15 Secondary Installations

15.1 Stand-by power systems

15.1.1 Overview

Stand-by power systems supply power to electrical equipment if the supply from the public distribution system is interrupted by faults or if a direct supply does not seem feasible for technical or business reasons.

The following grouping is based in the different requirements:

- emergency power systems,
- auxiliary power systems,
- frequency converters.

Table 15-1
Application for stand-by power systems

User group		Equipment with secure supply
public and commercial buildings	public assembly areas, shop and office buildings, banks, insurance companies, control centres.	emergency lighting as per DIN VDE0108
	high-rise buildings, hotels, government and administration buildings, conference centres, institutions, laboratories.	security, monitoring and power supply systems.
	hospitals	as per DIN VDE 0107 and 0108, special regulations, AV SV and ZSV network for security, monitoring and power supply systems, operating room lighting.
	warehouses and refrigerated storage	cooling units, security systems.
	communications centres, data processing centres.	data processing systems, air-conditioning systems.
traffic	airports, air traffic control	control centres, runway, tower and emergency lighting, radio and radar systems, data processing systems, aircraft on-board systems (400 Hz) for ground power.
	railway stations	control centres, emergency lighting, monitoring and signalling systems.
	road tunnels, highway intersections	lighting, ventilation, monitoring and signalling systems

(continued)

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Table 15-1 (continued)

Applications of stand-by power systems

User group		Equipment with secure supply
telecommunications and energy transmission	radio systems and telecommunications exchanges, relay stations, energy auxiliary equipment supply substations	telecommunications devices and installations, telecontrol systems, monitoring and power equipment
industry	manufacturing and functional processes	safety, monitoring and power supply installations, process computers, automation.

15.1.2 Stand-by power with generator systems

Generators with diesel engines are preferred for providing stand-by power to consumers for which there is sufficient time for starting a power generator; see DIN 6280 Parts 1 to 15.

The generator sets are used to generate power for

- emergency power supply installations that supply the regular consumers in the event of failure of the regular power supply,
- peak load operation to cover daily demand peaks,
- auxiliary supply of cogenerating systems with heat or current-controlled operation,
- installations in continuous operation without an adequate power supply system.

Diesel engines are most frequently used for emergency power systems. Units with an output above 100 kW are normally supplied with turbo charger only. High-speed machines with a rated speed of 1500 min^{-1} are mostly used. As well as better power-to-weight ratio, this allows better adaptation to synchronous generators of the standard type (4-pole design). However,diesel engines with turbo charger do have the disadvantage that they cannot produce their rated output in one stage.

The power generators used may be asynchronous generators (economical) or for installations of higher output, they can be alternators. The most common alternators have a brushless design. A built-in self-excited three-phase stationary-pole exciter with rotating diodes supplies the rotor current. The voltage is regulated in the three-phase exciter field. If fast compensation of the generator voltage is required, self-excited compound generators (constant-voltage generators) are to be preferred. Electronic voltage controllers are equivalent to the compound regulators.

The demands on the power supply of the consumers depend on the application. The operational response of the generator set must be able to meet the consumer's requirements. The following types are classified according to the application:

Type 1, low demands on the voltage and frequency response

Type 2, voltage response generally conforming to that of the public system

Type 3, increased demands on the voltage and frequency response

Type 4, maximum demands on the voltage and frequency response

The sets must be selected depending on the type. When rating the power of the generator, the connected loads of all power consumers must be determined, taking into account the simultaneity factor and the largest consumer that is to be connected. The connected load should be 60%-70% of the rated generator set output to ensure sufficient reserve power for reactive power requirements and switching operations. If 6-pulse three-phase rectifiers are connected as consumers, the output of the set must be adequately rated because of the resulting harmonics (overdimensional). In addition to the intrinsic response of the diesel engine and generator caused by design characteristics, the size and type of the connected consumers have a decisive influence on the required generator power. So with turbocharged diesel engines, a base load already provides better frequency response (turbine pre-acceleration). Rotor damping, type of excitation and overexcitation capacity are the main influences on the maximum voltage dip for the generator.

Typical values for the speed and voltage response are specified in DIN 6280 Parts 1 to 13 and the standard ISO 8528 Parts 1 to 6. Small generators (<10 kVA) are subject to the standard ISO 8528 Part 8.

The machine room should be sufficiently large. Rooms that are too small make operation and maintenance difficult and the ventilation problem is often difficult to solve satisfactorily. The questions regarding setup with proper noise isolation and fuel storage (observe TÜV regulations) are also important, as is the problem of putting the equipment into place and its accessibility once installed. There must be a 1 m wide space all around the set under all circumstances. The space required is also determined by other installations such as fuel tanks, sound absorbers, closed-circuit cooling, batteries and switching and control equipment; see also Section 4.7 Structural Requirements.

