SICAM AK mounting rack with 9 slots**

Fig. 6.3-33: **CM-2835 – SICAM AK mounting rack with 17 slots**

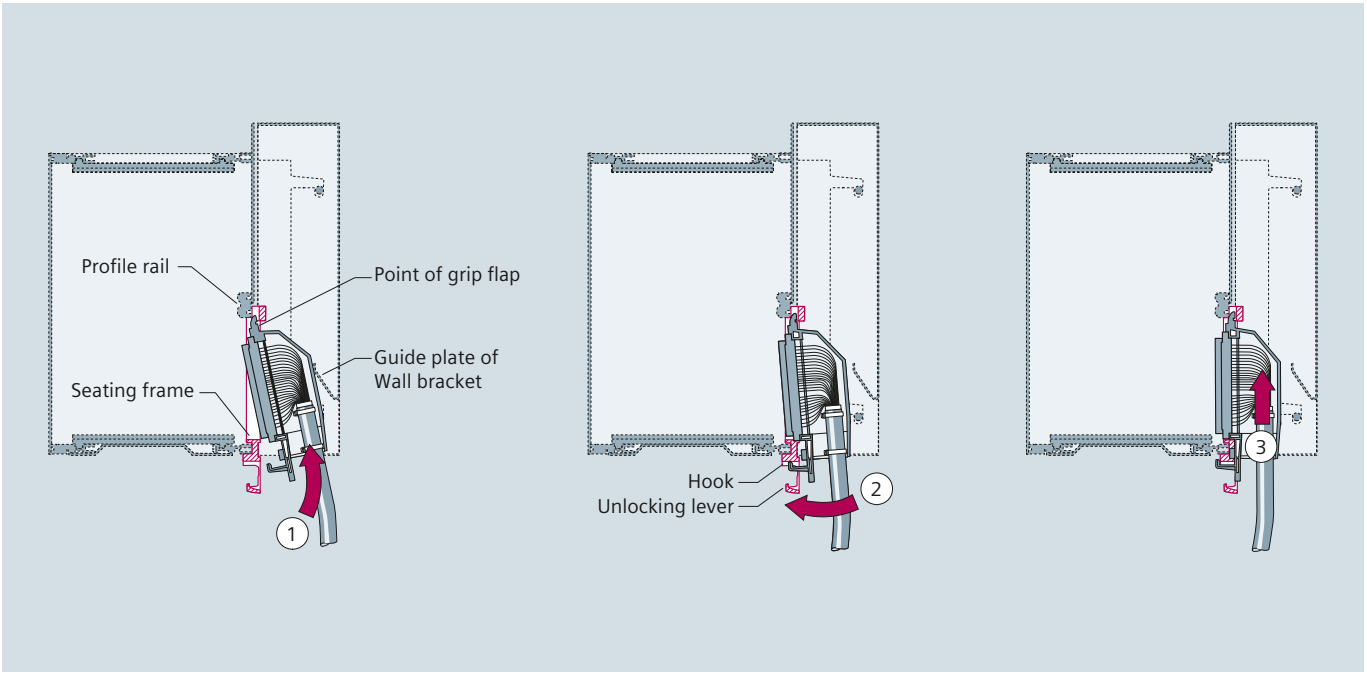


Fig. 6.3-34: **Connection technique for peripheral signals**

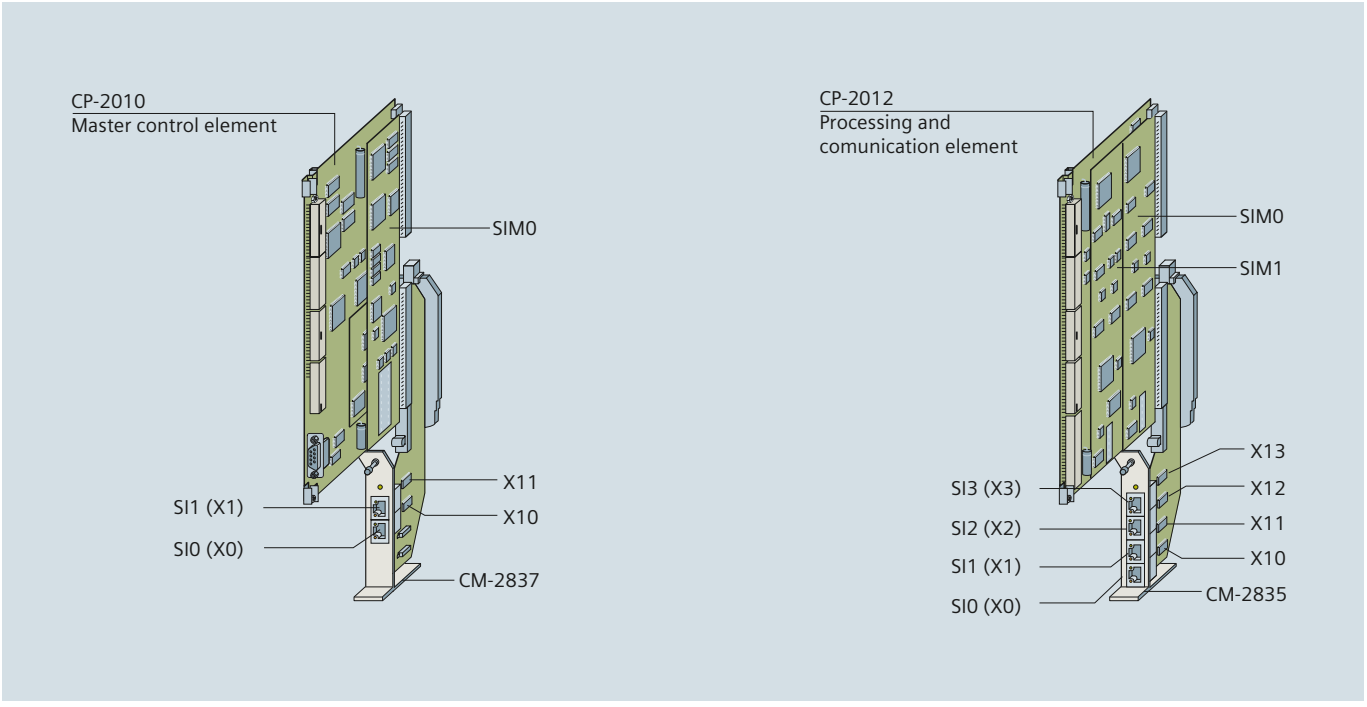


Fig. 6.3-35: **RJ45 connection technique for communication**

Fig. 6.3-36: **RJ45 connection technique for external Ax 1703 peripheral bus**

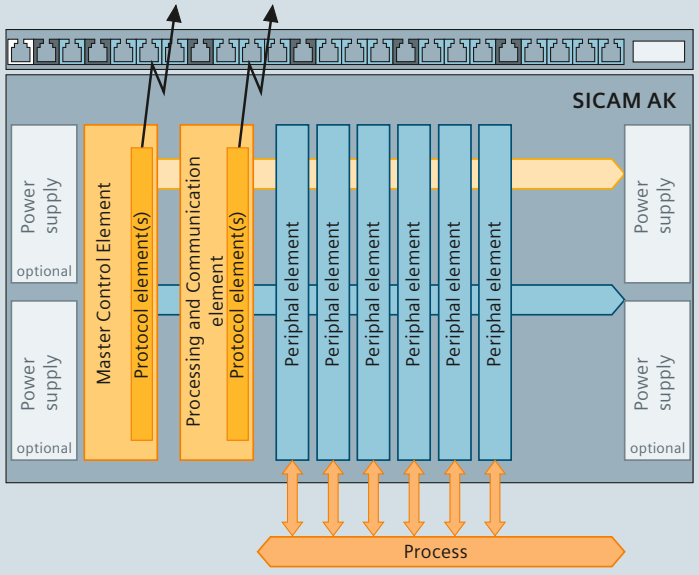


Fig. 6.3-37: **Basic mounting rack SICAM AK peripheral bus**

System architecture
The system architecture is shown in fig. 6.3-37.

Configuration
SICAM AK is structured from the following elements:
- Master control element
- Processing and communication element
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Mounting rack with one to four power supplies

Parts that are marked with (*) are system elements

Peripheral elements can also be installed outside of the basic mounting rack.

Configuration
The configuration of an automation unit Ax 1703 peripheral bus is shown in fig. 6.3-38, next page.

Configuration
- 1 master control element
  - Forms the independent Ax 1703 peripheral bus AXPE-C0, on which up to 16 peripheral elements can be installed
- Up to 16 processing and communication elements
  - Each processing and communication element forms an independent Ax 1703 peripheral bus AXPE-Cn (n = 1...16), on which up to 16 peripheral elements can be installed
- Up to 272 peripheral elements
- Up to 66 protocol elements (interfaces with individual communication protocol)
  - Up to 2 protocol elements on the master control unit
  - Up to 4 protocol elements for each processing and communication element

Ax 1703 peripheral bus
The Ax PE-Cn buses (n = 1...16) are available on connectors, in order to be able to connect peripheral elements outside the basic mounting rack. One of the buses can be selected, in order to also supply those peripheral elements in the basic mounting rack.

Peripheral elements outside the basic mounting rack
Peripheral elements may be
- installed in the basic mounting rack (as shown above), and / or
- installed in an expansion mounting rack and connected electrically, and / or
- installed at remote locations and connected electrically or optically.

System elements
A system element is a functional unit and consists of hardware and firmware. The firmware gives the hardware the necessary functionality.

Master control element
The master control element (fig. 6.3-39) forms the heart of the automation unit.

Functions of the master control element:
- Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
- Open / closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
- Communication with other automation units via protocol elements installable on the master control element (up to 2 interfaces)
- Central coordinating element for all system services and all internal and overlapping concepts, such as e.g.,
  - Data flow control
  - Monitoring functions
  - Diagnostic
  - Time management and time synchronization via minute pulse, serial time signal (DCF77 / GPS-receiver), serial communication link, NTP – Server over LAN / WAN
  - Local SICAM TOOLBOX II connection
  - Storage of parameters and firmware on a flash card

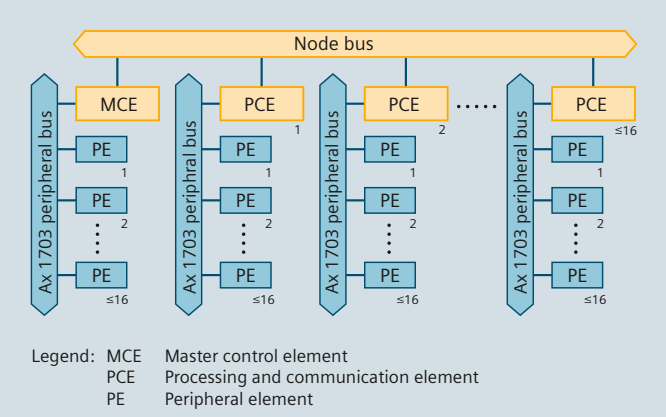


Fig. 6.3-38: **Configuration of an automation unit SICAM AK**

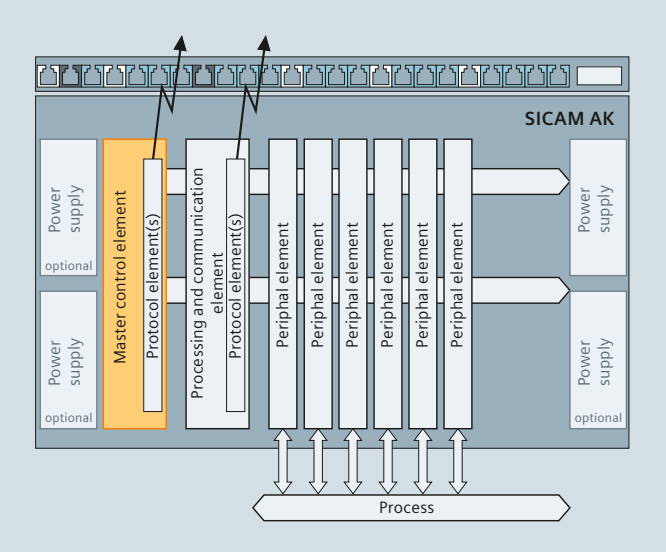


Fig. 6.3-39: **Master control element**

Processing and communication element
Functions of the processing and communication elements (fig. 6.3-40):

- Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
- Open / closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
- Communication with other automation units via protocol elements installable on the processing and communication element (up to 4 interfaces)

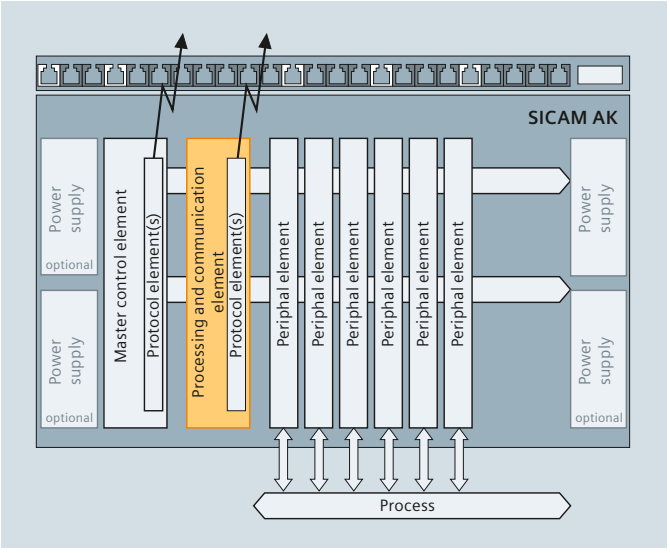


Fig. 6.3-40: **Processing and communication element**

Peripheral element
Peripheral elements, as shown in fig. 6.3-41, are used for acquisition or output of process information and perform process-oriented adaption, monitoring and processing of the process signals at each point where the signals enter or leave an automation unit. Processing is performed to some degree by

- hardware (e.g., filter, ADC, DAC) and by
- firmware (e.g., smoothing of measured values, time tagging)

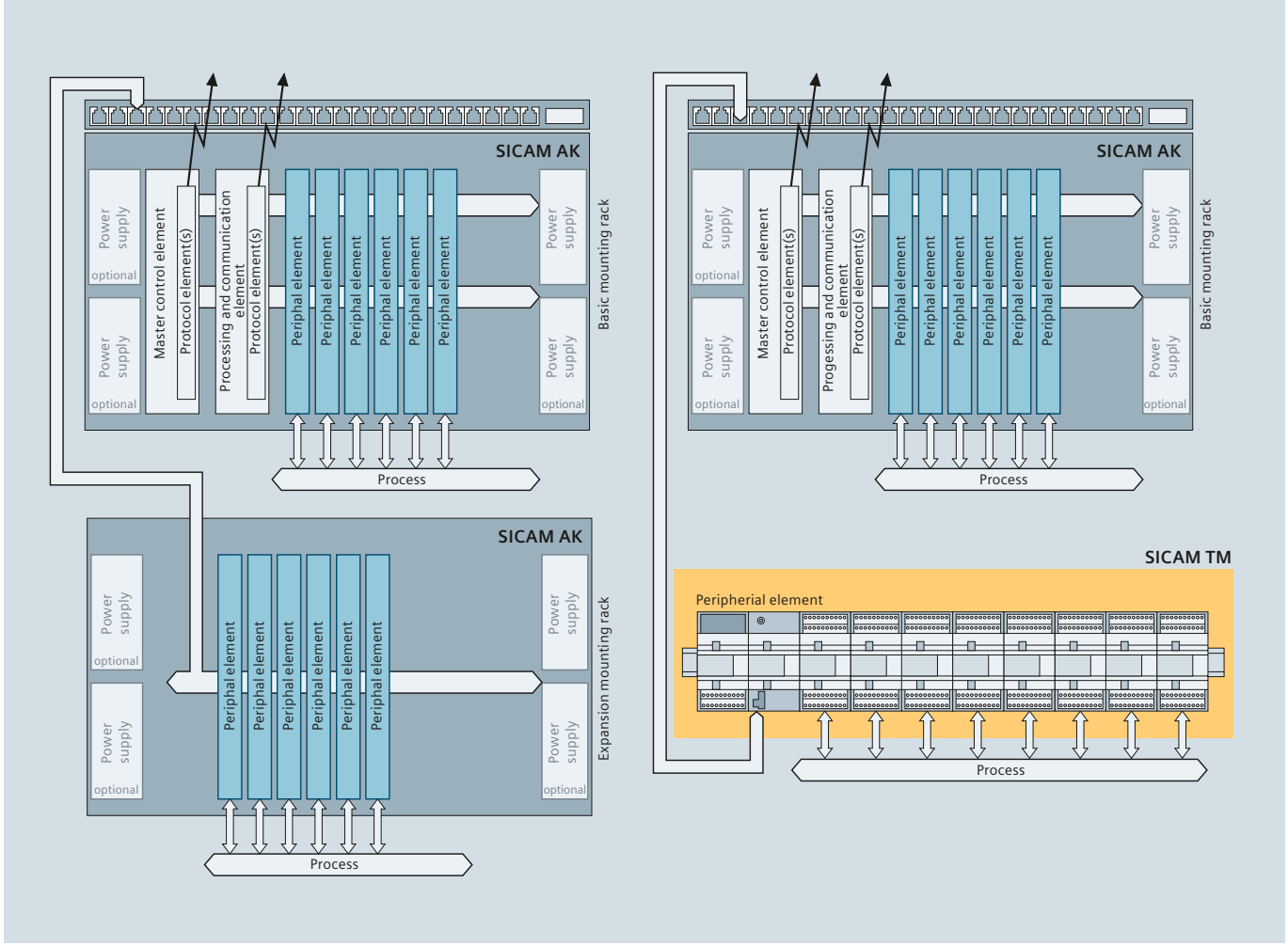


Fig. 6.3-41: **Peripheral elements**

The peripheral elements deliver over the Ax 1703 peripheral bus
- periodical information,
- messages with process information, and
- messages with system information (e.g., diagnostic information)

and receive
- messages with process information,
- periodical information, and
- messages with system information (e.g., parameters)

Protocol element

A protocol element (fig. 6.3-42) is used for the exchange of data – and thereby for the transmission of messages – over a communication interface to other automation units or devices of third-party manufacturers, e.g., control systems.

The hardware of a protocol element is a communication interface which – dependent on system and interface – can be available in different ways:
- Integrated on a basic system element
- On a serial interface module (SIM), which is installed – directly or cascaded (SIM on SIM) – on the basic system element

On every interface provided by the SIM, a communication protocol available for the interface can be loaded with the SICAM TOOLBOX II.