The core of the automatic controller for emergency generator sets is the “ABB neacontic automatic start/stop” with a programmable controller (Procontic family or third-party). It controls the following tasks:

“automatic” mode

– all-pole system voltage monitoring
– start command in the event of system fault (preferably time-delayed)
– starting procedure
– repeated start if applicable
– operational monitoring
– control of auxiliary equipment
– monitoring of generator voltage
– switching from network to generator operation (interlocked) or initialization of parallel circuit.
– detection of return of system availability
– delayed automatic return switching of consumers from generator to network operation with and without interrupting power supply.
– aftercooling
– shutdown
– cancellation of the shutdown procedure in the event of another system fault while the set is still running and immediate supply of power.

“manual” mode

– manual operation for startup and shutdown. Interlocked switchover from network and generator mode and back.

“test” mode

– test operation for checking all automatic processes (including transfer of power supply).
– test operation for checking all automatic processes (not including transfer of power supply).
– automatic transfer of power supply if the system fails during test mode operation.

“Off” mode

– all equipment operation blocked, e.g. for maintenance. The power supply to the consumers is not interrupted.

“EMERGENCY OFF” mode

– with mechanically interlocked “OFF” position
– stops in the event of danger to personnel or installation, regardless of the selected mode.

Fault monitoring operates at a higher level than all other operating modes and displays the fault message and shuts down the generator if required.

A generator operating in “automatic” mode can, depending on its size, take over supplying power after 10–15 s. Additional measures such as heating the room, preheating lubricant and coolant, assisted starting, compressed air starting and high-speed excitation can reduce this time to 5–10 s.

The automatic transfer synchronization ensures uninterruptible switchover of the consumers from the generator to the network and from the network to the generator, e.g. ABB synchrotact 4 (see also Section 14.3.6).

Emergency power systems with several generators operating in parallel require an automatic synchronization device for parallel switching. Another option is starting synchronization. This involves several generator sets being simultaneously switched in parallel over busbars during starting. The consumers are separated from the busbars during this process.

The use of equipment for automatic effective and/or reactive power sharing enables the output to be distributed in accordance with the percentage ratio of the load capacity of the individual generator sets.

An additional device (cosφ controller) makes it possible to retain a setpoint for the desired power factor for parallel system operation.

15.1.3 Uninterruptible power supply with stand-by generating sets (rotating UPS installations)

Rotating UPS installations are characterized by a generator running continuously at its rated speed. Its output must be sufficient to supply power to all consumers dependent on an uninterruptible power supply. This also applies for the design of the associated mechanical generator sets.

Rotating UPS installations are classified for the possible override time as follows:

– converter and flywheel for short-term override (about 1 s),

– converter and storage battery for part-time override (to about 30 min.),

– converter and flywheel and coupled diesel machine for long-term override (practically unlimited).

Uninterruptible power systems

The classical design of an uninterruptible power set has the most important components, a diesel engine, an electromagnetic clutch, a flywheel, a three-phase asynchronous motor and a three-phase alternator, installed on a common base frame (Fig. 15-1a).

The asynchronous motor is connected to the public power supply and runs the generator with the flywheel. The consumers that require uninterrupted power are continuously supplied with power from the system through the three-phase converter. The diesel engine is uncoupled and not operating at this time. In the event of a system fault, the asynchronous motor is shut down; at the same time the magnetic clutch is closed and the diesel engine is started by the flywheel.

During the transition from the faulty network to emergency diesel operation, the flywheel alone supplies the driving force for the generator while simultaneously supplying the energy to start the diesel engine. The flywheel start brings the diesel engine to its working speed within 1 . . . 1.2 s. This virtually precludes a failed start.

While in the first standard design described a motor generator supplies the consumers that require protection, in many cases one single electrical machine (reversing machine) is sufficient. It uses the available system voltage to drive the flywheel as a synchronous motor and operates as a diesel generator in the event of a power failure. Fig. 15-1b illustrates the principle of an uninterruptible power system with a synchronous reversing machine.

See Figs. 15-1c) and 15-1d) for other options.

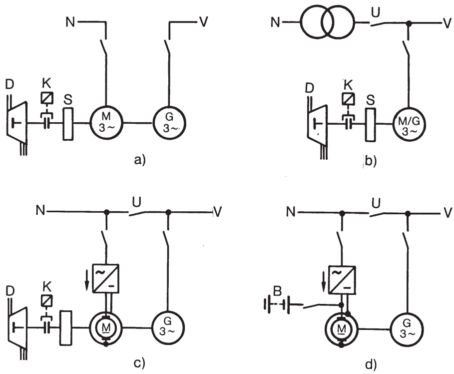


Fig.15-1
Basic design of uninterruptible power sets: a) with induction-synchronous generator set, flywheel and coupled emergency power diesel engine; b) with synchronous reversing machine, flywheel and coupled emergency power diesel engine, c) with direct current three-phase converter, flywheel and coupled emergency power diesel engine, d) with direct current-three-phase converter and storage battery separate from network; N network lead, U clutch, V consumer, S flywheel, B battery, K magnetic clutch, D emergency power diesel engine

Fast-start power sets

Fast-start power sets are special emergency power systems with flywheels that can be used where short-time interruptions of approximately 250 ms are permissible. Their design is generally similar to the uninterruptible power set with converter set. The difference is that with the uninterruptible power set, the generator supplies power continuously to the consumers while the consumers connected to the fast-start power set receive their energy from the network.

The total cost of all rotating UPS installations (purchase, maintenance, operation) is high. For this reason, they are primarily used with high power requirements.

15.1.4 Uninterruptible power supply with static rectifiers (static UPS installations)

Uninterruptible power supply systems that operate with static rectifiers and storage batteries are increasingly being installed in many areas, particularly for small to medium output applications.

Operation

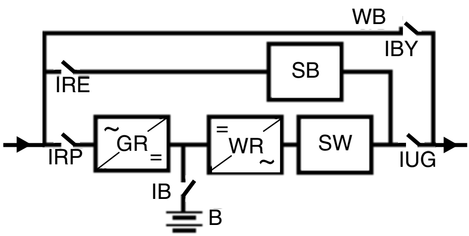
ABB UPS installations are based on a rotary converter. The UPS circuit diagram shows the six most important components (Fig. 15-2):

- – rectifier/battery charger (6-pulse) (GR)
- – battery (B)
- – inverter (WR)
- – static reversing switch (SW)
- – static bypass (SB)
- – maintenance bypass (WB)

All components are installed in one housing. The controller electronics for the rectifier, inverter and the bypass area are completely independent of one another. This means that a fault in one area cannot cause a fault in the adjacent area.

Fig.15-2

UPS circuit diagram



Features

UPS function

The **U**ninterruptible **P**ower **S**upply (UPS) is connected to the circuit between the power supply network and the power consumers (load). They are designed to guarantee a constant voltage supply for the load. If a network failure occurs, it can supply the load for a preset period (autonomous period). The UPS has also other advantages compared to conventional supply systems (network, engine-powered generators, etc.):

Better output characteristics

Monitoring the UPS output voltage and frequency guarantees constant output power. Variations in the system voltage and frequency, which are generally present in electrical power systems, do not influence the output voltage of the UPS.

Decoupling system distortions

The double conversion from AC to DC and back to AC filters out all system distortions. All UPS consumers are also fused for protection against power system faults, which can occur in industrial power supply systems. This is particularly important for sensitive electronic equipment such as computer systems, control systems and medicinal equipment.

Complete protection against power system faults

If the power supply system fails, the UPS supplies energy to the load from the battery. The battery is connected to the UPS rectifiers and inverters. The inverter supplies power to the load.

During standard operation, the inverter receives energy from the rectifier. The rectifier then charges the battery at the same time.

In the event of a power system fault, the connected battery automatically supplies power to the inverter. This means that the power supply to the load continues without interruption. However, the battery can only supply the load for a specified period (autonomy period). If longer periods of autonomy are required, it is worthwhile supplying the UPS with a diesel generator as an emergency power supply. In this case, the autonomy period is calculated for the period between network failure and full generator power.

Rectifier/battery charger

In the standard configuration, the charger is a 6-pulse three-phase rectifier. It converts the network AC voltage to DC voltage. It is normally connected directly to the power supply system via commutating reactors (no galvanic isolation). The commutating reactors reduce the system perturbations of the rectifier. The charger feeds the battery and the inverter. The battery is connected to the charger via a saturable reactor to reduce the residual ripple of the DC voltage. This ensures maximum battery life.

The rectifier is designed to supply the inverter and charge the battery with the maximum loading current simultaneously at maximum load. The floating charging voltage for standard batteries (maintenance-free lead battery) with 192 cells is kept constant at 432 V (2.25 V per cell). The battery is charged with I/U characteristic. This means that the charging current limit is reached by reducing the intermediate circuit voltage. This ensures that the battery is not damaged by excessive charging current. A 12-pulse rectifier is optional and requires the addition of a second rectifier bridge in the UPS cabinet and a phase-shifting transformer in a separate accessory cabinet.

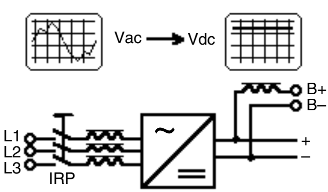


Fig.15-3

6-pulse rectifier circuit diagram

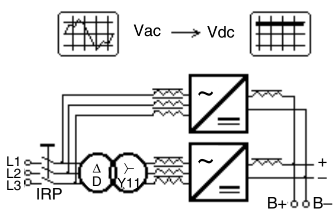


Fig.15-4

12-pulse rectifier circuit diagram

Battery

The battery supplies the inverter in the event of a short interruption or a system failure. The battery is designed to continue to supply the load for a specified period (autonomy period) depending on the battery capacity and the actual load.

The number of cells in the battery depends on the type and also on the customer-specific requirements. The standard number is 192 cells for lead-acid and 300 cells for NiCd batteries. The battery capacity (Ah) depends on the UPS output and the required autonomy period.

Inverter

The inverter, which is supplied by the rectifier or the battery, converts the DC voltage fed from the rectifier or the battery into a.c. voltage with constant voltage and frequency, a form of power suitable for the power supply of highly sensitive electronic equipment.