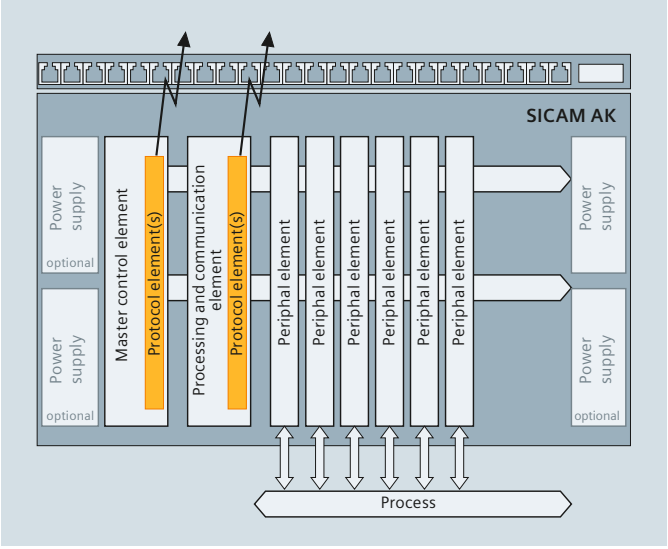


Fig. 6.3-42: **Protocol element**

System elements in SICAM AK

Master control element

Module	Designation
CP-2010 / CPC25	System functions, processing and communication

Processing and Communication Element

Module	Designation
CP-2017 / PCCX25	Processing and communication

Peripheral elements SICAM AK

Module	Designation
DI-2100 / BISI25	Binary signal input (8 × 8, DC 24 – 60 V)
DI-2110 / BISI26	Binary signal input (8 × 8, DC 24 – 60 V)
DI-2111 / BISI26	Binary signal input (8 × 8, DC 110 / 220 V)
DO-2201 / BISO25	Binary output (Transistor, 40 × 1, DC 24 – 60 V)
AI-2300 / PASI25	Analog input / output (16 × ± 20 mA + 4 × 2 opt. expans.)
AI-2301/TEMP25	Analog input (32 × Pt100)
AI-2302 / PASI25	Analog input / output (16 × ± 6mA + 4 × 2 opt. expans.)
DO-2210 / PCCO2X	Checked command output (64 × DC 24 – 60 V)
DO-2211 / PCCO2X	Checked command output (64 × DC 60 – 125 V)
MX-2400 / USIO2X	Signal input / output (DC 24 – 60 V, ± 20 mA, opt. exp.)

Supported peripheral elements SICAM TM

Module	Designation
PE-6410 / USIO66	Peripheral controller (Ax-PE bus el)
PE-6411 / USIO66	Peripheral controller (1x Ax-PE bus opt)

Power supply

The mounting racks CM-2832, CM-2835 and CM-2833 are to be equipped with 80W power supplies of the following types:

Designation	
PS-5620	Power supply (DC 24 – 60 V)
PS-5622	Power supply (DC 110 – 220 V, AC 230 V)

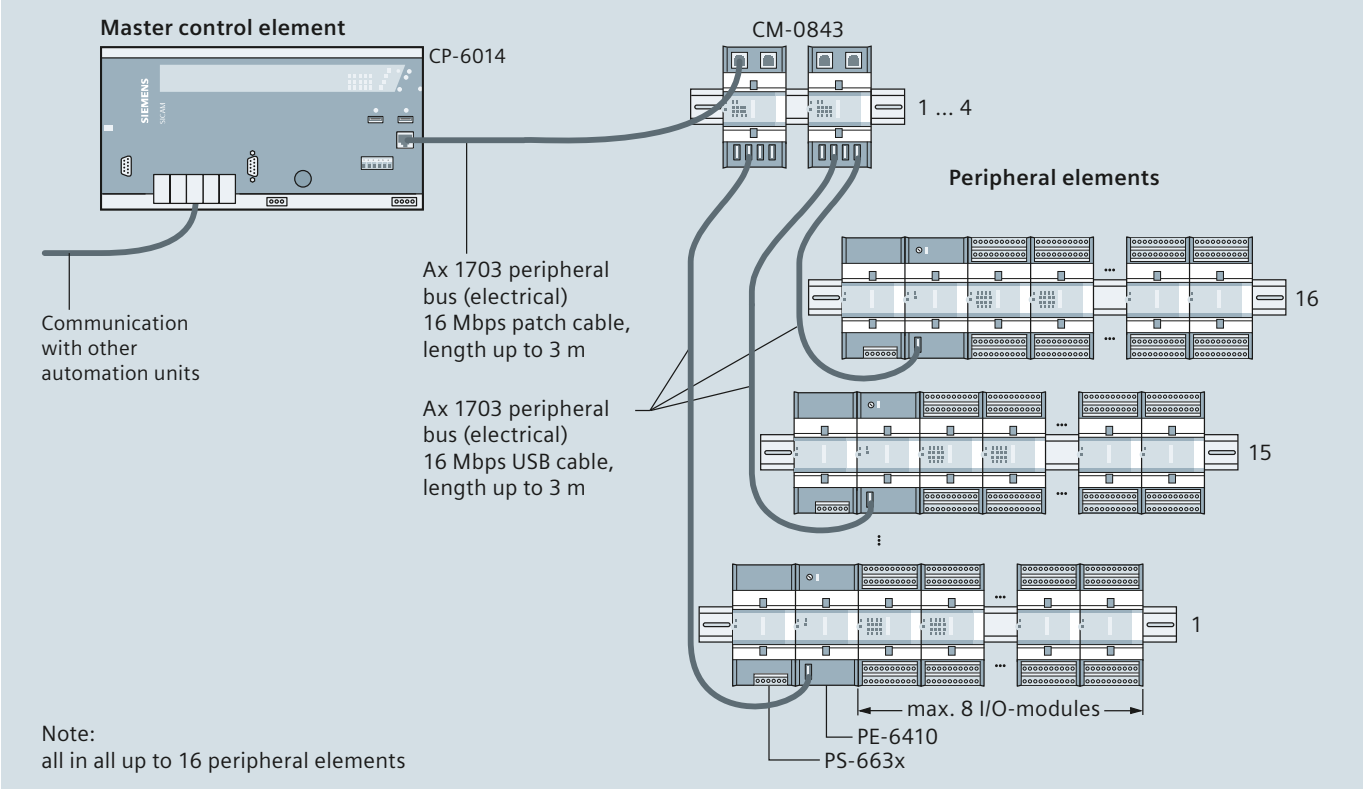


Fig. 6.3-43: **SICAM TM system architecture: connection of up to 16 peripheral elements via bus interface (electrical)**

6

Function packages

Telecontrol

The function package "Telecontrol" includes the following functions:

- Process input and output on peripheral elements
- Communication with other automation units
- Protocol elements
- Automatic data flow routing
- Data storage
- Priority control
- Redundant communication routes
- Communication within the automation unit
- Protocol element control and return information

Automation

The function package "Automation" includes the following functions:

- Process input and output on peripheral elements
- Telecontrol functions
  - Treatment for commands according to IEC 60870-5-101 / 104
  - Change monitoring and generation of messages with time tag
- Open / Closed-loop control function

System services

"System Services" is a function package providing general functions and basic services in an automation unit, which are required by other function packages:

- Communication with the engineering system
- Data flow control
- Addressing
- Time management
- General interrogation
- Self-test
- Failure
- Diagnostic and signaling
- Autonomy

System concept SICAM TM

SICAM TM is designed especially for easy installation and powerful application. Due to consequent development it fits optimally both for automation and telecontrol systems (fig. 6.3-43).

An essential feature of SICAM TM is its efficient and simple way of interfacing to the process signals. This is accomplished by so-called I / O modules boasting a robust housing, reliable contacting, and sound electronics. The I / O modules are arranged side-by-side. Contact between them is established as soon as they engage with one another, without requiring any further manual intervention. Even so, it is still possible to replace every

single module separately.

A clearly structured connection front featuring status indicator LEDs makes sure that things at the site remain clear and transparent. The structure of the terminals permits direct sensor / actuator wiring without requiring the use of intermediate terminals.

The I / O modules may, depending on the requirements, be equipped with either an electrical or an optical bus, whereby the peripheral signals can be acquired very close to their point of origin. Consequently, wide cabling can be reduced to a minimum.

SICAM TM is highlighted by the following future-oriented features:
- Modular, open and technology-independent system structure
- Direct periphery coupling without intermediate terminals
- Software parameter setting (hardware and software)
- Online parameter modification
- LED's for process and operating conditions
- Simplified connection handling by "intelligent terminals"
- 35 mm international standard profile rails
- Secured internal communication over all bus systems
- Little training needed
- Data storage via multi media card (plug and play for spares)
- Periodical processing and creation of automation functions carried out with the tool CAEx.plus
- Spontaneous processing supports the processing- and communication-orientated telecontrol functions and includes:
- Parameterizable telecontrol processing of the periphery
- Change monitoring, signal creation and time-stamping of the event data of the periodical processing
- Timely decoupling of the signal and prioritized transfer with the aid of a deterministic priority algorithm
- Prioritization of messages
- Energy metering value collection
- Extended temperature range (– 25 °C to + 65 °C / – 13 to 149 °F)
- High EMC (electromagnetic compatibility)
- Increased electric strength (class 2)

System architecture

A SICAM TM forms an automation unit of the SICAM AK, TM, BC, EMIC and MIC system family and is constituted of the following components:
- Master control element
- Modular, expandable and detachable peripheral elements
- Protocol elements for communications, mountable on the master control element (fig. 6.3-44).

Master control unit

The master control element forms the heart of the SICAM TM automation module. Process input and output is connected externally via peripheral elements. The communication interfaces can be fitted directly onto the master control element.

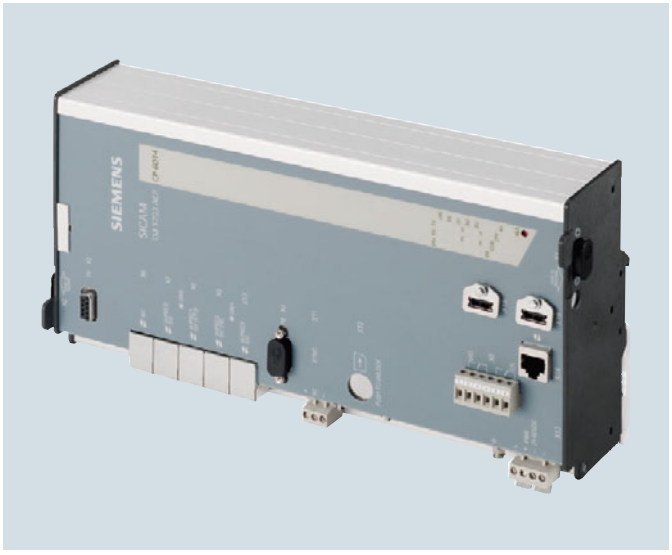


Fig. 6.3-44: **SICAM TM mounted on 35 mm DIN rails**

Functions of the master control element:
- Communication with peripheral elements via the serial Ax 1703 peripheral bus
- Open / closed-loop control functions with a user program created freely according to IEC 61131-3, e.g., in function diagram technology
- Parameterizable telecontrol functions
- Time management and time synchronization via minute pulse, serial time signal (DCF77 / GPS-receiver), serial communication link, NTP server via LAN / WAN
- Communication via the mountable protocol elements
- Engineering by means of SICAM TOOLBOX II
- Storage of parameters and firmware on a flash card

The master control element provides the open- / closed-loop functions and / or the parameterizable telecontrol function, as well as the node function for the communication via serial interfaces and LAN / WAN. Therefore, it also serves as a centrally coordinating element for all system functions and all internal and integral concepts.

This architecture ensures
- deterministic behavior of the open / closed-loop control function with guaranteed reaction times,
- autonomous behavior (e.g., in the case of communication failure), and
- integration of the telecontrol functionality (spontaneous processing and spontaneous communication) as well as the open / closed-loop control functions (periodical processing and periodical communication with the periphery) into one common automation device.

To connect peripheral elements to the master control element, a bus interface module must be arranged side by side with the master control element.

For this purpose,
- the master control element has a 9-pin D-SUB socket on its right side, and the
- bus interface module has a 9-pin D-SUB connector on its left side.

Up to 2 bus interface modules can be attached to one master control element.

Up to 14 peripheral elements can be connected to a master control element.

Peripherals
A peripheral element is constituted of
- 1 power supply module,
- 1 peripheral control module, and
- up to 8 I/O modules (fig. 6.3-45)

The respective data sheets document how many I/O modules may actually be used per peripheral element and in what order they can be used.

A key feature of SICAM TM is that it provides for the efficient and simple connection of the process signals. This is done at the I/O modules standing out for a robust housing, reliable contacting, and sound electronics.

The I/O modules are added side by side to the peripheral control module. Contact is established as soon as they engage with one another, without requiring any further manual intervention. Even so, every single I/O module can still be exchanged separately and mounted on a DIN rail. It may be installed horizontally or vertically.

Removable terminals (I/O connectors) are used for the simple handling of modules when they are to be mounted or exchanged. Since the terminals carry the wiring, no connections need to be disconnected when devices are exchanged.

To interface peripheral elements to the master control element, a bus interface module must be fitted on the side of the master control element. Using simple, standardized USB cables, the peripheral control modules are connected to the bus interface module, thereby reducing the assembly effort required for their connection to a minimum.

The Ax 1703 peripheral bus permits the secured, serial, in-system communication between the master control element and the peripheral elements. Serial communication also renders it possible to detach individual or all peripheral elements via optical links up to 200 m from the master, with full system functionality remaining intact.

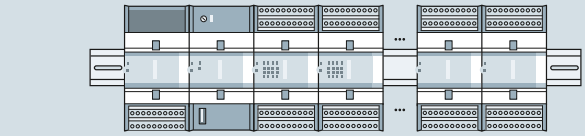


Fig. 6.3-45: **Peripheral element**

Functions of the peripheral control module:
- Secured data exchange with the master control element
- Secured data exchange with the connected I/O modules via the TM bus (Terminal Module Bus)
- Monitoring of the connected I/O modules
- Preprocessing of the input and output signals

Functions of the I/O modules:
- Acquisition and output of binary and analog process signals,
- Secured data exchange with the peripheral control element via the TM bus

The communication between the I/O modules and the peripheral control module takes place via the TM bus according to the master/slave method, with the I/O modules being the slaves.

By arranging the various modules side by side, contact will be established automatically throughout the TM bus so that no additional wiring is required.

Communication
The communication function is used for the exchange of data – and thus for the transmission of messages – via protocol elements to other automation units or control systems.

The hardware for the protocol elements is serial interface modules (SIMs), which can be mounted on the master control element. On one master control element, up to 2 SIMs can be mounted.

A serial interface module features:
- Two serial communication interfaces, or
- one LAN communication interface (Ethernet) plus optional serial interface, or
- one Profibus interface (DP master)

Since a communication interface corresponds to one protocol element, a total of up to 4 protocol elements can be used for each SICAM TM. This way, a multitude of communication options is available.

Product overview

Master control unit

Module	Designation
CP-6014 / CPCX65	Processing and communication

Bus interface module

Module	Designation
CM-0843	Ax-bus interface, electrical
CM-0842	Ax-bus interface, optical fiber

Peripherals

Module	Designation
PS-6630	Power supply module (DC 24-60 V (EMC+))
PS-6632	Power supply module (DC 110 / 220 V (EMC+))
PE-6410 / USIO66	Periphery interfacing for Ax electrical peripherals bus
PE-6411 / USIO66	Periphery interfacing for Ax peripherals bus 2 x optical
PE-6412 / USIO66	In combination with SICAM AK in redundancy configurations
DI-6100	Binary input (2 × 8, DC 24-60 V)
DI-6101	Binary input (2×8, DC 110 / 220 V)
DO-6200	Binary output transistor (2 × 8, DC 24-60 V)
DO-6212	Binary output relays (8 × DC 24-220 V / AC 230 V)
DO-6220	Command output basic module (4 × DC 24 – 110 V)
DO-6221	Command output basic module measure (4 × DC 24 – 110 V)
DO-6230	Command output relais module (16 × DC 24 – 110 V)
AI-6300	Analog input (2 × 2 ± 20 mA / ± 10 mA / ± 10 V)
AI-6307	Analog input (2 × 2 ± 5 mA)
AI-6310	Analog input (2 × 2 Pt100 / Ni100)
AO-6380	Analog output (4 × ± 20 mA / ± 10 mA / ± 10 V)

Compact RTU SICAM MIC

SICAM MIC, as a part of SICAM AK, TM, BC, EMIC and MIC, is designed for application of compact telecontrol systems.

Installation takes place on a 35 mm rail. It must be considered that the modules are mountedhorizontally or vertically on a vertically standing rack.

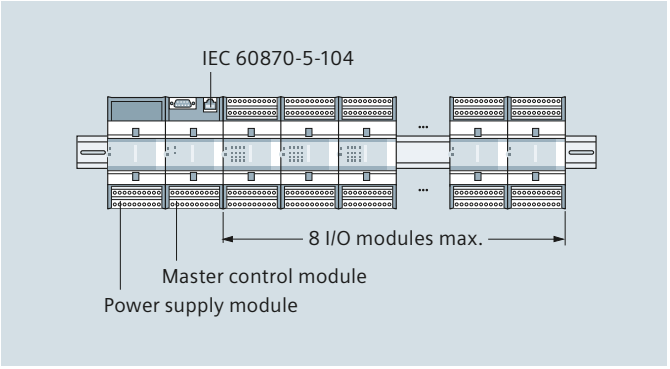


Fig. 6.3-46: **SICAM MIC system architecture**

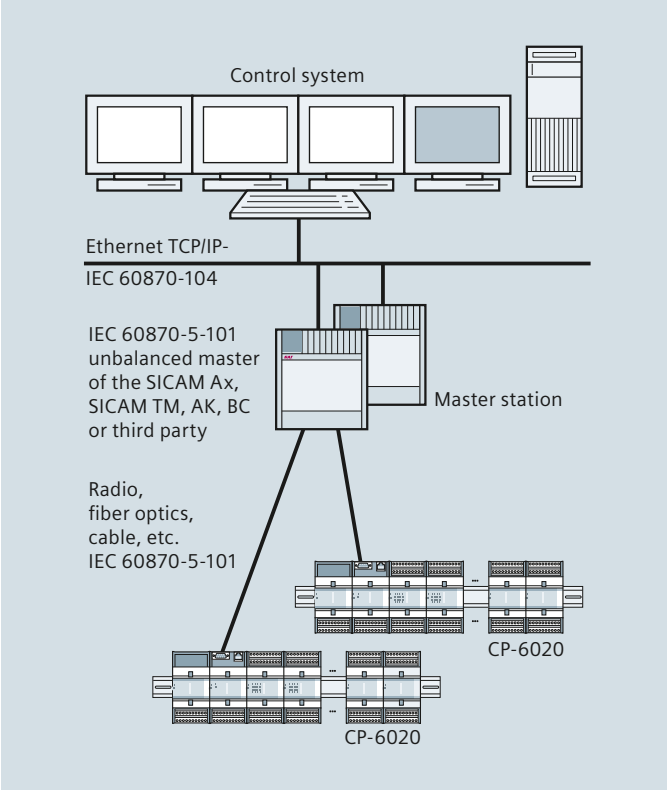


Fig. 6.3-47: **SICAM MIC configuration – multi-point traffic**

The sequence of modules from left to right or from top to bottom is prescribed as follows:

- Power supply module
- Master control module
- Up to 8 I / O modules in arbitrary order (fig. 6.3-46)

The power supply and TM bus are electrically connected during the process of latching together, wherein each module can be individually replaced.