Pulse duration modulation is used to generate the AC voltage. The output voltage (harmonic content < 1%) is smoothed by a high operating frequency of the power semiconductor and the use of an output filter (transformer and capacitors).

Every phase-to-earth voltage at the output of the inverter is regulated separately. This ensures that the UPS output voltages remain constant even under very non-symmetrical loads.

For protection of the inverter, the inverter electronics restrict the inverter output current to 150% of the rated current in the event of a short circuit. In the event of overload, it restricts the inverter output voltage to no more than 125 % of the rated power. If a serious overload occurs, it automatically switches to bypass mode, if the bypass is available.

Saturation monitoring or an “electronic fuse” protects the inverter transistors from destruction by short circuits.

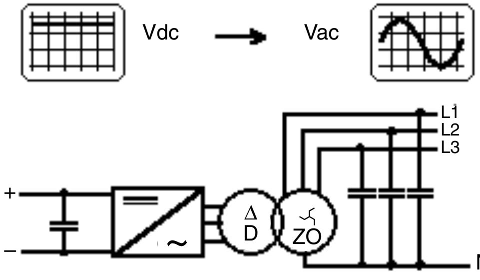


Fig. 15-5

Inverter circuit diagram

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Static switches

The circuit diagram shows the two static switches, which are thyristor switches. In standard operation, SW is closed and SB is open. This switches the load to the inverter output.

In the event of an overload or the destruction of an inverter, SB is closed and SW is open, switching it to an auxiliary power supply (network, output of another UPS, diesel generator, etc.). The two switches, SW and SB, are always closed at the same time for a short period when switching between inverter and bypass mode. This prevents any interruption in the power supply even in the event of a fault. This condition is essential to enable all demands by the connected sensitive devices on the voltage supply to be met.

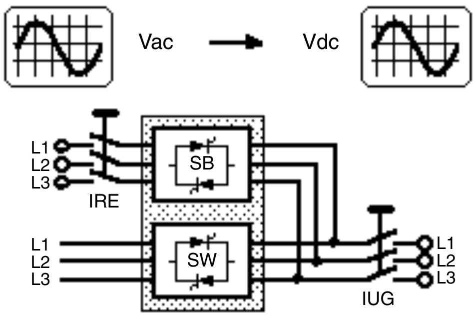

Fig.15-6

Static switch circuit diagram

Maintenance bypass

During UPS maintenance work, the maintenance bypass supplies the connected load directly over the network. The maintenance bypass consists of a switch (IBY).

The UPS installations allow switching from the various operating modes to the maintenance bypass without interrupting power. If the maintenance bypass is activated, the rest of the UPS can be switched completely voltage-free to allow maintenance or repair (up to the input and output terminals and their connections to the IRP, IRE, IUG, IB circuit-breakers).

To prevent faulty switching of the IBY maintenance bypass switch, which could be caused by parallel switching between inverter and maintenance bypass system, the IBY maintenance bypass switch is electronically interlocked against the static SW reversing switch. If IBY is closed, SW opens automatically. This prevents parallel switching between inverter and maintenance bypass system.

ABB can supply an external wall-mounted uninterruptible maintenance bypass switch as an option. This switch enables simple switchover to the maintenance bypass with no possibility of faulty switching and without interrupting the load. This makes it possible to switch all power to the UPS by shutting off its power supply completely.

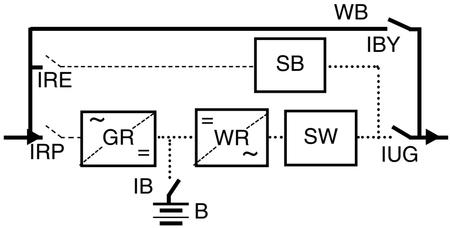

Fig. 15-7

Internal maintenance bypass circuit diagram

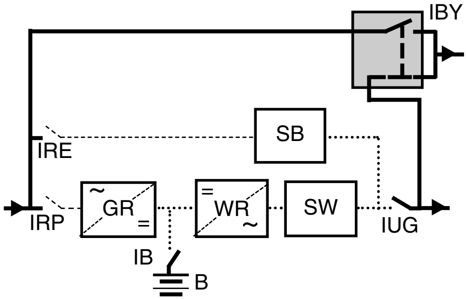

Fig. 15-8

External maintenance bypass circuit diagram

Hot stand-by operation

A hot stand-by UPS system is basically two (or more) UPS installations, which operate independently of one another. Each installation can supply the load at any time.

- All installations are in operation continuously, but at any time only one UPS is supplying the load.
- If a fault occurs in the active installation, another installation is ready to take the load without interrupting the output voltage; i.e. a constant power supply to the load is guaranteed at all times.
- The load is only supplied from the static bypass if there is no inverter in the system able to take the load.

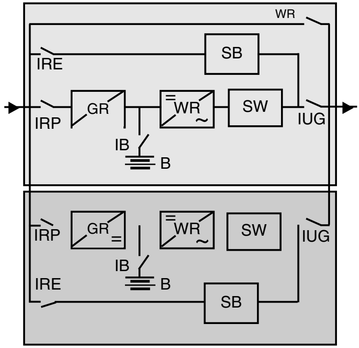

Fig. 15-9

Hot stand-by operation circuit diagram

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Redundant parallel operation

A parallel UPS system consists of two to six UPS installations switched in parallel over which the load is equally distributed. Every installation has its own static bypass (SB), this ensures SB redundancy in the system. This means that if one SB fails, the bypass system is still always available.

The parallel system does not have a central controller. Each installation has its own separate paralleling electronics to monitor all functions and to provide full redundancy.

Parallel operation

This configuration is identical with that of the redundant parallel operation, except that the rated power of the UPS systems normally conforms to the output power and there are no redundant installations. UPS installations of varying output can be parallel switched in this configuration, because the load is distributed proportionally to the installation output. The parallel configuration conforms to the redundancy configuration if the load has been reduced to a value that allows the system to continue to supply the reduced load with one (or more) installation(s) fewer. This makes one (or more) installation(s) redundant and the controller is identical.

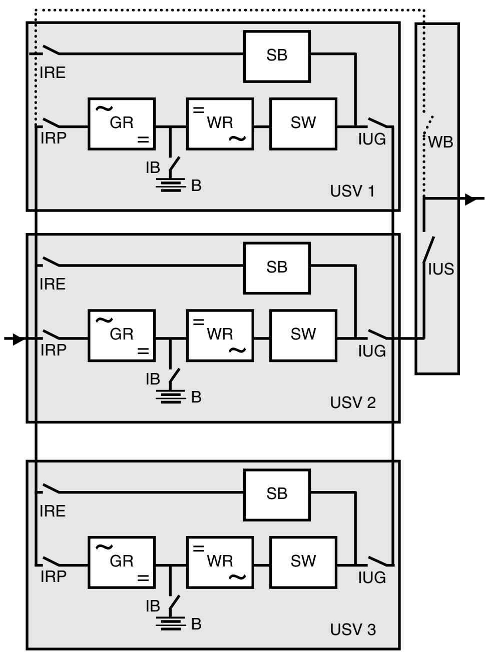

Fig. 15-10

Parallel operation circuit diagram

Table 15-2

ABB UPS system range with technical data

Type		ABB/Mini	ABB/MP	ABB/S400	ABB/PX4
Unit capacity	kVA	0.5 to 10	7.5 to 25	10 to 120	150 to 400
Input voltage	V	230/1ph.	400/230	400/230	400/230
permissible voltage tolerance	%	± 10	± 10	± 10	± 10
Input frequency	Hz	50 (60)	50 (60)	50 (60)	50 (60)
permissible frequency tolerance	%	± 5	± 5	± 5	± 5
Output voltage	V	230/1ph.	230/1ph.	400/230	400/230
voltage tolerance at:					
– symmetrical load	%	± 3	± 1	± 1	± 1
– at 50 % step change in load	%	± 4	± 4	± 4	± 4
– at 100 % step change in load	%	± 6	± 10	± 5	± 10
Output frequency	Hz	50 (60)	50 (60)	50 (60)	50 (60)
frequency tolerance	%	± 0.5	± 0.5	± 0.5	± 0.5
Distortion factor	%	< 4	< 3	< 2	< 3
Current carrying capacity:					
– inverter 1 min.	%	120	150	150	150
– static bypass 1 min.	%	150	200	200	200
Total efficiency	%	83	90	90	93
Noise level	db(A)	ca. 50	ca. 60	ca. 61	ca. 63

Notes on all ABB UPS types:

System configuration: on-line (double conversion)
setting ranges for input and output voltages:
380/220 V/400/230V/415/240 V

Radio interference suppression: limit class A as per EN 50091-2

Design: in accordance with European directives 89/336/EEC and 73/23/EEC

ABB UPS installations meet the requirements of European directives 89/336/EEC and 73/23/EEC and of EN 50091-2 (1995) and EN 50091-1 and therefore have the CE mark.

ABB UPS installations conform to limit class A as per EN 50091-2
The installation may radiate electromagnetic fields in its immediate vicinity. In this case, the operator is expected to conduct additional measurements or take action.

15.2 High-speed transfer devices

15.2.1 Applications, usage, tasks

In power and industrial plants, large motors and other important consumers must have a backup in case the general power supply system fails, because otherwise availability, production, profitability and safety will be restricted or people may be injured and the environment and process equipment may be damaged. With such high outputs, backup generators are no longer sufficient. A second power supply ready for immediate operation is required. It is important for the second power supply to be independent of the effects of a fault in the general power supply system. The supply must come from another transmission network or a different power generator.

The fast transfer to the second power supply is generally done at the same voltage level as the large consumers, i.e. in the rated voltage ranges up to 24 kV. However, in some situations, the transfer is done in the low-voltage network or at the level of a transmission voltage. This can basically involve switching over one large consumer, such as a motor, and also switching over a whole group of important consumers linked together over one busbar section.

The transfer must be done very quickly and without any serious feedback to the consumers and power supply, i.e. the switching must be controlled with very short transfer times with regard to the physical processes in the network and at the consumers. This task is handled by high-speed transfer devices, which are based on digital hardware technology and can be integrated into every modern installation protection design.