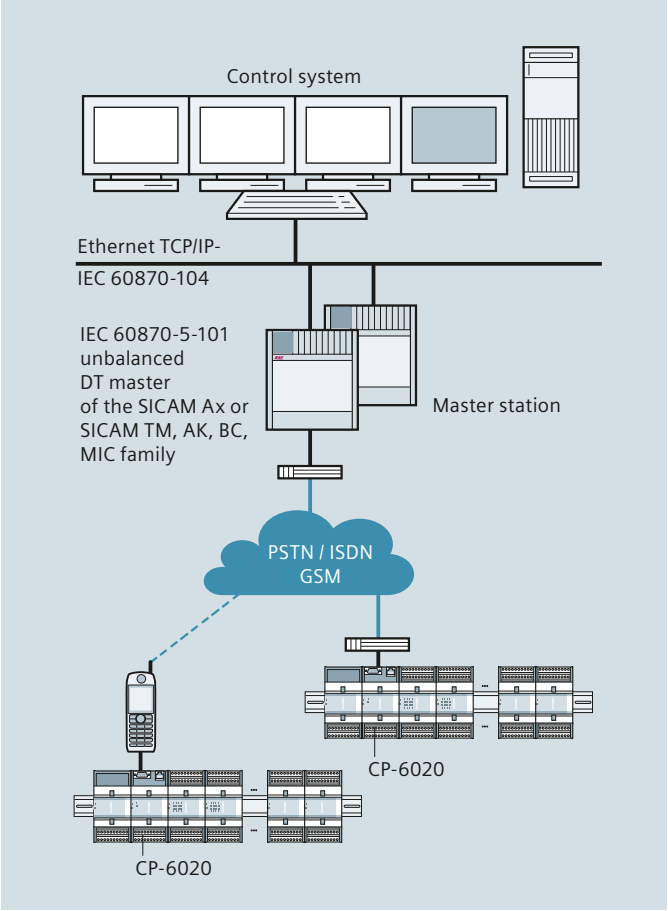


Fig. 6.3-48: **SICAM MIC configuration – simple dial-up traffic**

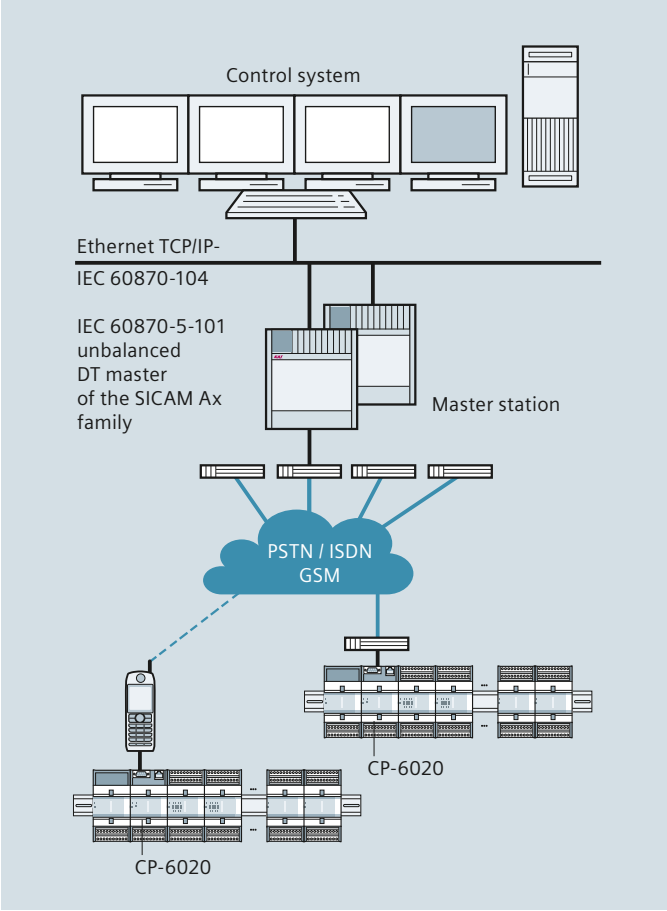


Fig. 6.3-49: **SICAM MIC configuration – multi-master dial-up traffic**

The master control modules are:
- CP-6020 master control module (V.28 / 8 modules)
- CP-6040 master control module (ET10TX / V.28 / 8 modules)

Configuration
The following figures show the configurations of multi-point traffic (fig. 6.3-47), of dial-up traffic (fig. 6.3-48), of multimaster dial-up traffic (fig. 6.3-49), of LAN / WAN (fig. 6.3-50) and of GPRS (fig. 6.3-51).

Bay control units
The Bay Control Unit (BCU) is the linking member between the station control level and the primary system, and is integrated in the feeder-related local control cubicle.

It is therefore designed for rough electric and thermal ambient conditions and is based on the SICAM BC bay controller.

The bay control unit acquires all feeder-relevant process data and time tags them at a resolution of 1 ms. All feeder related functions are executed autonomous in the bay control unit:
- Interlocking
- Synchrocheck
- Automatic voltage regulation by control of transformer onload tap changer (option)
- Closed-loop control for arc suppression coils (option)
- Operation cycle counter
- Calculation of r.m.s. values of currents and voltages, active and reactive power

Local control panel for feeder operation
The bay control unit comes in two mechanical sizes (fig. 6.3-53): SICAM BC is designed for compact feeders (typical in distribution); SICAM BC is the modular version for larger amounts of I / O (typical in transmission).

Both versions are based on the same system architecture and use the same modules. They are ruggedised for use as near as possible to the primary equipment featuring the highest EMC and a broad temperature range, and the I / O-modules are designed for direct interfacing of all signals from the process without any interposing level (e.g., interposing relays, measuring transducers, etc.). This means a peripheral voltage of up to DC 220 V or direct interfacing of transformers with 1 A to 6 A or AC 110 / 220 V.

Architecture of SICAM BC
A SICAM BC forms an automation unit of the SICAM system family and consists of the following elements:

- Master control element (control) (*)
- Processing element (protection) (*)
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Operation and display panel
- Mounting rack with one or two power supplies

The mounting rack is available in two sizes:
- The compact SICAM BC can host up to 2 peripheral elements
- The modular SICAM BC can host up to 15 peripheral elements.

Seamless communication
SICAM BC offers a complete solution based on IEC standards (IEC 60870-5-101 / 103 / 104 and IEC 61850).

A serial interface is included in the control master CPU based on IEC 60870-5-103 SLAVE via fiber-optic for communication with upper levels. Local communication to the maintenance notebook for the engineering tool is done via a 9-terminal connector on the front side of the device. In addition, a SIP (Serial Interface Processor) with two serial interfaces or a NIP (Network Interface Processor) with one Ethernet interface, or a combined SIP+NIP with one serial and one Ethernet interface can be equipped for enhanced communication capability.

Parts that are marked with (*) are system elements

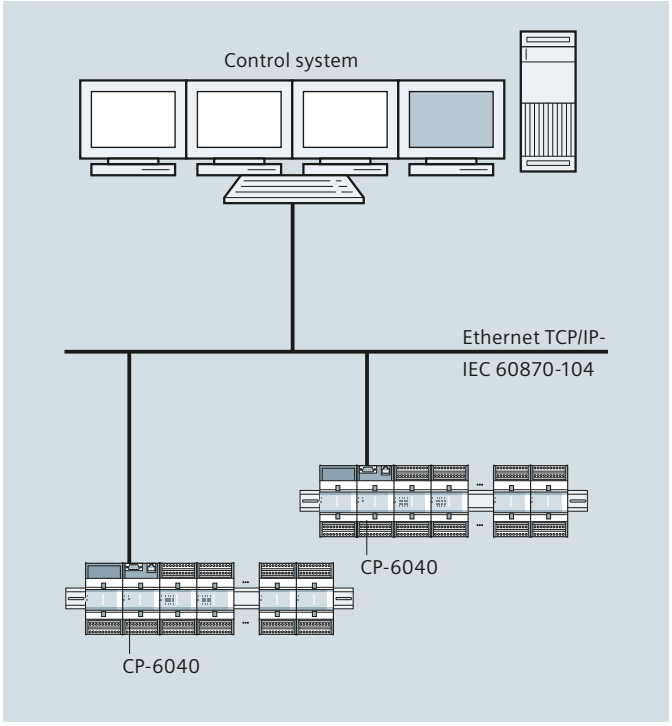


Fig. 6.3-50: **SICAM MIC configuration – LAN / WAN**

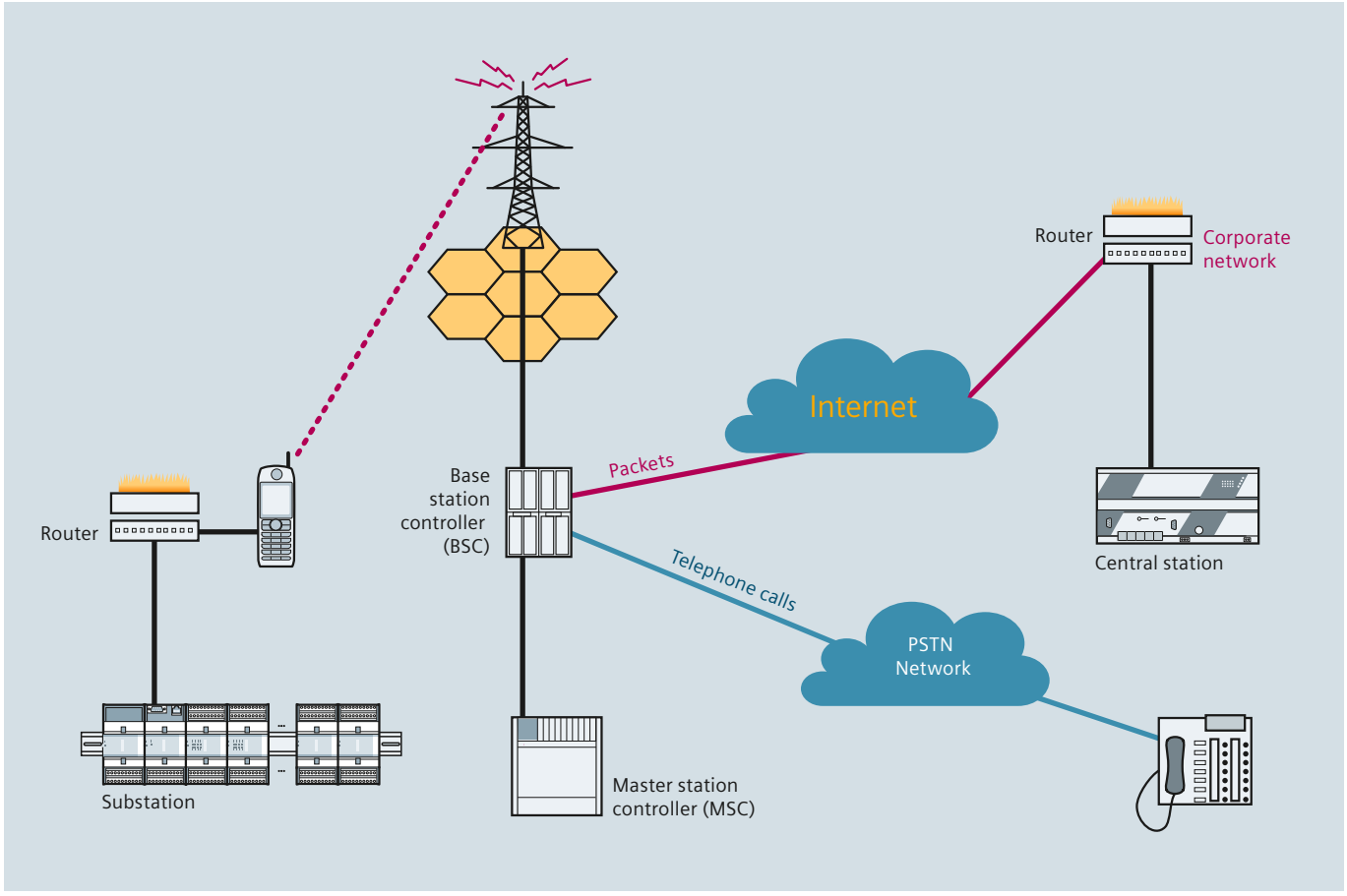


Fig. 6.3-51: **SICAM MIC configuration – GPRS**

Plug and play for spare parts by flash card
Parameters and firmware are stored directly on flash card. That means that no tool for device exchange is necessary. This facilities the maintenance and service tasks. Additionally the flash card can be written by the engineering tool.

General features
- Power supply is available in DC 110–220 V / AC 230 V (80 W) or DC 24–60 V (80 W) and a second power supply can be added for redundancy
- The signal acquisition has a 1 ms resolution of real-time stamping.

As shown in the picture, the bay control units are designed for rough electric and thermal environments.

The operating temperature ranges from – 25 °C to + 70 °C/ – 13 to + 158 °F. Installation in outdoor cabinets is intended.

Bay control unit HMI
In order to make it easier for the system operator's staff to perform operation and maintenance tasks from the local bay control cubicle, the SICAM BC bay control unit can be operated through a display panel (fig. 6.3-52).

The local operation panel is designed as a dedicated solution to show all necessary information about the status of a feeder in a clear and simple way, and to support easy and secure local operation directly at the feeder. It is designed for use in the door of local bay control cubicles at all voltage levels of a substation. Therefore it complies with highest EMC and a wide temperature range.

It provides an interface to be used with the SICAM BC, and can be combined both with the compact and the modular version of the bay controller. It can be directly attached to the SICAM BC, or be used separated with only two connecting cables (up to 3 m). The integrated and divided frame allows for either surface mounting, without the need for a big cut-out in the door, or for flush mounting. Operation and display have been arranged in accordance with ergonomic principles, and are compatible with similar sequences on the station operation terminal. The display shows the status of the dynamic single-line diagram of the feeder, plus selected measurement information. By changing to other images, the operator gets information about all accessible measurements, statistical data, important alarms, etc. Additional LEDs indicate important status and alarms beside the display, so that any unusual condition can be recognized immediately. The associated description is provided with a slide-in strip, so that image and status are shown simultaneously. Two key locks give access to the operation mode: one for local / remote / test, and the other one for interlocked / non-interlocked operation. Command initiation is done securely in multiple steps. In this way, inadvertent input is definitely avoided.

Temperature range: – 25 °C to + 70 °C / – 13 to + 158 °F. The display has a limited readability below – 10 °C / 14 °F. External dimensions (H × W × D) are 280 mm × 220 mm × 37 mm / 11.0236 × 8.6614 × 1.45669 inch.

Fig. 6.3-52: **Bay control units (BCU)**

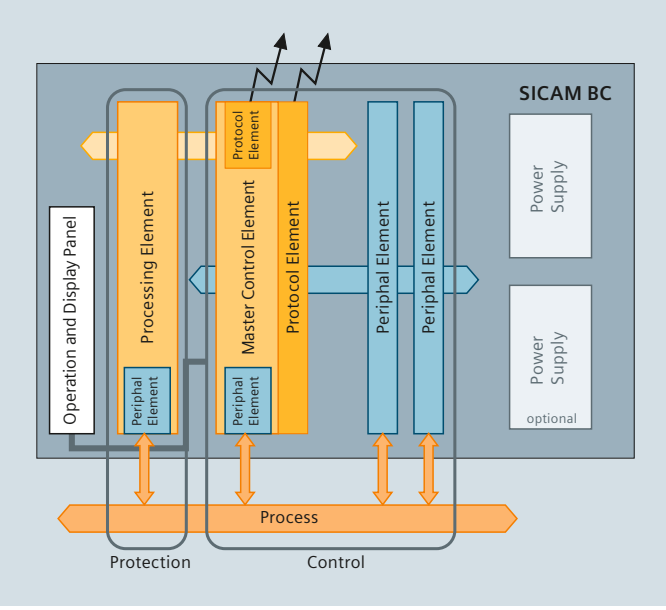


Fig. 6.3-53: **SICAM BC**

6

6.3.7 SICAM EMIC – a Member of the Proven SICAM Family

With growing pressure on costs in virtually all processes, there is an increasing need to also automate smaller stations to make better and more reliable use of existing equipment. Modern, high-performance automation systems allow the integration of smaller stations to provide universal and reliable management of complex processes. But smaller stations are also being equipped with greater functionality because of the increased demand for more information.

From straightforward monitoring activities to control functions and the integration of additional equipment, modern systems need to offer a wide range of functionality.

Flexible use of SICAM EMIC

As the logical consequence of these demands, SICAM EMIC (Terminal Module SICAM enhanced microcontrol) represents the expansion of the provenproduct SICAM MIC. SICAM EMIC is a low-cost, flexible and modular telecontrol station, and is part of the proven SICAM AK, TM, BC, EMIC and MIC automation family. The hardware consists of a master control element and various I/O modules, and is designed for DIN railmounting. The proven I/O modules can be used and fitted on all products in the SICAM AK, TM, BC, EMIC and MIC family.

The master control element is used for interfacing and supplying the I/O modules and provides three communication interfaces (1 × Ethernet and 2 × serial) to meet a wide range of requirements. Complete flexibility is ensured here as well, becausedifferent communication protocols can be allocatedfreely. The option of automation functions roundsout the range of functionality of the SICAM EMIC.

Integrated Web server for simple engineering

Keeping the engineering process as simple as possible was a top priority with the SICAM EMIC – the master control element has an integrated Web server for configuration, diagnostics and testing, so that no special tools or additional licenses are needed. The tool is already integrated in SICAM EMIC and is operated with a standard Web browser. Engineering, diagnostics and testing of the SICAM EMIC can also be carried out with the proven SICAM TOOLBOX II, the integrated engineering tool for the entire SICAM AK, TM, BC, EMIC and MIC family. SICAM EMIC puts everything on one card and receives the parameterizing data via a flash card. Consequently, the correct parameters are always available locally and there is no need to load data from a PC. This makes exchanging devices during servicing a straightforward Plug & Play operation, and it is very simple to transfer configuration data to the replacement device with the flash card. For this reason, and because of the comprehensive remote diagnostics options, downtimes can be reduced to a minimum.

Thanks to its node functionality, SICAM EMIC has many different potential applications. SICAM EMIC can be used as an ordinary telecontrol substation with any kind of communication to a control center. If SICAM EMIC doesn't offer adequate signal scope, additional SICAM EMIC systems can be connected. Freely programmable application programs for local control functions complete the all-round versatility of the SICAM EMIC.

Highly flexible options for communication to the control center

- Multi-point traffic
  - External data transmission equipment –can be connected via the V.28 interface for multi-point traffic transmission.
- Dial-up traffic
  - A wide range of connection-oriented trans-–mission media (analog, ISDN, GSM, TETRA) are supported as standard for dial-up traffic as well.
- LAN/WAN
  - IEC 60870-5-104/DNPi communication based on Ethernet TCP/IP is used for communication via LAN/WAN networks.

SICAM EMIC – the system in detail

Functions of the master control element:

- Central processing functions
- Storing of the parameters and the firmware on a flash card
- Interfacing and supplying of the I/O modules
- 3 communication interfaces, with different individual communication protocols (IEC 60870-5-101, 103, 104, Modbus, DNP 3.0, other protocols on request)

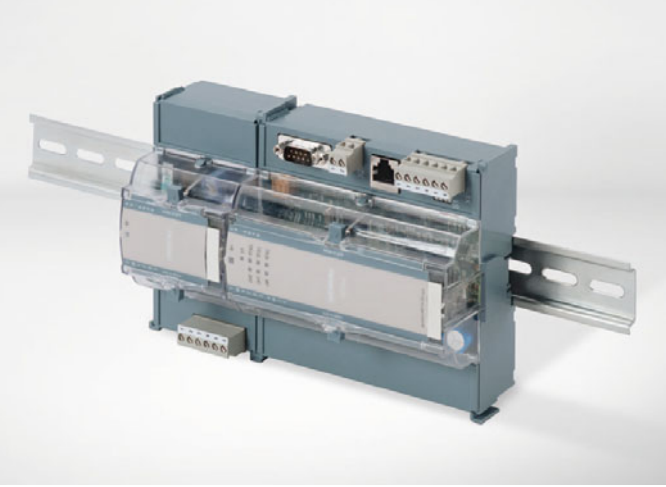


Fig. 6.3-54: **SICAM EMIC – the new member of the proven SICAM AK, TM, BC, EMIC and MIC family**

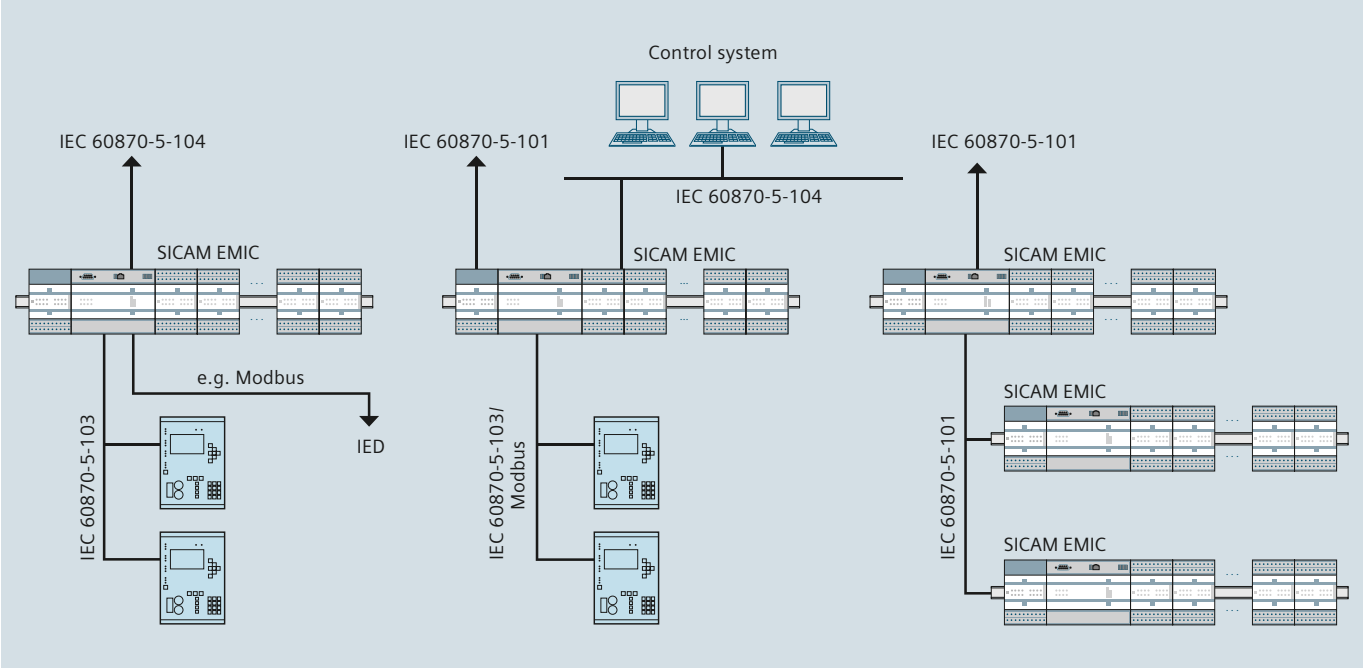


Fig. 6.3-55: **Practical applications of SICAM EMIC**

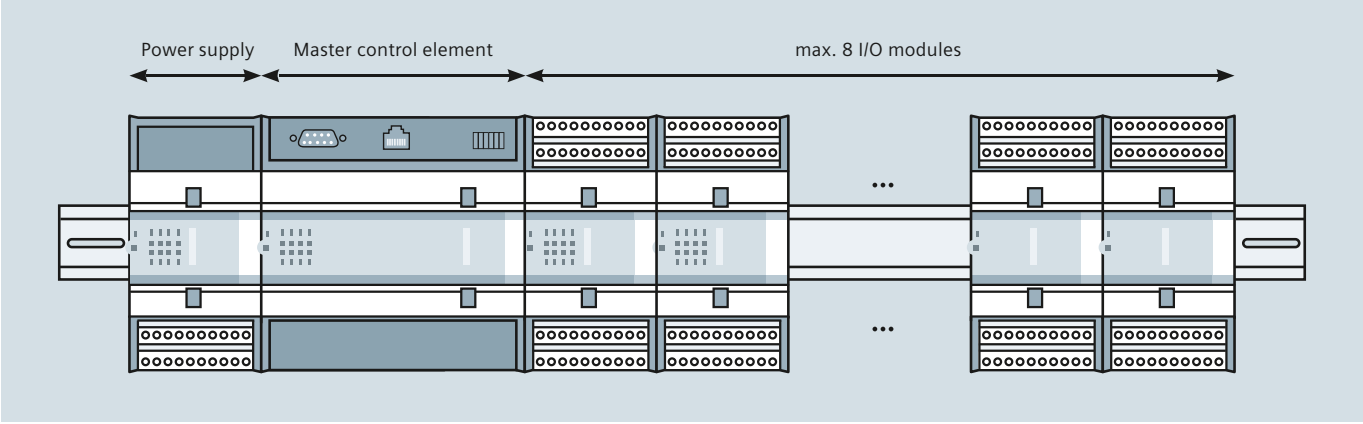


Fig. 6.3-56: **Architecture of SICAM EMIC**

For further information:
www.siemens.com/sicam

6.4 Power Quality and Measurements

6.4.1 Introduction

Power quality

Supply quality
Quality is generally recognized as an important aspect of any electricity supply service. Customers care about high quality just as much as low prices. Price and quality are complementary. Together, they define the value that customers derive from the electrical supply service.

The quality of the electricity supply provided to final customers results from a range of quality factors, for which different sectors of the electricity industry are responsible. Quality of service in the electrical supply has a number of different dimensions, which can be grouped under three general headings: commercial relationships between a supplier and a user, continuity of supply, and voltage quality.

To avoid the high cost of equipment failures, all customers must make sure that they obtain an electricity supply of satisfactory quality, and that their electrical equipment is capable of functioning as required even when small disturbances occur. In practice, the voltage can never be perfect.

Electrical supply is one of the most essential basic services supporting an industrial society. Electricity consumers require this basic service:
- To be available all the time (i.e. a high level of reliability)
- To enable all consumers' electrical equipment to work safely and satisfactorily (i.e. a high level of power quality).

Voltage quality
Voltage quality, also termed power quality (PQ), covers a variety of characteristics in a power system. Chief among these is the quality of the voltage waveform. There are several technical standards defining voltage quality criteria, but ultimately quality is determined by the ability of customers' equipment to perform properly. The relevant technical phenomena are: variations in frequency, fluctuations in voltage magnitude, short-duration voltage variations (dips, swells, and short interruptions), long-duration voltage variations (overvoltages or undervoltages), transients (temporarily transient overvoltages), waveform distortion, etc. In many countries voltage quality is regulated to some extent, often using industry-wide accepted standards or practices to provide indicative levels of performance.

Everybody is now aware of the effects of poor power quality but few really have it under control. The levels of power quality disturbances need to be monitored weekly, sometimes even

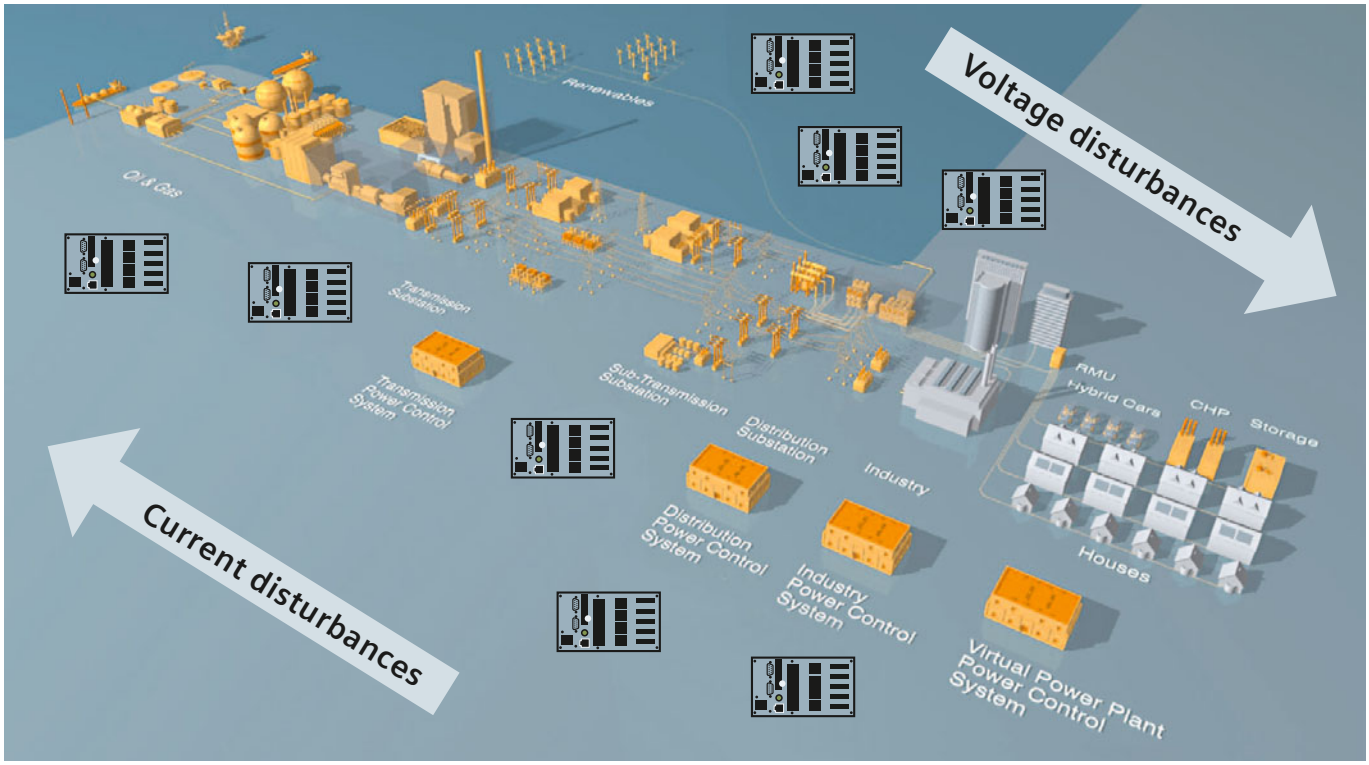


Fig. 6.4-1: **Power quality monitoring provides value to everyone – to the local utility, to the consumer, to the local economy and to the environment**

daily, in order to trigger appropriate remedial measures before severe consequences occur.

The power utility therefore has an interest in monitoring the power quality, showing that it is acting correctly and improving its know-how about the system. This ensures customer satisfaction by providing electricity with quality and reliability.

The availability and quality of power is of even greater concern to distribution companies. The liberalization of the electricity market has put them in the uncomfortable position of being affected by other players' actions. This situation has been stabilizing and power quality is becoming a top priority issue in the restructuring process. With increasing customer awareness of energy efficiency, it is clear that the quality of supply will be receiving much attention.

Most power quality problems directly concern the end user, or are experienced at this level. End users have to measure the power quality and invest in local mitigation facilities. However, consumers often turn to the utility company, instead, and exert pressure to obtain the required supply quality.

The EN 50160 power quality standard describes the main characteristics of the voltage at the customer's supply terminals in public low, medium, and, in the near future, high-voltage systems, under normal operating conditions.

Who is responsible?
An interesting problem arises when the market fails to offer products that meet the customer's power quality needs. If a customer cannot find equipment that is designed to tolerate momentary power interruptions, the customer may, for example, pressure the power supplier and the regulator to increase the power quality of the overall distribution system. It may be in the supplier's interest to help the customer address the power quality and reliability problem locally.

The electrical supply system can be considered a sort of open-access resource: In practice, almost everybody is connected to it and can "freely" feed into it. This freedom is now limited by standards, and / or agreements. In European countries, the EN 50160 European standard is generally used as a basis for the supply quality, often also termed the voltage or power quality. There is currently no standard for the current quality at the point of common coupling (PCC), but only for equipment. The interaction between the voltage and current makes it hard to draw a line between the customer as "receiving" and the network company as "supplying" a certain level of power quality. The voltage quality (for which the network is often considered responsible) and the current quality (for which the customer is often considered responsible) affect each other in mutual interaction.

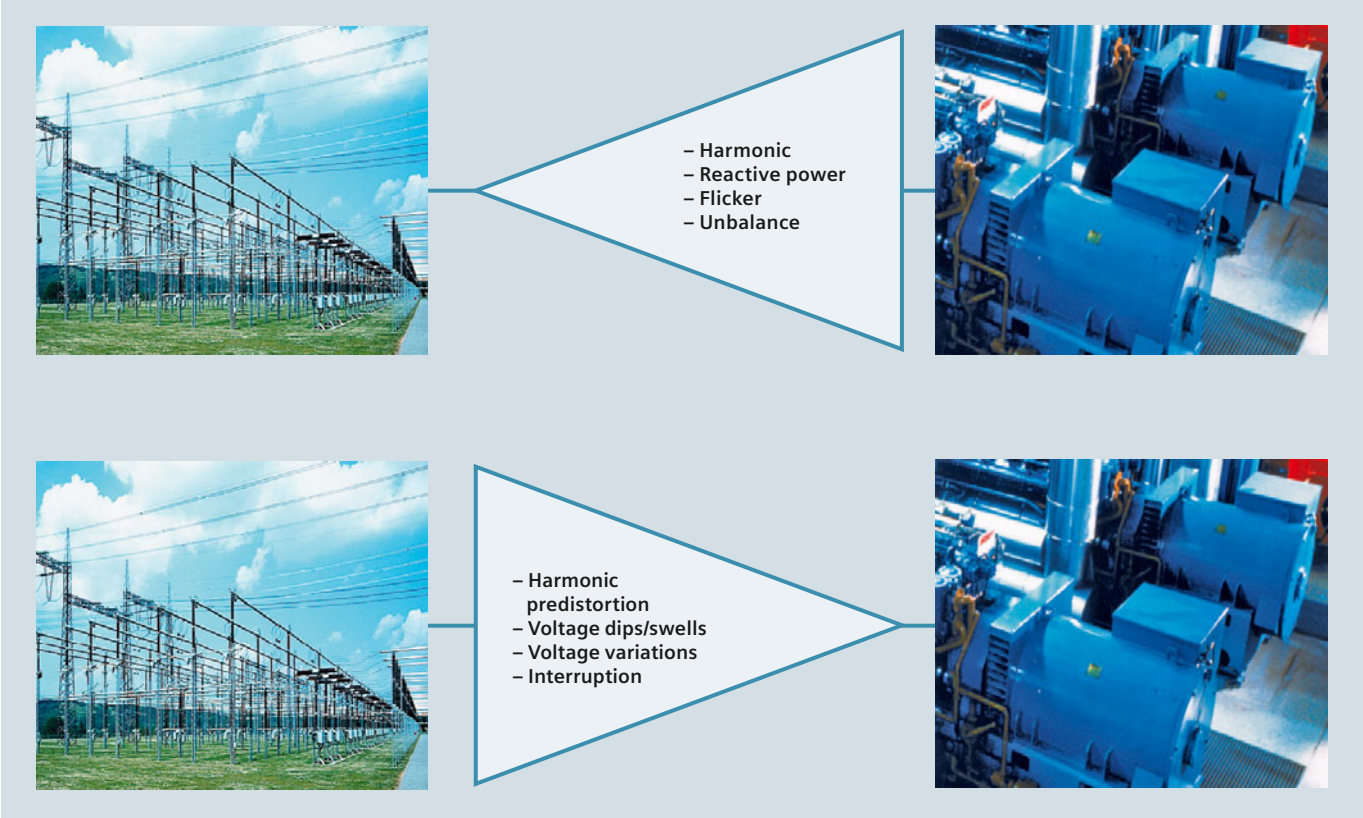


Fig. 6.4-2: **Utility and industries, both are responsible for voltage quality**

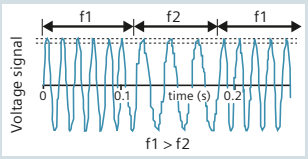
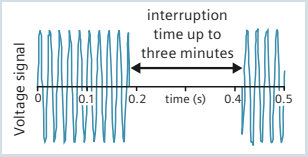
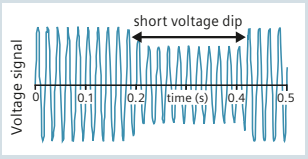
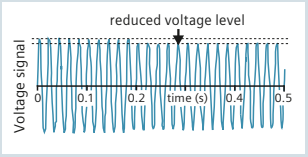
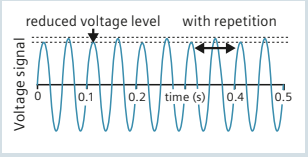
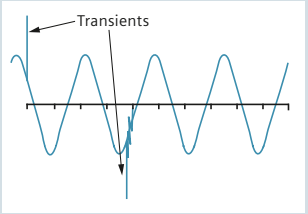
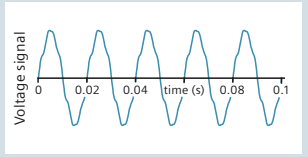
Problem	Description	Cause	Effect
	**Frequency distortions:** A frequency variation involves variation in frequency above or below the normally stable utility frequency of 50 or 60 Hz	• Start-up or shutdown of very large item of consumer equipment, e.g. motor • Loading and unloading of generator or small co-generation sites • Unstable frequency power sources	• Misoperation, data loss, system crashes and damage to equipment and motor • For certain kinds of motor load, such as in textile mills, tight control of frequency is essential
	**Supply interruption:** Planned or accidental total loss of power in a specific area Momentary interruptions lasting from a half second to 3 seconds Temporary interruptions lasting from 3 seconds to 1 minute Long-term interruptions lasting longer than 1 minute	• Switching operations attempting to isolate an electrical problem and maintain power to your area • Accidents, acts of nature, etc. • Fuses, actions by a protection function, e.g. automatic recloser cycle	• Sensible processes and system shutdown or damages • Loss of computer / controller memory • Production losses or damage
	**Voltage dip / sag or swell:** Any short-term (half cycle to 3 seconds) decrease (sag) or increase (swell) in voltage	• Start-up or shutdown of very large item of consumer equipment, e.g. motor • Short circuits (faults) • Underdimensioned electrical circuit • Utility equipment failure or utility switching	• Memory loss, data errors, dim or bright lights, shrinking display screens, equipment shutdown • Motors stalling or stopping and decreased motor life
	**Supply voltage variations:** Variation in the voltage level above or below the nominal voltage under normal operating conditions	• The line voltage amplitude may change due to normal changing load situations	• Equipment shutdown by tripping due to undervoltage or even overheating and / or damage to equipment due to overvoltage • Reduced efficiency or life of electrical equipment
	**Flicker:** Impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time	• Intermittent loads • Motor starting • Arc furnaces • Welding plants	• Changes in the luminance of lamps can result in the visual phenomenon called flicker on people, disturbing concentration, causing headaches, etc.
	**Transient:** A transient is a sudden change in voltage up to several thousand volts. It may be of the impulsive or oscillatory type (also termed impulse, surge, or spike) **Notch:** This is a disturbance of opposite polarity from the waveform	• Utility switching operations, starting and stopping heavy equipment, elevators, welding equipment static discharges, and lightning	• Processing errors • Data loss • Lock-up of sensitive equipment • Burned circuit boards
	**Noise:** This is an unwanted electrical signal of high frequency from other equipment **Harmonic:** Distortion is alteration of the pure sine wave due to non-linear loads on the power supply	• Noise is caused by electromagnetic interference from appliances, e.g. microwave, radio and TV broadcasts, arc welding, heaters, laser printers, thermostats, loose wiring, or improper grounding • Harmonic distortion is caused by non-linear loads	• Noise interferes with sensitive electronic equipment • It can cause processing errors and data loss • Harmonic distortion causes motors, transformers, and wiring to overheat • Improper operation of breakers, relays, or fuses