To take full advantage of the possibilities of high-speed transfer devices, the general design must meet the following requirements:

– there must be at least two, generally independent of each other synchronous power supplies
– circuit-breakers with short operating times
– switchgear installation must be suitable for system transfers
– fast protection relays for initiating the high-speed transfer device

Transfers initiated by operational conditions can be started manually using the high-speed transfer device, but in the event of a fault, the transfer system reacts automatically.

Examples of applications of the ABB SUE 2 high-speed transfer device is shown in Figs. 15-11a and 15-11b.

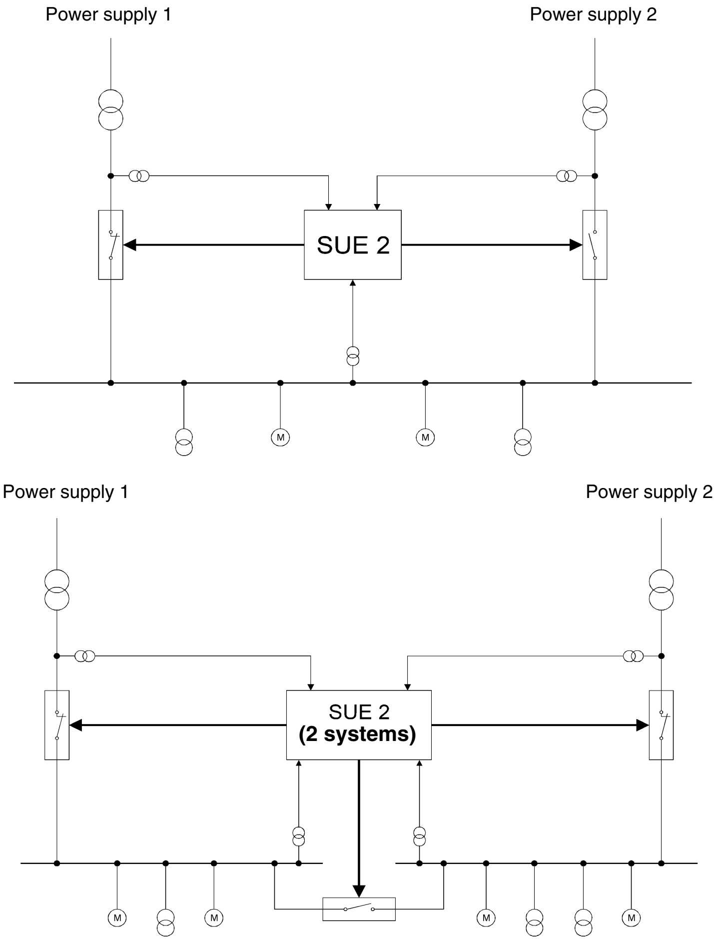

Fig.15-11

Example of a switchgear installation with high-speed transfer devices

a) Single busbar with two power supplies

b) Single busbar with two power supplies and bus sectionalizer

15.2.2 Integration into the installation

Corresponding to its great importance, the high-speed transfer device must be considered at the planning stage of a switchgear installation and its secondary components, because it communicates with many other station components (Fig. 15-12). There are interfaces to the following components, among others:

– switchgear installation (circuit-breakers, voltage transformers, overcurrent relays etc.)
– protection (block, transformer, differential, cable, undervoltage protection etc.)
– control systems/control room (remote control, signalling system)
– voltage supply (DC power supply).

Additional interlocking, releases or blocking in conjunction with other components may be required because of the large number of individual design options for a switchgear installation as well as the operational conditions.

Fast, direct and undelayed starting by external protection relays is also important for optimum conformity with all demands on the high-speed transfer device.

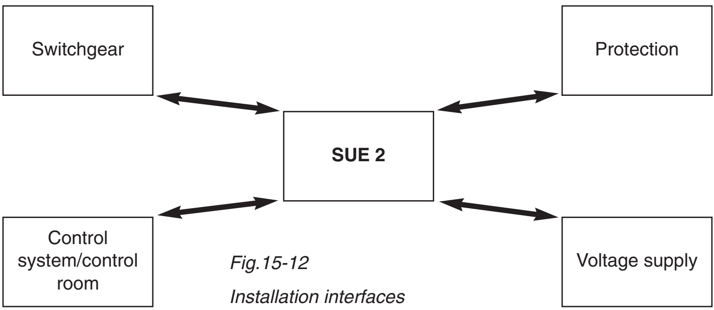

Fig.15-12

Installation interfaces

15.2.3 Design of high-speed transfer devices

The ABB Type SUE 2 high-speed transfer device primarily consists of the following three function groups:

– logical processing module
– digital phase comparison unit
– test device

The logical processing module consists of a modular, programmable logic controller (PLC). All functions required for controlling the circuit-breaker, for interlocking, blocking, acknowledgements, signalling and monitoring are controlled by the PLC.