Table 6.4-1: **Main problems with power quality**

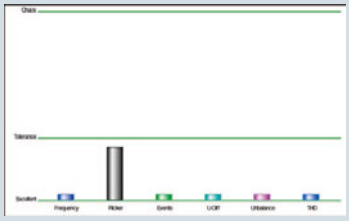
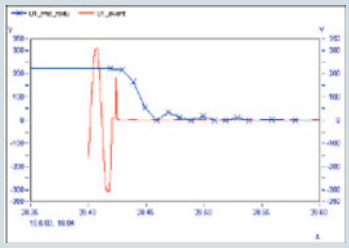
PQ application	Description	Hardware	Measurements	
Regulatory power quality:	Regulative PQ analysis approaches the comparison of the quality of voltage or power with recognized standards (e.g. EN 50160) or with the quality defined in power supply contracts. Periodically produce compliance reports.	Power Quality Recorders (mainly Class A)	Voltage quality parameters (at least) at selected system interfaces and customer supply points (e.g. EN 50160) for: Power system performance Planning levels (i.e. internal objectives) Specific customer contracts	
Explanatory power quality:	Explanatory PQ analysis to provide an understanding of what is going on in particular cases, such as fault analysis, to support the wider aspects of system stability. It is a process that aims to document selected, observed power quality and maximize the level of understanding, possibly including knowledge of the cause and consequences and possible mitigation of power quality problems.	PQ recorders Class A, S or B and fault recorder / PMU	V+I_{rms}, waveforms, status of binaries, power swing, MV transformers, busbars and loads	

Table 6.4-2: **Power quality applications**

Power quality recording steps

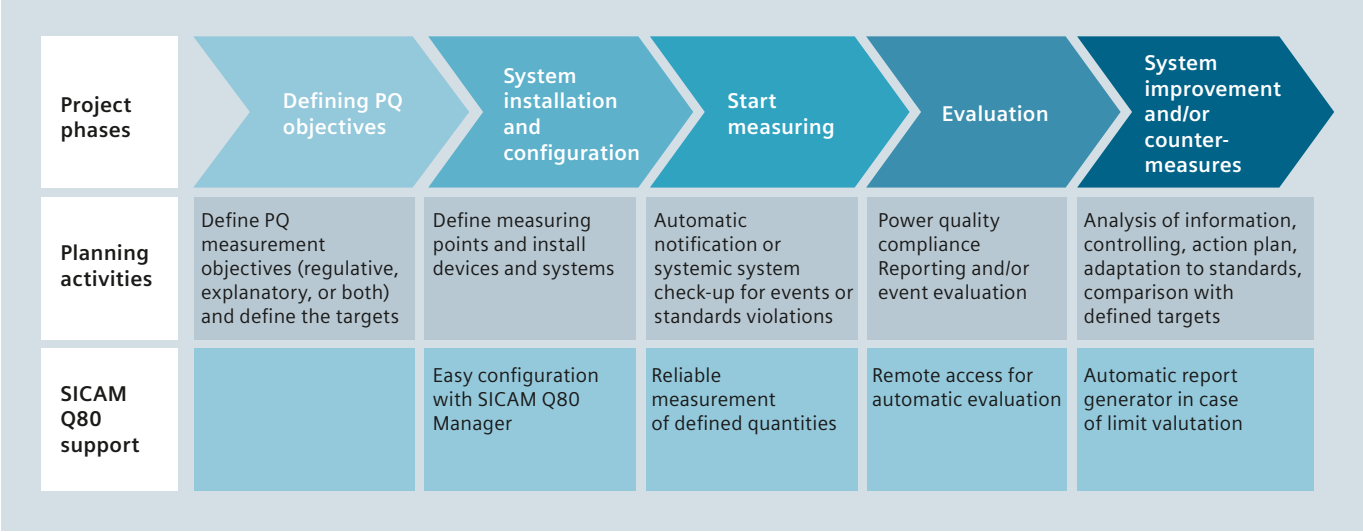


Fig. 6.4-3: **Power quality recording in five steps**

Standards

The purpose of power quality indexes and measurement objectives is to characterize power system disturbance levels. Such indexes may be defined as "voltage characteristics" and may be stipulated in a Grid Code that applies to electrical system interfaces. Power quality Grid Codes make use of existing standards or guidelines defining voltage and current indexes to be applied to interfaces in low, medium, or high-voltage systems, for example, EN 50160. This standard defines and describes the main characteristics of the voltage at the system operator´s supply terminals in public LV and MV power distribution systems. Indexes for HV-EHV will also be described in the new edition of EN 50160. Since electrical systems among regions and countries are different, there are also many other regional or national recommendations, mainly described in Grid Codes, defining specific or adapted limit values.

These local standards are normally the result of practical voltage quality measurement campaigns or the system experience, which are mostly acquired through a permanent and deep electrical system behavior know-how. Measuring according to EN 50160 is, however, only part of the power quality measurement process. Another important standard for power quality measurement is IEC 61000-4-30, which defines the measurement methodology.

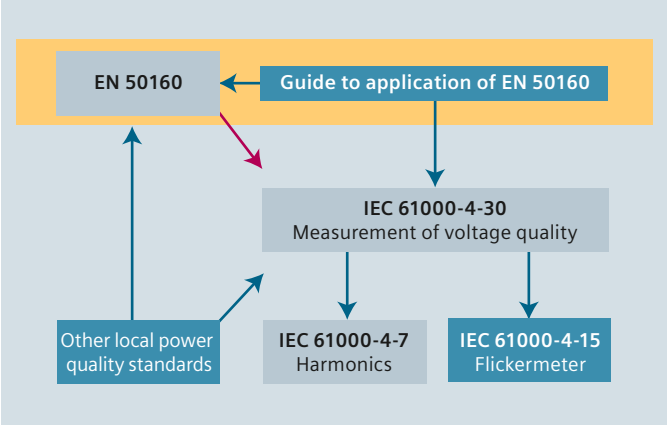


Fig. 6.4-4: **Overview of international and national standards for power quality**

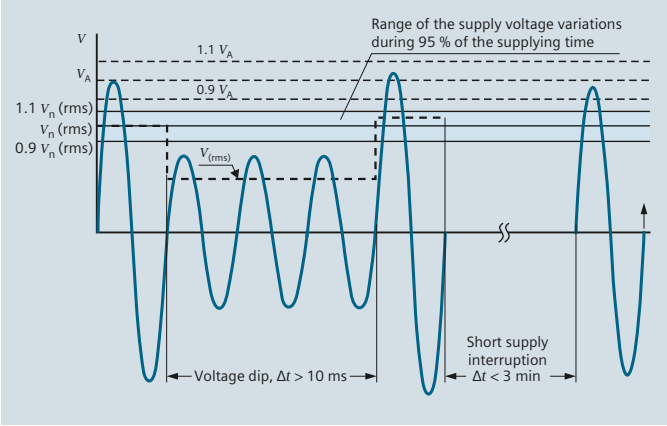


Fig. 6.4-5: **Illustration of a voltage dip and a short supply interruption, classified according to EN 50160; V_N – nominal voltage of the supply system (r.m.s.), V_A – amplitude of the supply voltage, $V_{(r.m.s.)}$ – the actual r.m.s. value of the supply voltage**

Parameter	Supply voltage characteristics according to EN 50160
Power frequency	LV, MV: mean value of fundamental measured over 10 s ± 1 % (49.5 – 50.5 Hz) for 99.5 % of week – 6 % / + 4 % (47 – 52 Hz) for 100 % of week
Voltage magnitude variations	LV, MV: ± 10 % for 95 % of week, mean 10 minutes r.m.s. values (fig. 6.4-5)
Rapid voltage changes	LV: 5 % normal 10 % infrequently $P_{lt} \leq 1$ for 95 % of week MV: 4 % normal 6 % infrequently $P_{lt} \leq 1$ for 95 % of week
Supply voltage dips	Majority: duration < 1 s, depth < 60 %. Locally limited dips caused by load switching on LV: 10 – 50 %, MV: 10 – 15 %
Short interruptions of supply voltage	LV, MV: (up to 3 minutes) few tens – few hundreds/year duration 70 % of them < 1 s
Long interruption of supply voltage	LV, MV: (longer than 3 minutes) < 10 – 50 / year
Temporary, power frequency overvoltages	LV: < 1.5 kV r.m.s. MV: 1.7 V_c (solid or impedance earth) 2.0 V_c (unearthed or resonant earth)
Transient overvoltages	LV: generally < 6 kV, occasionally higher; rise time: µs to ms MV: not defined
Supply voltage unbalance	LV, MV: up to 2 % for 95 % of week, mean 10 minutes r.m.s. values, up to 3 % in some locations
Harmonic voltage / THD	Harmonics LV, MV THD: 8
Interharmonic voltage	LV, MV: under consideration

Table 6.4-3: **Requirements according to EN 50160**

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
Order h	Relative voltage (%)	Order h	Relative voltage (%)	Order h	Relative voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6 ... 24	0.5
13	3	21	0.5		
17	2				
19	1.5				
23	1.5				
25	1.5				

Table 6.4-4: **Values of individual harmonic voltages at the supply terminals for orders up to 25, given in percent of V_N**

From IEC 61000-4-30 also accuracy classes, Class A "higher accuracy" and Class S "lower accuracy" are derived. In other words, in a simple way, if the EN 50160 defines "what" to measure, the IEC 61000-4- 30 defines "how" to measure it. The end result of a measurement process is expected to be fully automated, standard compliant documentation of all measurements.

Calculation of r.m.s. values after every half period is the touchstone of an IEC 61000-4-30 Class A measurement device. To defi ne the range of normal voltage states, a hysteresis range is specifi ed for event detection. SICAM Q80 meets the precision requirements for a Class A measurement device according to the IEC 61000-4-30 standard.

IEC 61000-4-30, Ed. 2, 2008-10:
Power Quality Measurement Methods: This standard defines the methods for measurement and interpretation of results for power quality parameters in AC supply systems.

IEC 61000-4-15:1997 + A1:2003:
Flickermeter, Functional and Design Specifications: This section of IEC 61000 provides a functional and design specification for flicker measuring apparatus intended to indicate the correct flicker perception level for all practical voltage fluctuation waveforms.

IEC 61000-4-7, Ed. 2, 2002-08:
General Guide on Harmonics and Interharmonics: This is a general guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

Definition of a measuring point and power quality measurement objectives
Power quality measurements address the aspect of power performance by describing the quality of every individual interface in an electrical system and in the networks of its various customers. Identifying, defining, profiling the power quality measurement points are essential tasks in defining a power quality project. However, the electrical system is dynamic by nature, so optimizing the measuring points is a routine that is developed by day-to-day learning. This may not help predict changes, but will permit a more effective response to them.

Identification of measuring points
Measurement points may be located and defined as shown in table 6.4-5.

Measuring power quality requires not only an effective choice of measuring points but also defined objectives for the PQ analysis at the measuring points.

We generally classify "power quality" monitoring as a mixture of data gathering technologies classified by their purpose or application.

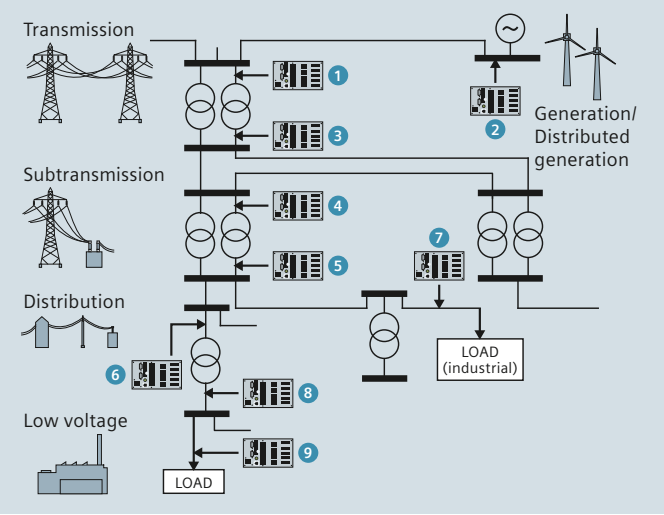


Fig. 6.4-6: **General system online diagram**

No.	Measurement points	Location
1	Transmission feeder (line or transformer)	Possibly busbar
2	Generation station / distributed generation	Busbar, transformer or generator connection
3	Subtransmission, line supply	Busbar (e.g. where the busbar is owned and operated by the transmission company)
4	Subtransmission feeder (line or transformer)	Remote line terminals (e.g. where the lines are owned and operated by the transmission company)
5	Distribution, line supply	Transformer secondary side or cable to neighbor's substation
6	Distribution feeder (line or transformer)	Step-down transformers
7	Distribution load	Step-down transformers, (e.g. where the transformers are owned by the distribution company)
8	LV supply	Transformer of the distribution company
9	LV load	Load or transformer at the customer

Table 6.4-5: **Measurement points and system location**

6.4.2 SICAM P Power Meter

SICAM P is a power meter for panel mounting with graphic display and background illumination, or for standard rail mounting, used for acquiring and/or displaying measured values in electrical power supply systems. More than 100 values can be measured, including r.m.s. values of voltages (phase-to-phase and/or phase-to-ground), currents, active, reactive and apparent power and energy, power factor, phase angle, harmonics of currents and voltages, total harmonic distortion per phase plus frequency and symmetry factor, energy output, as well as external signals and states.

SICAM P is available with mounting dimension of 96 mm × 96 mm and can be ordered with or without display.

The SICAM P comes standard with two binary outputs, which can be configured for energy counters, limit violations or status signals. By ordering, SICAM P can be fitted with 1 additional analog input or output modules.

The unit is also able to trigger on settable limits. This function can be programmed for sampled or r.m.s. values. SICAM P generates a list of minimum, average and maximum values for currents, voltages, power, energy, etc. Independent settings for currents, voltages, active and reactive power, power factor, etc. are also possible. In case of a violation of these limits, the unit generates alarms. Up to 6 alarm groups can be defined using AND/OR for logical combinations. The alarms can be used to increase counter values, to trigger the oscilloscope function, to generate binary output pulses, etc.

Fig. 6.4-7: **SICAM P – power meter**

Function overview

- Measurement of voltage, current, active & reactive power, frequency, active and reactive energy, power factor, symmetry factor, voltage and current harmonics up to the 21st, total harmonic distortion
- Single-phase, three-phase balanced or unbalanced connection, four-wire connection
- Communications: PROFIBUS-DP, MODBUS RTU / ASCII or IEC 60870-5-103, MODBUS RTU/ ASCII (only SICAM P50 Series) communication protocol
- Simple parameterization via front key or RS485 communication port using SICAM P PAR software

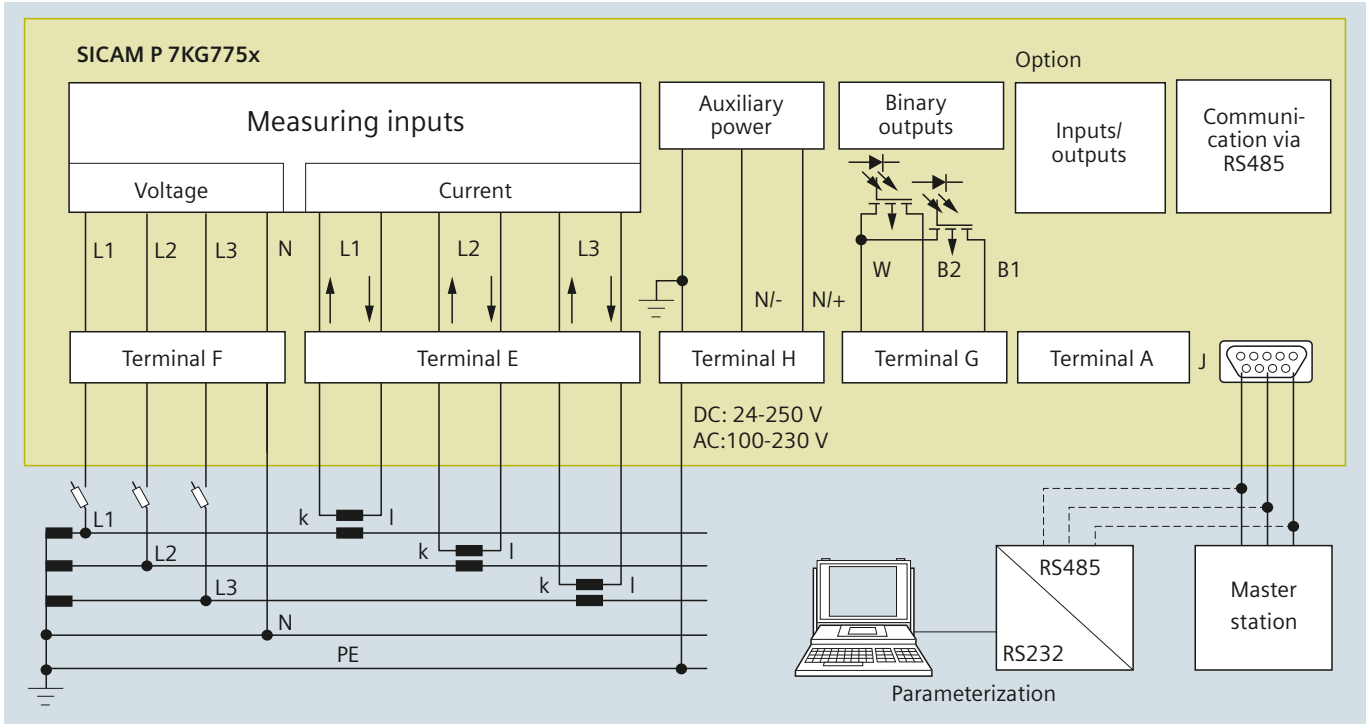


Fig. 6.4-8: **Input/outputs for P50 Series**

- Graphic display with background illumination with up to 20 programmable screens
- Real-time clock: Measured values and states will be recorded with time stamps
- 1 MB memory management: The allocation of the nonvolatile measurement memory is programmable
- Recording and display of limit value violations and log entries.
- Battery: Recordings like limit value violations or energy counter values stay safely in the memory up to 3 months in case of a blackout.

Applications

Power monitoring systems with SICAM P, a permanently installed system, enables continuous logging of energyrelated data and provides information on operational characteristics of electrical systems. SICAM P helps identify sources of energy consumption and time of peak consumption. This knowledge allows to allocate and reduce energy costs.

The major application area is power monitoring and recording at MV and LV level. The major information types are measured values, alarms and status information.

SICAM P50/P55

Input and output modules

SICAM P50/P55 can be equipped with additional analog or digital input or output modules. SICAM P50/P55 comes with 1 slot where the module may be installed. For different application areas, 5 different modules are available.

Application

The input modules can be used for acquisition, display and further processing of external signals with a measurement range of 0–20 mADC.

Measured values can be shown together with their units on the display. Transmission of the current status of a measured signal to a central master station via PROFIBUS-DP V1, MODBUS RTU/ASCII or IEC 60870-5-103 is also possible.

In addition, mean values of all external analog channels as well as states of digital channels can be recorded and saved into the memory.

All recorded quantities and binary state information can be "read out" and evaluated with the configuration software SICAM P Manager.

Output modules can be used for conversion of any electrical quantity (current, voltage, etc.) into a 0–20/4–20 mADC output signal, generation of impulses for metering, indication of limit value violations, as well as for switching operations.

Module assignment

The assignment of the different analog/digital modules can only be done in the course of an order of a SICAM P. A change or a retrofit of modules of an existing SICAM P is not possible.

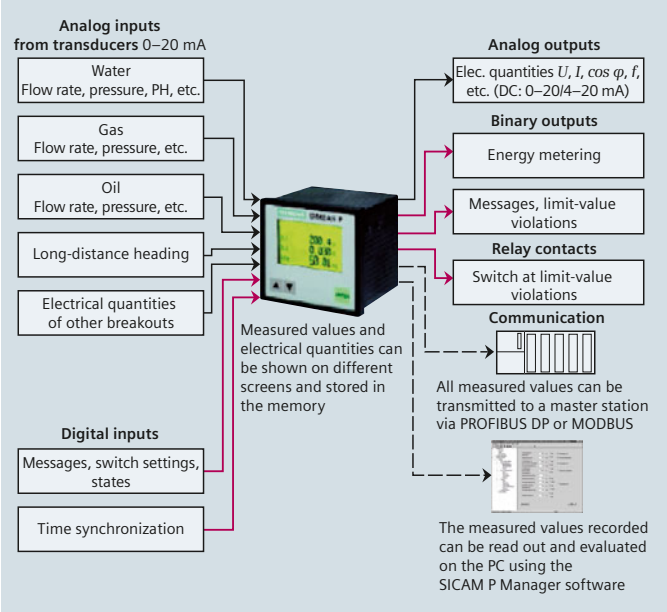


Fig. 6.4-9: **SICAM P sample applications**

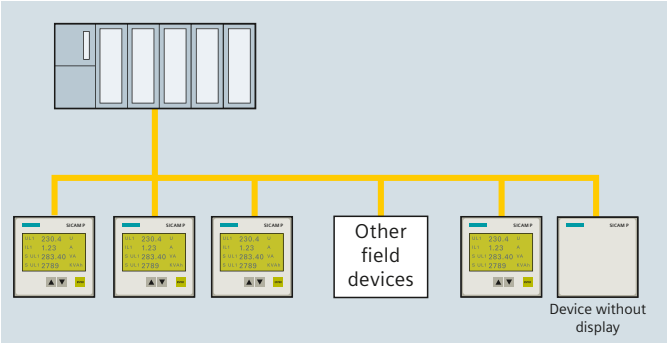


Fig. 6.4-10: **SICAM P with PROFIBUS-DP, MODUBS and IEC 60870-5-103**

Fig. 6.4-9 shows an example of extended I/O for various applications.

Application example (fig. 6.4-10)

SICAM P as a panel-mounted or snap-on mounted device for use on a process bus.

Network linking is possible with the integrated RS485 port with the standard PROFIBUS-DP and MODBUS RTU/ASCII communication protocol. Furthermore, it is also possible to integrate SICAM P50 into communication networks with IEC 60870-5-103 as standard protocol. That allows several SICAM P measured parameters to be indicated, evaluated and processed at a central master station.

The major application area is the integration into PLC systems as a transducer.

6.4.3 SICAM T – Electrical Measurement Transducer

The SICAM T is an digital measurement transducer that allows the measuring of electrical quantities in electrical networks in a single unit. In industries, power plants and substations, transducers are especially used for measurand (e.g. current, voltage, power, phase angle, energy or frequency) assignment into further processing through analog outputs or communication interface for precise control, notification or visualization tasks.

Device type
- Top-hat rail mounted device
- Plastic case 96 mm × 96 mm × 100 mm / 3.7795 × 3.7795 × 3.9370 inch (W × H × D)
- Degree of protection IP20.

Input and output circuits
- 4 inputs for alternating voltage measurements
- 3 inputs for alternating current measurements up to 10 A continuous
- 4 optional DC analog outputs freely configurable:
  - Direct currents: 0 mA to 20 mA, 4 mA to 20 mA and –20 mA to 20 mA
  - Direct voltages: 0 V to 10 V and –10 V to 10 V
- individually programmable binary outputs.

Signalization LEDs
- Automatically monitor the functions of the hardware, software and firmware components.

Communication
- Ethernet: IEC 61850 or MODBUS TCP communication protocol
- Optional serial RS485 interface that enables the device to communicate via the MODBUS RTU or the IEC 60870-5-103 communication protocol.

Measurands
The following measurands can be recorded or calculated from the measured quantities:
- TRMS (True RMS) for alternating voltage and current

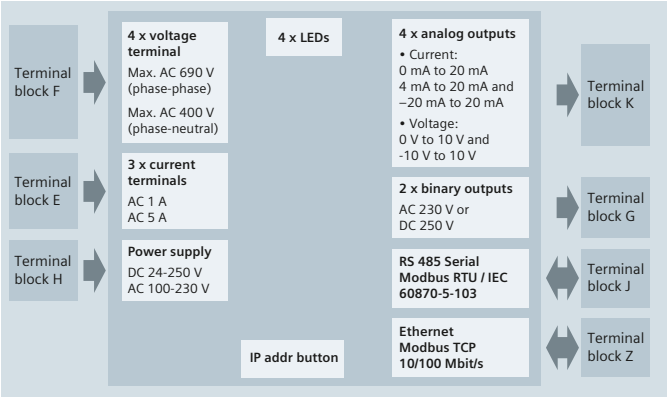


Fig. 6.4-11: **Block diagram SICAM T 7KG9661**

Fig. 6.4-12: **SICAM T electrical measurement transducer**

- Active, reactive and apparent power
- Active, reactive and apparent energy
- Power frequency
- Phase angle
- Power factor and active power factor
- Voltage and current unbalance
  - Mean value of the 3 phase voltages: V_{avg}
  - Mean value of the 3 phase currents: I_{avg}

Time synchronization
For a common time basis when communicating with peripheral devices and time stamping of the process data.
- External time synchronization via Ethernet NTP
- External time synchronization via field bus using the MODBUS RTU or the IEC 60870-5-103 communication protocol
- Internal time synchronization via RTC (if external time synchronization is not available).

Response time for analog and binary outputs
The faster response time of the analog and binary output is a very important feature of SICAM T that enables a reliable reaction of the controlling applications. The response time of the device is 120 ms at 50 Hz and 100 ms at 60 Hz.

Applications
- Conversion and integration of measurands into substation automation, protection or SCADA process via RTU and/or via protocols IEC 61850 (for KG9662 variant), MODBUS TCP, IEC 60870-5-103 for further control and/or monitoring tasks
- Monitoring of lower voltage levels and heavy load control, e.g. air conditioning and motors
- Depending on the device type, the input circuits for voltage measurement are either designed as voltage dividers or they are galvanically isolated. Devices with galvanic isolation can be used without voltage transformers in the power systems IT, TT and TN. Devices with a voltage divider can also be used in these power systems; for IT power systems, however, an upstream voltage transformer is required.

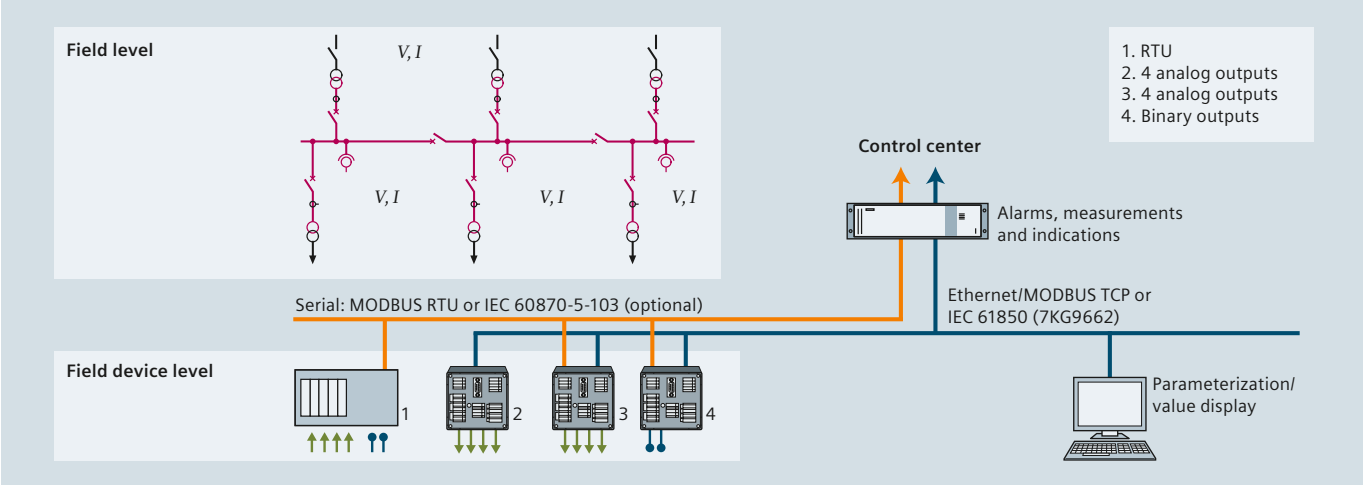


Fig. 6.4-13: **SICAM T applications**

Main features

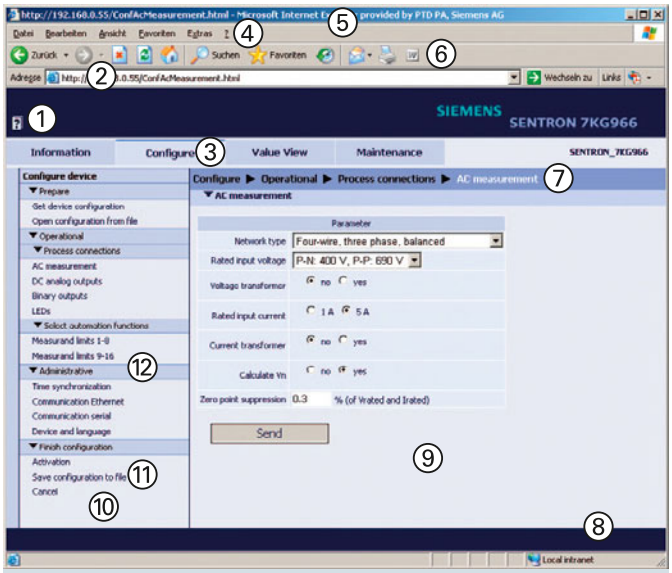
- Design: compact and robust for flexible application in industrial and utility environments
- Connections in 1-phase systems, in 3-wire and 4-wire systems
- Applications: flexible for power utilities, industrial and commercial sectors applications
- Measurements: up to 60 measured or calculated values available
- Temperature range: –25 °C to +55 °C / –13 to 131 °F
- High accuracy: typically 0.1 % for voltage and current at rated input IEC 60688, and 0,2s acc. to IEC 62053-21
- High EMC immunity: according to standards EN 61000-6-2 and EN 61000-6-4 for the EMC directives, and with the standard EN 61010-1 for the low-voltage directive
- UL Certfication: This product is UL-certified to Standard UL 61010-1.

SICAM T applications

Local monitoring or control purposes through assignment of up to 60 available electrical parameters to analog outputs, notifications through binary outputs or integration into SCADA/monitoring systems through communication interface, e.g. serial or Ethernet (fig. 6.4-13).

Highlights

- Flexible current measurement range (up to 2 × I_n)
- 4 fast analog outputs (reaction approx. 120 ms at 50 Hz and 100 ms at 60 Hz) for reliable control
- 2 individually binary outputs for fast switching, indications (e.g. limit violation) and operation status monitoring
- 4 LEDs for local status visualization
- Ethernet communications via IEC 61850 and Modbus TCP and serial interface via MODBUS RTU or IEC 60870-5-103
- Internal battery for real time clock and saving of energy counter values in case of a power outage
- User-friendly operation through Web server (no extra software for parameterization needed, no converters and extra cables)
- Real time clock (RTC), field bus synchronization or network synchronization possible via NTP.



① Online help
② Address bar
③ Tab
④ Menu bar
⑤ Microsoft Internet Explorer
⑥ Toolbar
⑦ Navigation bar
⑧ Status bar
⑨ Input/output window
⑩ Navigation window
⑪ Element
⑫ Menu

Fig. 6.4-14: **Layout of the SICAM T GUI user interface**

Graphical user interface

Parameterization and monitoring software

The device is configured from a connected PC or notebook only. The user interface SICAM T GUI (GUI = Graphical User Interface) is implemented in the device, meaning that for the whole operation and parameterization of the device no additional software is required. It is possible to navigate through the Microsoft Internet Explorer using the icons on the toolbar.

Device status, so as communication, parameterization, log files, value view and maintenance can be easily processed through SICAM T GUI interface (fig. 6.4-14).

6.4.4 Monitoring and Analysis of Voltage Quality with SICAM Q80

Power quality is a complex issue. The voltage quality is affected by all parties connected in the power system: power utilities of transmission and distribution, power producers and consumers. Inadequate power quality has an adverse effect on the dependability of loads in the power supply system, and can have serious consequences. SICAM Q80 is a compact and powerful recorder designed for utilities and industries to continuously monitor the power quality for regulatory purposes (e.g., evaluation against the standards) as well as event-based recordings for explanatory purposes (e.g., wave shape recording), from the generation plant to the last customer in the electrical supply chain.

With SICAM Q80, the quality of the power supply system can be continuously monitored. This can be based on the quality criteria defined in the European electricity supply system quality standard EN 50160 or other assessment criteria. Moreover, data that are above or below the defined threshold values are stored and can thus be used for a meaningful overall analysis. It provides information that allows to see the whole electrical healthy of the power system!

Fig. 6.4-15: **SICAM Q80 – the quality recorder**

Field of application of SICAM Q80

- Regulatory power quality application: measurement, comparison and profiling of power quality parameters at the individual electrical system interfaces: e.g., generation, transmission, subtransmission and distribution systems.
- Explanatory power quality application: disturbance recording (e.g., waveform capture) support to understand the causes and consequences of power quality problems.

Benefits

- Customer satisfaction: Companies with a suitable power quality monitoring system are proven to be more reliable suppliers and users of energy.
- Asset protection: Early identification of disturbances and active response to them. Comprehensive information for enhancing the visibility and control of assets at the edge of the grid.
- In case of negotiations or disputes, power quality monitoring provides evidences to align interests and to support agreements between parts.
- Quality of supply is in the interests of power utilities, regulators, consumers and the environment.

Function overview

Measurement of continuous phenomena and disturbances according to the necessary accuracy requirements, as stipulated in IEC 61000-4-15, IEC 61000-4-7 and IEC 61000- 4-30 (Class A).

Recording and evaluation

- Voltage frequency: frequency deviation
- Slow voltage variation: detection and monitoring of supply interruption
- Rapid voltage variations: voltage dips, voltage swells, rapid voltage changes and voltage fluctuations (flicker)
- Power line signaling superimposed on the supply voltage
- Voltage waveshape: harmonics (up to the 50th harmonic) and up to 10 interharmonics
- Flexible value limit and event definition
- Fault recording triggered by waveform and binary values
- Comparison and reporting of power quality profile according to EN 50160 or local standards.

Features

- Suitable for monitoring single-phase, 3- and 4-wire power systems (up to 1,000 V_{rms})
- 4 voltage, 4 current, or 8 voltage measuring channels
- Standard: 4 binary inputs, 4 binary outputs
- Sampling rate 10 kHz for network analysis
- Measurement accuracy 0.1 % of the range
- High local storage capability: removable compact flash (standard delivery 2 GB)
- Enhanced data compression process (power quality data)
- Automatic data transfer
- Automatic comparison and reporting of the power quality profile according to EN 50160 or your local standards
- Automatic notification in case of a fault or violations by e-mail, SMS, and fax
- Export functions
- Ethernet and modem communication interfaces for parameterization, remote monitoring and polling
- GPS / DCF-77 / IRIG-B and NTP for synchronization
- Network trigger system
- Simple operation, compact and robust design.

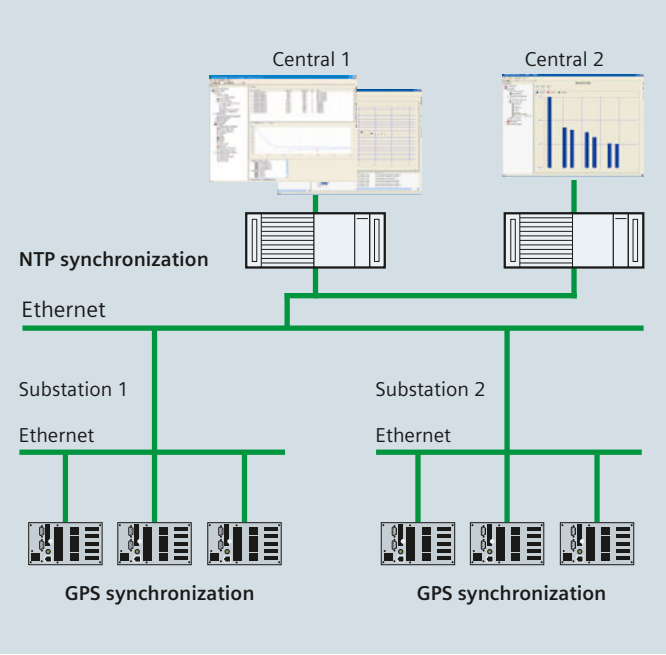


Fig. 6.4-16: **Model configuration for a PQ monitoring system**

6.4.5 SIPROTEC 7KE85 – Digital Fault Recorder with integrated Power Quality (PQ)* Measurement and Phasor Measurement Unit (PMU)

Application

- Stand-alone stationary recorder for extra-high, high and medium-voltage systems
- Component of secondary equipment of power plants and substations or industrial plants

Function overview

- Integration to SIPROTEC 5 family
  - Consistent HW concept
  - Variety of extension modules
  - DIGSI as configuration tool
  - Choice of functionality via functional points
- Disturbance recorder class S for applications in substations at MV / HV / EHV level and in power plants
  - 1 × FastScan recorder
  - 2 × SlowScan recorder
  - 5 × Continuous recorder
- Power quality recorder class S according to EN50160 for analysis and recording / archiving of power quality problems of all power applications
- Event recorder for binary signals for observation of the status of various primary components like circuit-breakers, disconnectors, etc.
- PMU according to IEEE C37.118.
- Communication with IEC 61850
- Sampling frequencies programmable between 1kHz and 16KHz
- Time synchronization via IRIG B / DCF77 / SNTP
- Internal mass storage:
  - 12 GByte ring buffer
  - Health monitoring / Lossless data compression
- Flexible routing
  - Any assignment of a measured value to each recorder
  - Free combination of measuring groups for power calculation
- Recorded quality bits
  - Quality statement for each recorded value + monitoring of channel quality in SIGRA or SIC AM PQ Analyzer
- Recording of and triggering on GOOSE values
- Creating of flexible trigger conditions with CFC (Continuous Function Chart)
- Auxiliary functions for simple tests and comissioning
- Test recorder for commissioning and system test

*in preparation

Fig. 6.4-17: **Generator and motor protection device 7KE85**

Fig. 6.4-18: **Expansion module**

Fig. 6.4-19: **Rear view of a basic module**

Application as Phasor Measurement Unit
With the digital fault recorder 7KE85, the function "Phasor Measurement Unit" (PMU) is available like in the past.

Fig. 6.4-20 shows the principle. A measurement of current and voltage with regard to amplitude and phase is performed with PMUs on selected substations of the transmission system. Due to the high-precision time stamps assigned to these phasor quantities by the PMU, these measured values can be displayed together at a central analysis point. This provides a good overview of the condition of the system stability, and enables the display of dynamic processes, e.g., power swings.