The digital phase comparison is implemented with an intelligent, programmable microcontroller unit. The unit has integrated A/D transformers, which read in the required measurement voltages. Comparison of the electrical parameters of voltage, frequency and phase relationship is an extremely time-critical process, which is secured by its implementation in low-level assembly programming.

The test device enables the functioning of the high-speed transfer device to be tested, including a continuity test of the control coils of the circuit-breakers that they actuate. It also provides information on the system status of the installation. In the event of a fault, an internal diagnosis provides detailed information on possible faults.

15.2.4 Functionality

The high-speed transfer device continuously compares the busbar voltage with the voltage available in reserve. The transfer criteria are generated from the monitoring process of the voltage amplitudes, the frequency difference and the phase angle.

The different transfer situations described below are initiated at the moment of starting based on the current power system status.

The high-speed transfer device must always be started externally. This is normally done manually from the control room or initiated by suitable fast protection relays. Basically, if a limit value defined as an undervoltage in the current power supply is reached, an undervoltage initiation can also be independently generated. The transfer direction – either from the main to the reserve power supply or vice versa – is information taken from monitoring the corresponding circuit-breaker positions. The high-speed transfer device is only ready for operation when both circuit breakers that are to be actuated are definitely in different switching states (plausibility check) and are in operating position.

Switching commands from the high-speed transfer device to the circuit-breakers – bypassing all switchgear interlocks that might be present – are sent directly to the control coils.

15.2.5 Types of transfer

The decisive criterion for the type of transfer is the power system relationships at the moment of starting the high-speed transfer device. In principle, the following transfer options are available:

- fast transfer
- Transfer at the 1st phase coincidence
- residual voltage transfer
- long-time transfer

The preferred and most important functional principle of the SUE 2 high-speed transfer device is to conduct fast transfers. If there are no prerequisites for this, the device offers additional, optional function mechanisms.

A fast transfer occurs if the main and reserve power supply are quasi-synchronous within preset limit values, i.e. slip and phase angle between the networks are limited and the reserve voltage is above a minimum value. During this process, the high-speed transfer device sends OFF and ON commands to the circuit-breakers simultaneously. The pause without power that occurs for the consumers in this case depends almost entirely on the difference between the make and break properties of the switchgear.

A transfer in the 1st phase coincidence occurs when the networks were not synchronized at the moment of starting but specific conditions are met. In this type of transfer, the OFF command is sent immediately and the reserve power system is activated in the 1st minimum of the difference of reserve and busbar voltage.

The high-speed transfer device uses predictive calculation to determine the course of the differential voltage and the time of the 1st phase coincidence. To compensate for the processing time dictated by the equipment (SUE 2 mechanical system delay, circuit-breaker delay periods), the ON command is issued at an appropriate period before the actual occurrence of the minimum differential voltage – within a previously defined switching window.

A residual voltage transfer is initiated if the networks are not synchronized at the moment of starting and a beat transfer is also not possible. In this case the OFF command is sent immediately to the feeder circuit-breaker and the ON command is sent to the switch that is to be closed when the busbar voltage has decayed to a set permissible value and the feeder circuit-breaker is safely opened. The reserve network is activated independently from the phase angle and the slip.

There is also a residual voltage transfer if the starting is initiated by the undervoltage monitoring implemented in the SUE 2 or by external undervoltage relays.

A long-time transfer is initiated if the busbar voltage cannot be monitored during a transfer (that does not occur as a fast transfer) (e.g. because of failure of an automatic device). The OFF command is sent immediately, but the ON command is only sent after a defined period as is the return confirmation that the feeder circuit-breaker is open.

The conclusion is that the selection of the type of transfer at the moment of starting the high-speed transfer device is decisive. In general, fast transfers are initiated because the networks are usually synchronized. The principle of issuing commands simultaneously to the circuit-breakers guarantees the shortest possible transfer times and safe, virtually uninterrupted power supply. If the switch that is to be opened fails on a fast transfer, e.g. because of mechanical problems, the high-speed transfer device detects this state and the switch that was just closed is opened again after a preset period, thereby preventing non-permissible, long-duration coupling of the networks.

If the networks are not synchronized at the instant of starting, a fast transfer is not initiated. The resulting dead times without power vary depending on the installation, with the load that is to be switched determining the run-down response of the busbar voltage.

The various types of transfer can be selectively activated and deactivated depending on the direction. This ensures that the optimum transfer concept for the entire installation can be implemented with regard to the special requirements.

A fast transfer is the smoothest type of transfer and in most cases guarantees continued operation of the installation with no interruption. The busbar voltage generally remains stable and the closing currents after the transfer are limited.

When conditions allow switching at the 1st phase coincidence, this type of transfer – a fast transfer was not possible –- is the second best choice, followed by the residual voltage-dependent and the long-time transfer. If the reserve networks are not stable enough for certain transfers, the high-speed transfer device can send signals to initiate targeted load shedding before switching.

The high-speed transfer device is designed to initiate the optimum possible transfer automatically depending on the general conditions. The oscillograms in Fig. 15-13 show some typical transfers.