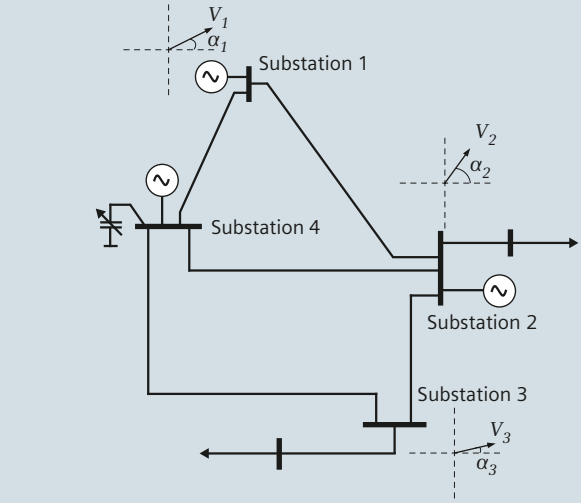


Fig. 6.4-20: **Principle of distributed phasor measurement**

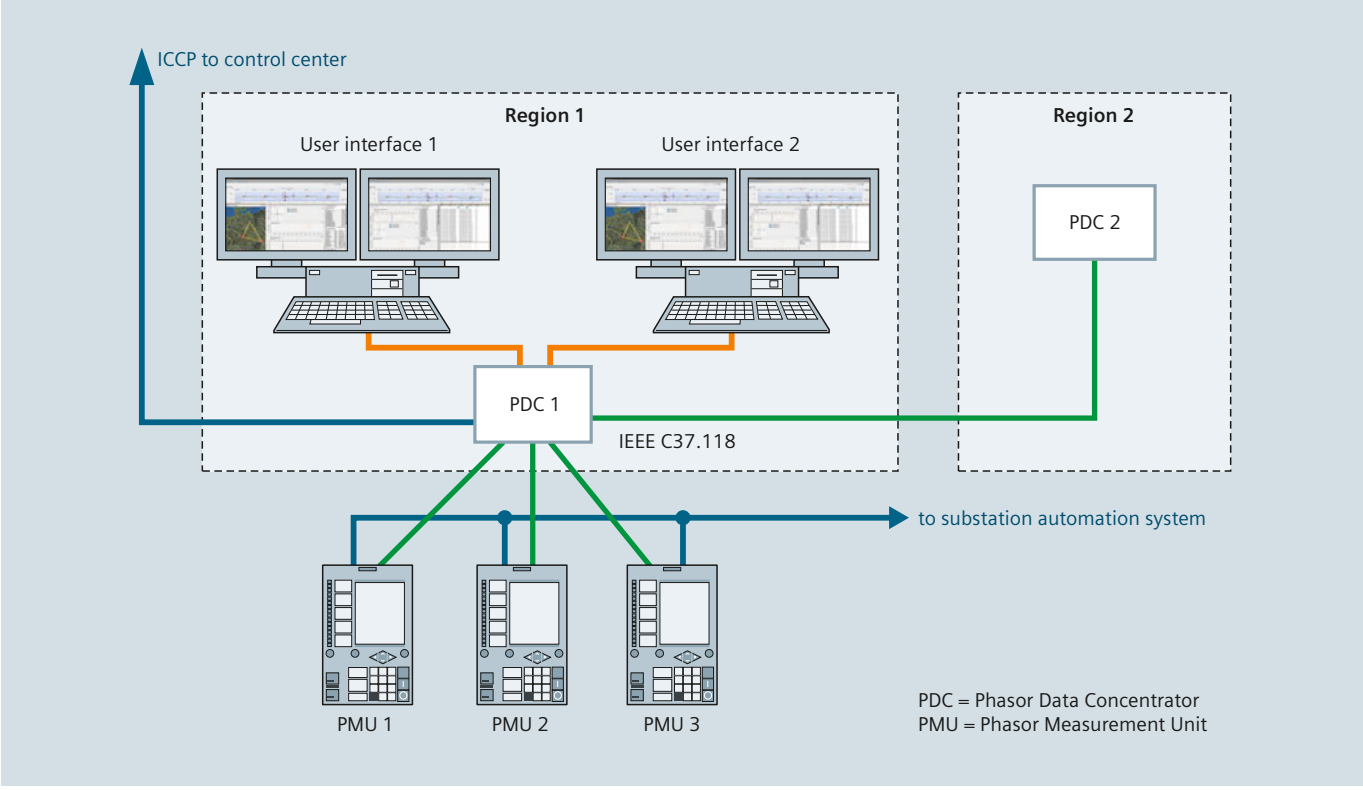


Fig. 6.4-21: **Connection of 3 Phasor Measurement Units with two Phasor Data Concentrators (PDCs) SIGUARD PDP**

If the option "Phasor Measurement Unit" is selected, the devices determine current and voltage phasors, mark them with high-precision time stamps, and send them to a phasor data concentrator together with other measured values (frequency, rate of frequency change) via the communication protocol IEEE C37.118, see fig. 6.4-21.

By means of the synchrophasors and a suitable analysis program (e.g., SIGUARD PDP) it is possible to determine power swings automatically and to trigger alarms, which are sent, for example, to the network control center.

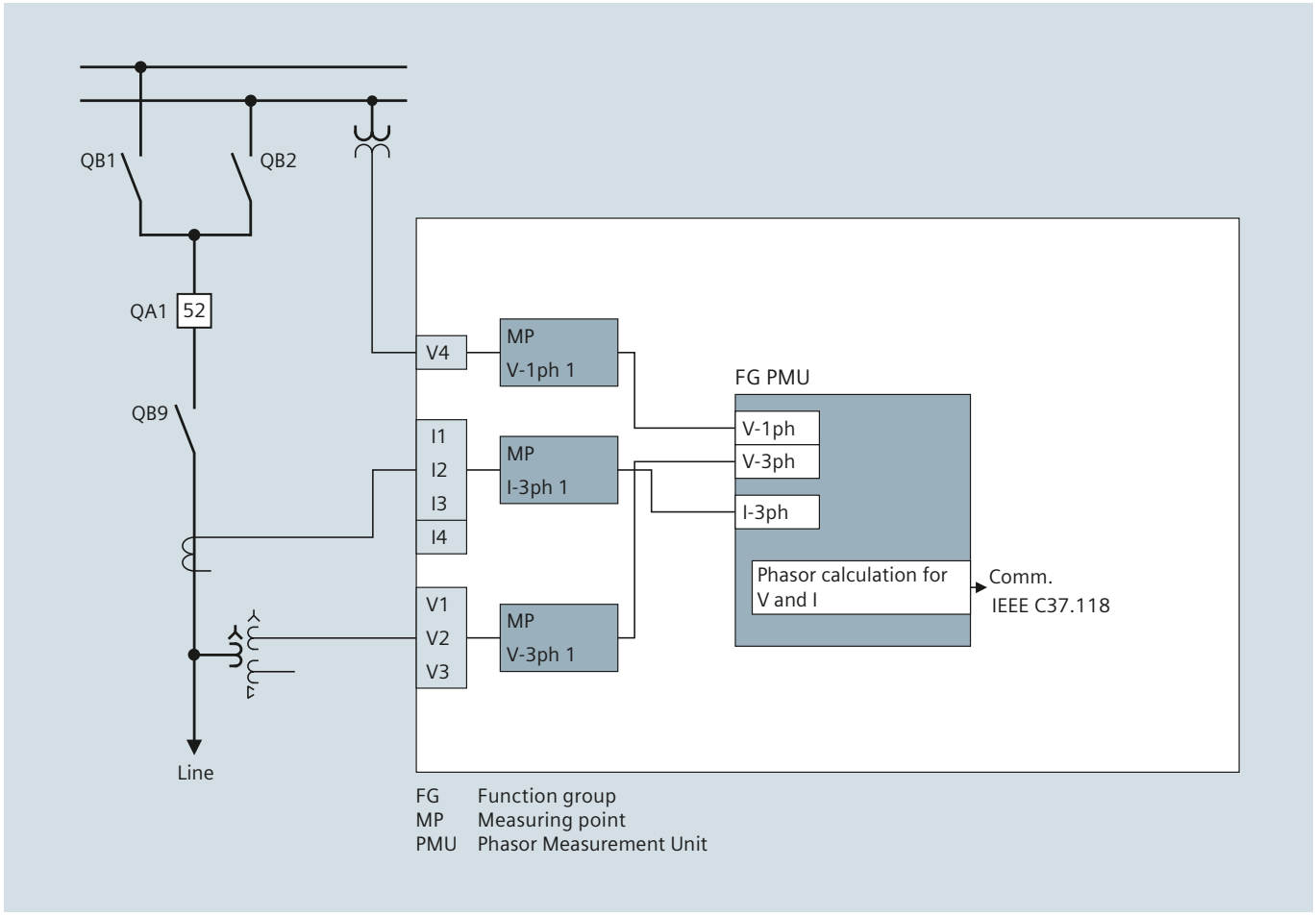


Fig. 6.4-22: **Application example**

When the PMU function is used, a "PMU" function is created in the device, see fig. 6.4-22. This function group calculates the phasors and analog values, sets the time stamps, and sends the data to the selected Ethernet interface with the protocol IEEE C37.118. There they can be received, stored and processed by one or more clients. Up to three client IP addresses can be allocated in the device.

Information for project planning with 7KE85

The secondary components of high or medium-voltage systems can either be accommodated in a central relay room or in the feeder-related low-voltage compartments of switchgear panels. For this reason, the 7KE85 system has been designed in such a way as to allow both centralized or decentralized installation.

The 7KE85 can be delivered in different widths, depending on the selected IO combinations. For example the small version is favorable if measurands of only one feeder are to be considered (8 analog and 8 binary signals).This often applies to high-voltage plants where each feeder is provided with an extra relay kiosk for the secondary equipment. In all other cases the extension with more analogue und binary signals via IOs is more economical.The modular structure with a variety of interface and communication modules provides a maximum of flexibility.

Typical applications of 7KE85

- Monitoring the power feed
  Monitoring the infeed from a high-voltage network via 2 transformers on two busbars of the medium-voltage network. This application is relevant for the infeeds of municipal utilities companies and medium to large industrial enterprises (fig. 6.4-24).
- Monitoring the infeed (fig. 6.4-24)

Fault monitoring and power quality in power distribution networks

Power supply companies with distribution networks are not only suppliers but also consumers, particularly of renewable energy. Therefore, it is important to monitor power quality both at the transfer points of critical industrial enterprises and at the power supply points of the suppliers (fig. 6.4-25).

Monitoring power quality in an industrial enterprise

All industrial enterprises with sensitive productions need to document the power quality at the transfer point, and thus document any claims for damages against the suppliers. For internal control, it is important to monitor individual breakouts with regard to cost-center accounting and specific quality features (fig. 6.4-26).

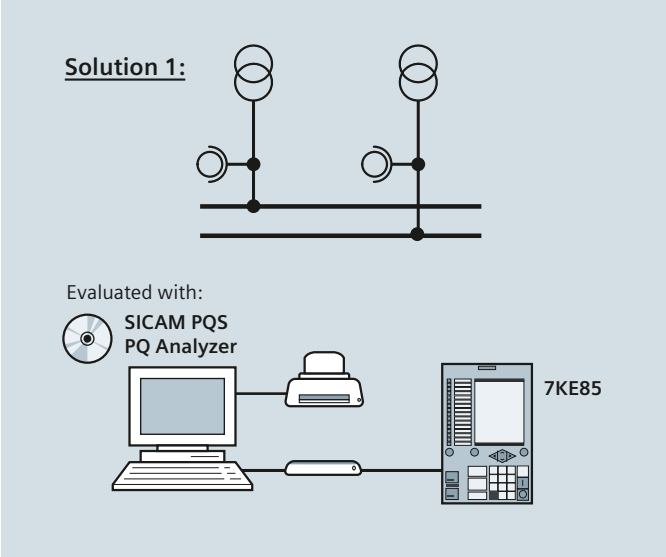


Fig. 6.4-23: **Monitoring the power feed**

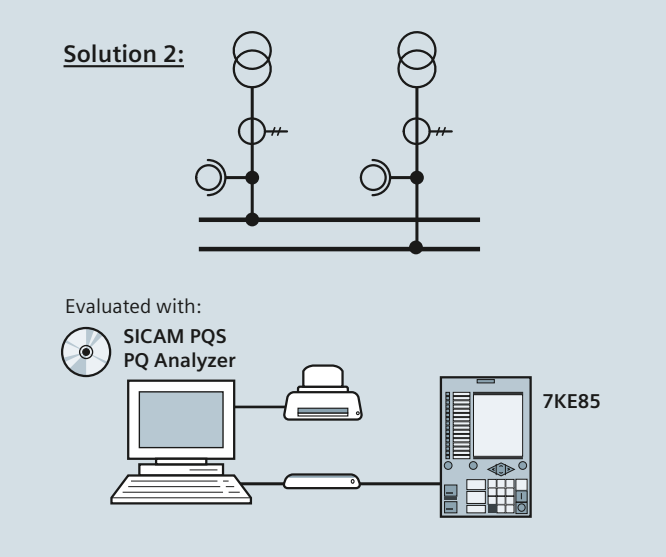


Fig. 6.4-24: **Monitoring the infeed**

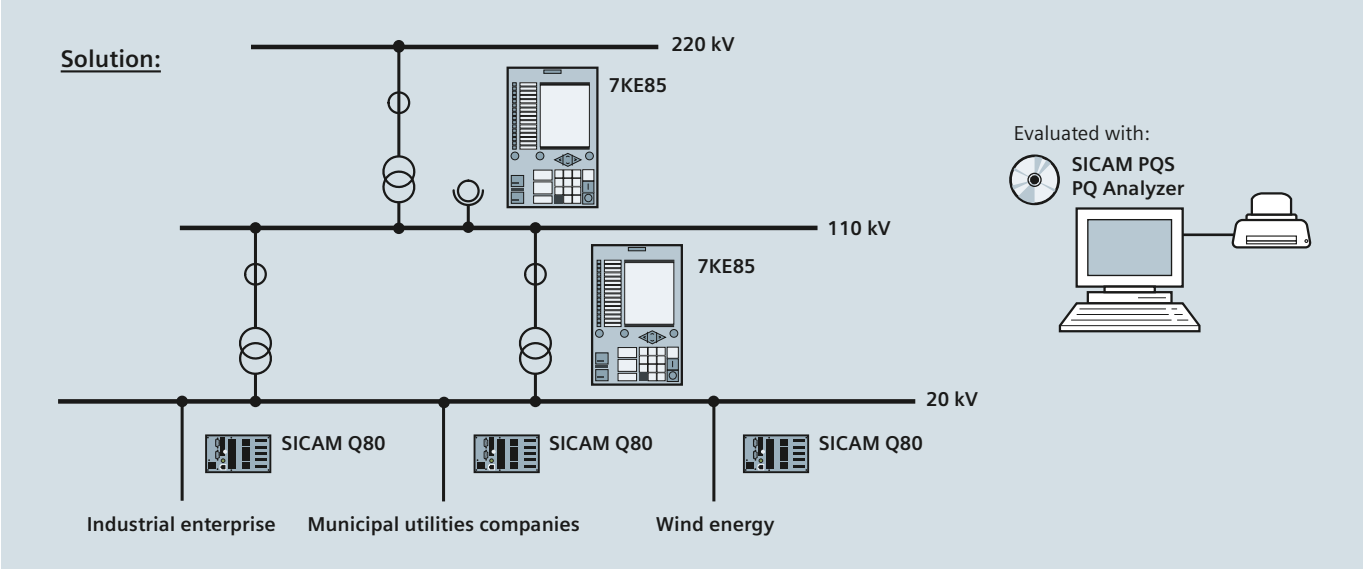


Fig. 6.4-25: **Monitoring the quality in power distribution systems**

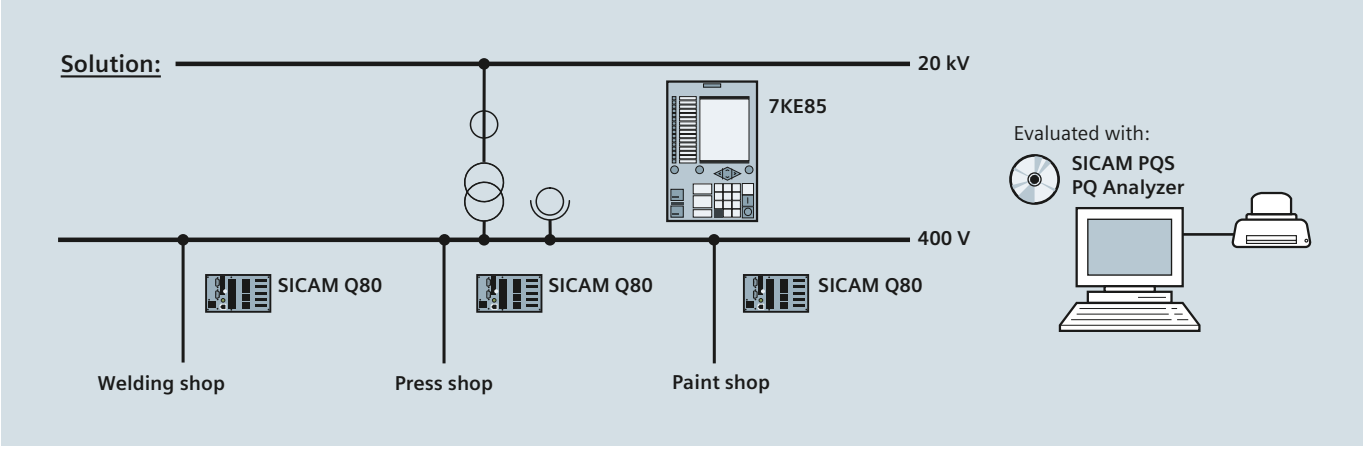


Fig. 6.4-26: **Monitoring the power quality in an industrial enterprise**

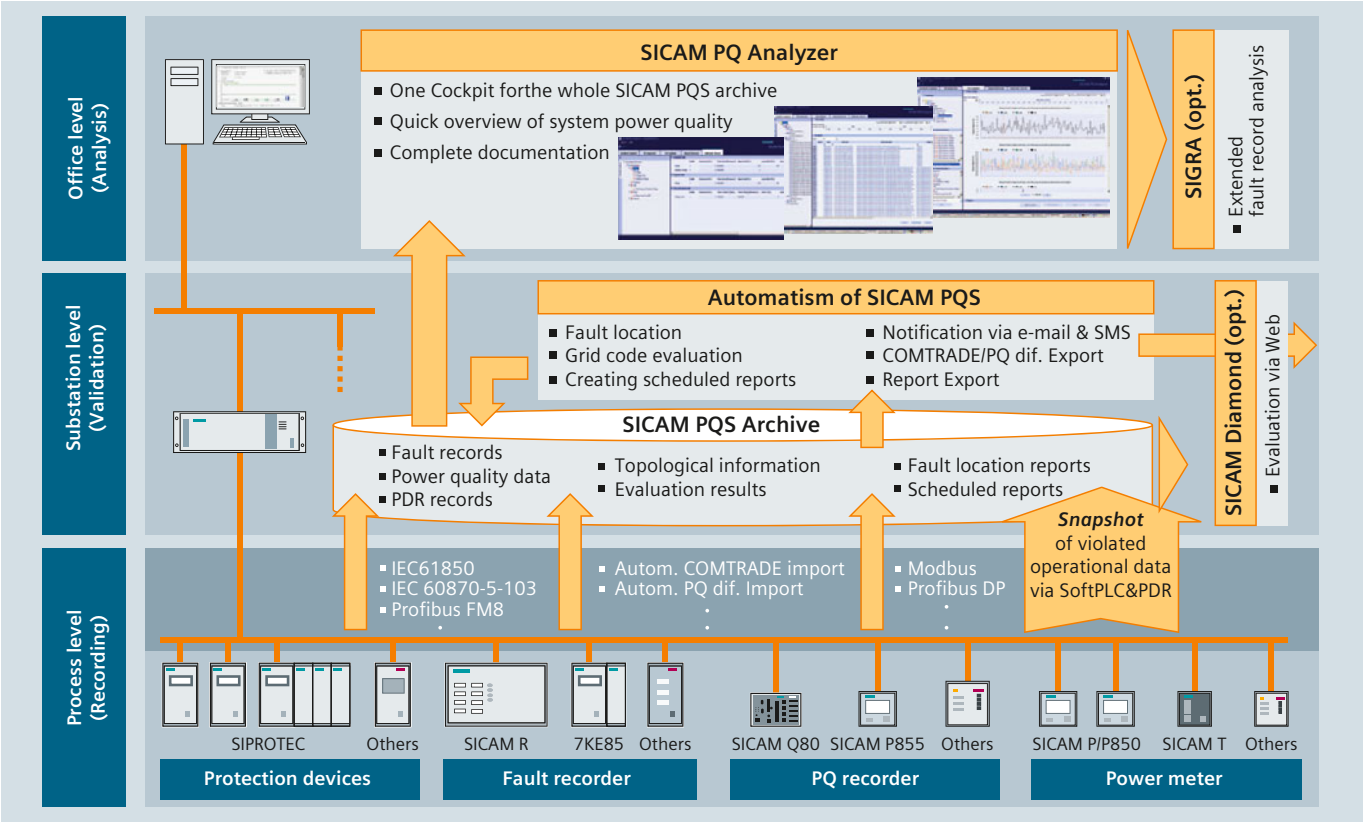


Fig. 6.4-27: **SICAM PQS – One System for all Power Quality Data**

SICAM PQS fault record and power quality analysis software
The SICAM PQS software package is suitable for use in personal computers provided with the operating systems MS Windows 7. It is used for remote transmission IEC61850, evaluation and archiving of the data received from 7KE85, digital protection devices as well as from SICAM Q80 power quality recorders. The program is used to setup the system configuration and to parameterize the 7KE85 and SICAM Q80 units installed in the field. It enables fully-automated data transmission of all recorded data (fault records, events, mean values) from the acquisition units to one or more networked SICAM PQS evaluation stations; the received data can then be immediately displayed and evaluated and benchmarked according to quality standards so called Grid Codes (fig. 6.4-27).

SICAM PQS offers a variety of applications and evaluation tools enabling the operator to carry out detailed fault record analysis by using time diagrams with curve profiles, vector diagrams etc. The individual diagrams can, of course, be adjusted to individual requirements with the help of variable scaling and zoom functions. The different quantities measured can be immediately calculated by marking a specific point in a diagram with the cursor (impedance, reactance, active and reactive power, harmonics, peak value, r.m.s. value, symmetry, etc.).

Additionally automatic distance to fault calculation and report generation will be executed after an event was recognized in the power supply system.

The power quality analysis is based on the applicable standards EN 50160 and IEC 61000 or on any user-defined Grid Code, and uses an effective reporting tool that provides automatic information about any deviations from the defined limit value.

The data transmission is preferably effected via WAN (Wide Area Network) or telephone network. Depending on the power system which has to be monitored the SICAM PQS system can be aligned accordingly. The modular structure of SICAM PQS permits the use of individual functional packages perfectly matched the requirements. Furthermore the SICAM PQS can also easily expand to create a station control system for combined applications. The program fully supports server / client system architecture.

Highlights
- Vendor-neutral integration of fault recorders, protection devices and power quality equipment via standard protocols or COMTRADE/PQDIF import
- Quick overview of system quality through the chronological display of the PQ index
- Seamless documentation of power system quality
- Automatic notification in case of violation of thresholds of a predefined Grid Code.
- Automatic and precise fault location with parallel line compensation
- Structured, consistent and permanent data documentation and archiving
- Automatic generation of cyclic power quality report

SICAM PQS functional packages

Incident explorer

Incident explorer is the central navigation interface of SICAM PQS. It acts as a cockpit for the user and delivers a structured overview of events throughout the whole system. It visualizes the contents of the entire power quality archive with fault records, fault locating reports, post-disturbance review reports, power quality reports, and the ability for manual fault location and manual import of comtrade files. The comtrade viewer, which is part of the scope of delivery, makes it possible to analyze the fault (fig. 6.4-28).

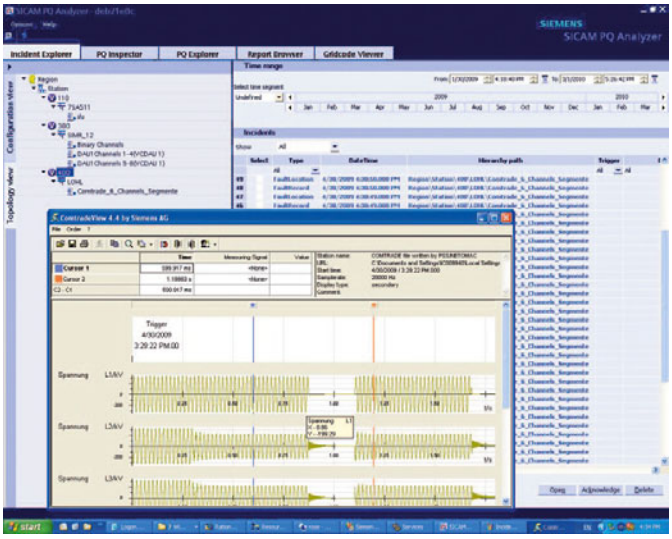


Fig. 6.4-28: **Incident explorer**

PQ inspector

The PQ inspector is a supplementary module that shows at a glance the power quality condition of the entire network for a selected period. This allows for quick identification of the origin and type of violation. Another feature of PQ inspector is the option of generating power quality reports through step-by-step user prompting and on the basis (fig. 6.4-29).

Fig. 6.4-29: **PQ inspector**

PQ explorer

PQ explorer makes detailed analyses possible based on comparing the measured power quality data directly with the Grid Codes. This comparison and the large number of different diagrams available for displaying power quality data make it possible to understand the nature and extent of a power quality violation very quickly and to initiate adequate (fig. 6.4-30).

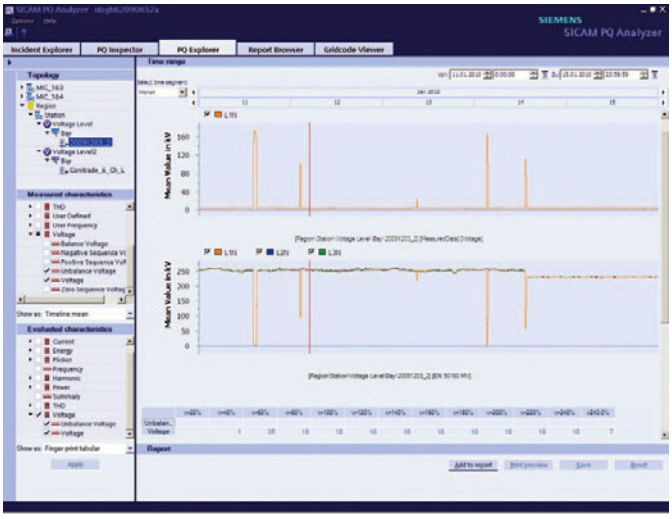


Fig. 6.4-30: **PQ explorer**

Report browser
Reports are created automatically at weekly, monthly, and annual intervals and in the event of a violation of the Grid Code. The report browser shows an overview of these automatically generated reports in selected time ranges and the assessment of the results. The individual reports can be opened directly in the report browser (fig. 6.4-31).

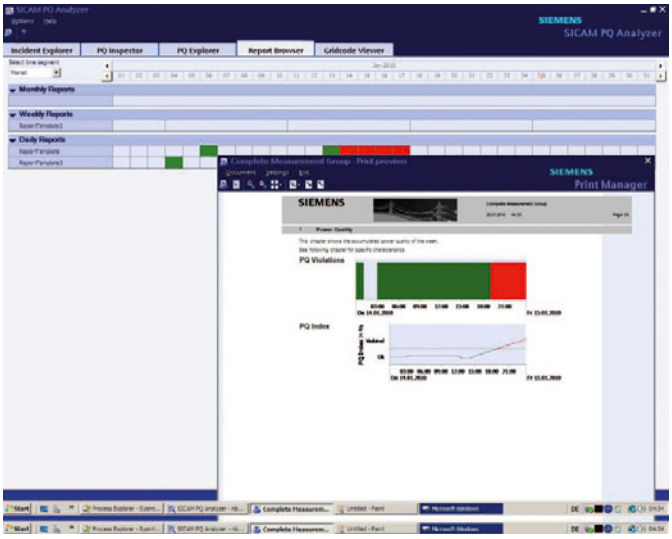


Fig. 6.4-31: **Report browser**

Fault location with parallel line compensation
Single- or two-sided fault location allows precise pinpointing of the fault, and this can be refined even more through the inclusion of parallel line compensation. The report generated for each fault location computation contains all the important data required. Fast, reliable localization of the fault allows more efficient coordination of personnel deployment and thus helps minimize downtimes (fig. 6.4-32).

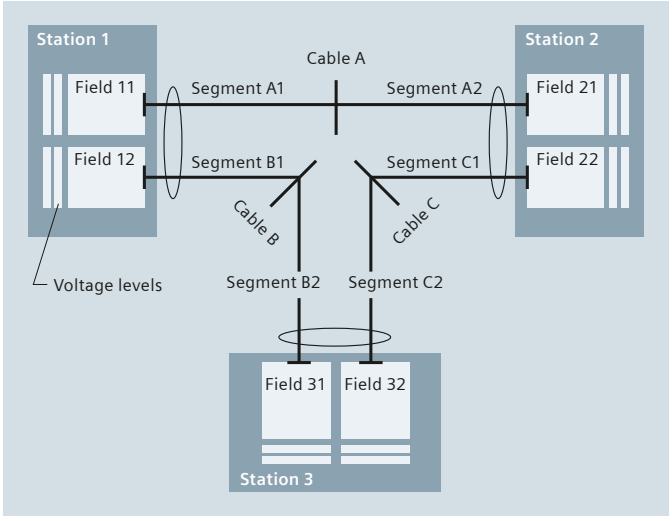


Fig. 6.4-32: **Fault location with parallel line compensation**

Monitoring of fault records and PQ reports via Web Tool SICAM Diamond

Simple access via web to the PQ Archive with SICAM Diamond. It is possible to monitor the Fault records, PQ violation reports (the result of a validation of the PQ data against a assigned Grid Code), fault location reports, scheduled reports (the automatic cyclically generated user-defined PQ reports).

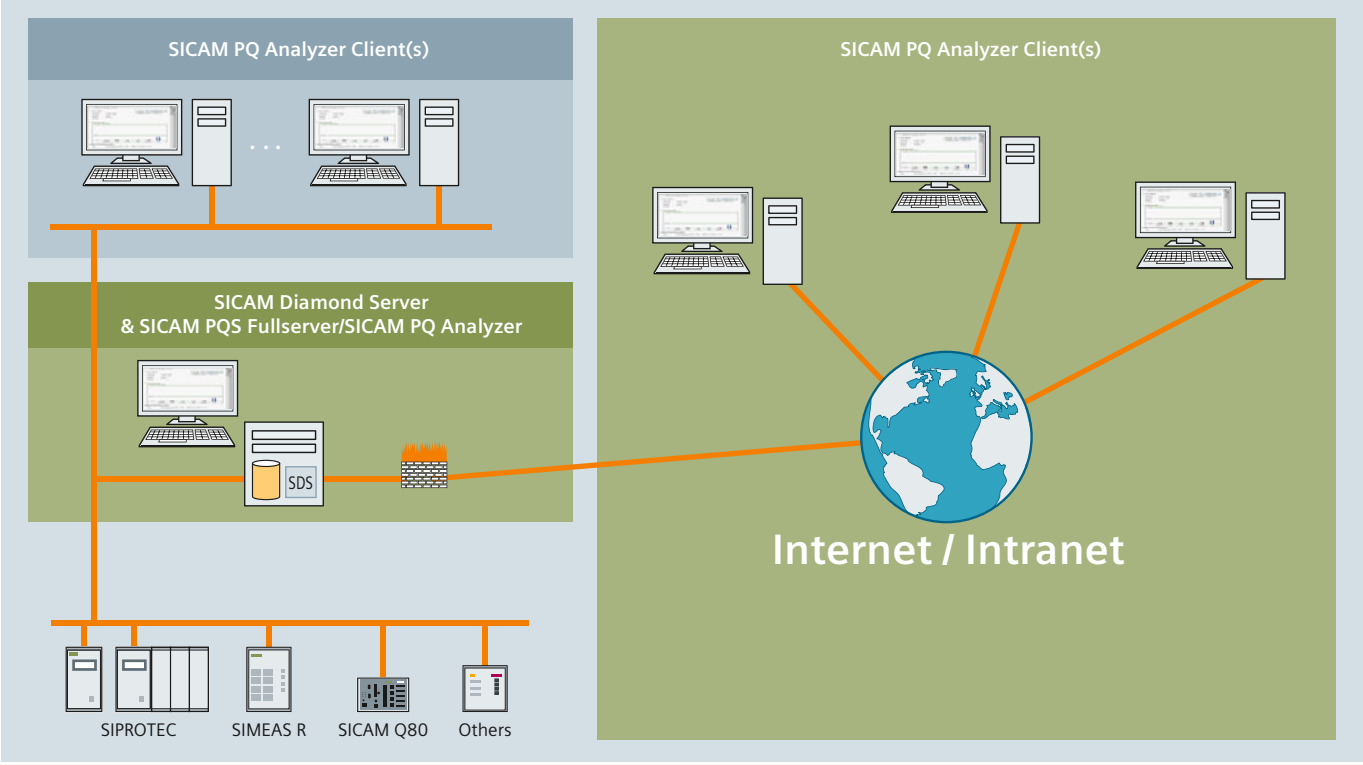


Fig. 6.4-33: **SICAM PQS V7.01 / SICAM Diamond V4.0 HF1 goes Web via SICAM Diamond**

6.4.6 SIGUARD PDP – Phasor Data Processor

SIGUARD PDP – Reliable System Operation with Wide Area Monitoring

The load on electricity supply systems has increased continuously over the past few years. There are many reasons for this:

- Increased cross-border power trading in Europe, for example, is placing new demands on the tie lines between control areas. For example, power transmission on tie lines in the European grid increased almost 6-fold from 1975 to 2008 (source: Statistical Yearbook of the ENTSO-E 2008)
- Increased input of wind power and the planned shutdown of existing power plants will extend the transmission distances between generation and consumers.
- Severe weather and storms can put important lines out of operation, for a short time exposing the remaining grid to increased load quickly.

This means that the power system is increasingly operated closer to its stability limit and new load fl ows arise that are unfamiliar to network control center operators.

This is where SIGUARD PDP (Phasor Data Processor) comes in. This system for network monitoring using synchrophasors helps with fast appraisal of the current system situation. Power swings and transients are indicated without delay to help the control center personnel fi nd the causes and take countermeasures.

Highlights

- Phasor data processor per IEEE C37.118 standard
- 2 selectable monitoring modes:
  - Online mode
  - Offline mode (analysis of past events)
- Vector view or time chart view can be selected for all p hasors
- Calculation and display of the power system status curve
- System monitoring, incl. communication links and PMU status
- Geographic overview (based on Google Earth)
- Basis for fast reporting after faults
- Flexible analysis with formula editor for calculations based on measured values
- Limit values that can be changed online
- Runs under Windows XP and Windows 7, as a pure PDC (without user interface) also under Windows Server 2008.

Applications

- Analysis of the power flows in the system
  SIGUARD PDP can display a clear and up-to-date image of the current power fl ows in the system with just a few measured values from widely distributed phasor measurement units (PMU). This requires no knowledge of the network topology. The power fl ows are shown by means of phase angle differences.

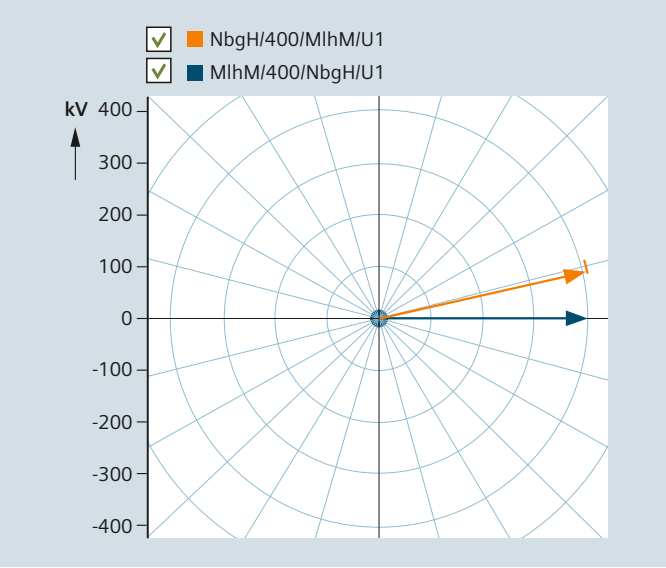


Fig. 6.4-32: **Voltage vector of two measurement points in the network**

- Power Swing Recognition
  All measured values from PMUs can be displayed and monitored with easy-to-confi gure phasor diagrams and time charts. Any power swings that occur are quickly and reliably detected. The zone being monitored can be fl exibly adjusted to the current situation in terms of time, geography, and content.
- Evaluation of the damping of power swings
  Using the function “Power Swing Recognition” (available as from Version V2.1), an incipient power swing is detected and the appropriate damping determined. Detection of a power swing and, if applicable, its insufficient or non-existent damping is signaled (alarm list).

- Monitoring of the load on transmission corridors
  The voltage-stability curve is especially suitable for displaying the instantaneous load on a transmission corridor. The currently measured operating point is shown on the work curve of the line (voltage as a function of the transmitted power). In this way, the remaining reserve can be shown at any time. This requires PMUs at both ends of the line.

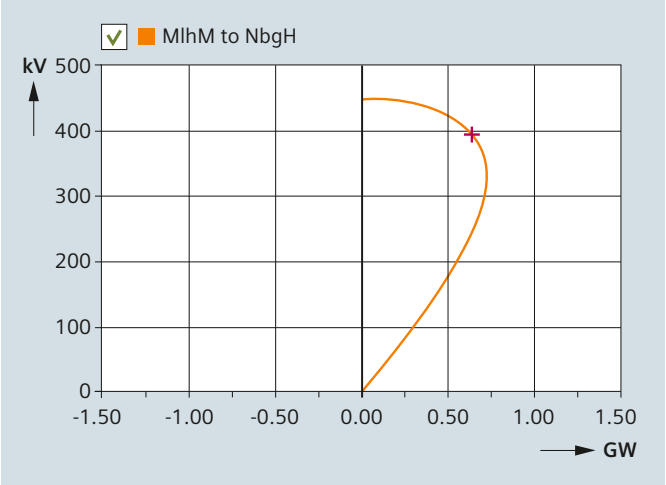


Fig. 6.4-33: **Voltage stability curve**

- Island state detection
  This function automatically indicates if parts of the network become detached from the rest of the network. For this purpose, frequency differences and rates of frequency changes can be automatically monitored. If islands are detected, warnings and event messages are output.
- Retrospective event analysis
  SIGUARD PDP is ideal for analyzing critical events in the network. After switchover to offl ine mode, the entire archive can be systematically analyzed and the events played back as often as necessary. This makes dynamic events transparent, and reports can be quickly and precisely compiled. Simply copy the informative diagrams from SIGUARD PDP into your reports.
- Alarming on limit value violation with an alarm list and color change in the geographic network overview map
  This allows you to locate the position and cause of the disturbance quickly. This function is also available for analyzing the archive.
- Display of the power system status as a characteristic value for the stability of the power system
  Due to the constant availability of the power system status curve in the upper part of the screen, the operator is constantly informed about trends in system dynamics and any remaining reserves. This curve shows a weighted average of the distances of all measured values, to their limit values.

11:09:52....	2010-...	Island detection	ISD potential network subsplit	appearing
11:09:52....	2010-...	Island detection	ISD network subsplit	appearing
11:09:52....	2010-...	Island detection	ISD potential network subsplit	disappearing

For further information:
www.siemens.com/powerquality

6

For further information to chapter 6:
www.siemens.com/protection
www.siemens.com/sicam
www.siemens.com/powerquality