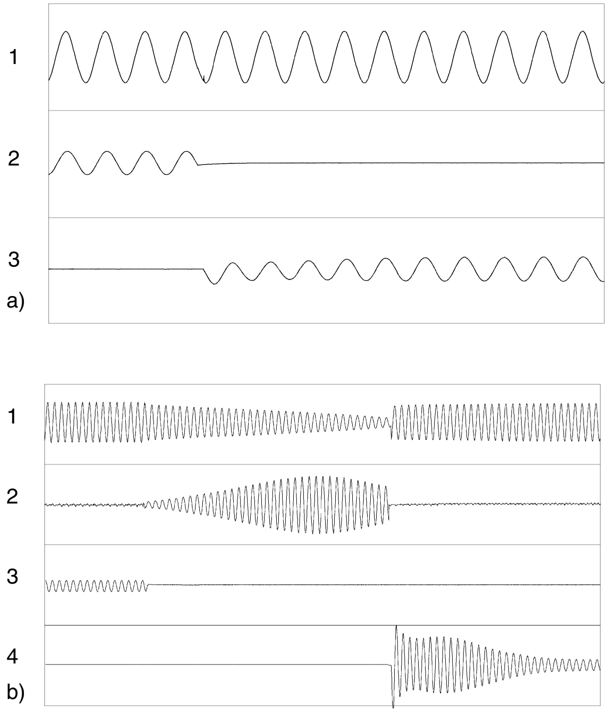

Fig. 15-13 Oscillograms

a) fast transfer
1 = busbar voltage
2 = current main Feeder
3 = current standby Feeder

b) residual voltage-dependent transfer
1 = busbar voltage
2 = differential voltage ($U_{standby}$ - U_{SS})
3 = current main Feeder
4 = current standby Feeder

15

15.3 Stationary batteries and battery installations, DIN VDE 0510, Part 2

15.3.1 Types and specific properties of batteries.

Battery sets are used in switchgear installations as sources of energy for network-independent power supply of controller protection, regulating and signal circuits and similar.

The battery direct voltage can also be used via inverters to generate "safe AC voltage". In installations with modern secondary technology, the power supply modules for computers and the electronic protection and also standard data processing devices such as PCs, monitors and printers are supplied with safe alternating voltage (UPS) (Section 15.1.4).

Two types of cells are used in stationary batteries:

- The closed cell has a sealed cell cover with one or more openings through which the gas generated can dissipate or through which water can be added. The openings are closed with suitable stoppers, e.g. fastener stoppers.
- The sealed cell is maintenance-free throughout its life and can generally be installed without regard to position. The internal gas pressure can be released through an automatically closing cell valve.

Note:

It is not possible to prevent the generation of oxygen and hydrogen in a lead-acid battery! A gas density seal is possible only with the NiCd battery. Its negative electrode is above the hydrogen potential.

The nominal voltage and the capacitance of a battery are determined by the required service voltage with consideration of the permissible voltage tolerance of the individual consumers (switchgear and protection devices), the input power of the various power consumers, their duty factor and the type of current draw. Switchgear installations primarily use two types of batteries:

Lead-acid batteries with electrodes of lead and lead alloys and weak sulfuric acid as electrolyte. They are used in switchgear installations, substations and power plants to provide high power requirements for long operational periods, such as emergency lighting.

Important cell types used in lead-acid batteries:

- OGI : with positive and negative grid plates
- OPzS : with positive iron-clad plates
- GroE : with positive high-surface-area plates
- GroE-H : with positive high-surface-area plates, high-current design

Nickel-cadmium batteries with positive electrodes of nickel compounds, negative electrodes of cadmium and weak caustic potash solution as electrolyte.

Important cell types used in nickel-cadmium batteries:
– with pocket-type plates, application type .. L*), preferred for switchgear installations
– sintered cells, e.g. for aircraft
– with bonded plastic plates, application types .. L, .. H and .. M*),
– with fibre plates, application type .. H*), e.g. for motor vehicle batteries.

*) .. H = high current, short duration
.. L = low current, long duration
.. M = medium current, medium duration.

Advantages of NiCd batteries over lead-acid batteries:
– high reliability
– long life
– small footprint
– low maintenance costs
– low reduction in capacity at low temperatures
– fast recharging
– high mechanical and electrical stability
– good storage capacity
– low-charge resistant
– resistant to overcharging
– low self-discharge
– high cycle-capacity
– no pole corrosion

Disadvantages of NiCd batteries over lead-acid batteries:
– high price
– lower cell voltage
– less efficiency
– no full capacity when charged with charge retention voltage
– at high cyclic stress and high temperatures pocket-type cells may require new alkaline electrolyte after some years
– larger voltage window with charging/discharge

Electrical values of *batteries* (see also Table 15-3).

The DIN 40 729 standard defines the basic terms for batteries.

Nominal voltage:

The nominal voltage (U_N) of a cell is a specified value. In the lead-acid battery it is 2.0 V, in the nickel-cadmium battery it is 1.2 V.

The nominal voltage of a battery is the product of the number of cells connected in series and their nominal voltage.

Rated capacity:

The rated capacity (C_N[1]) is the quantity of electricity that a battery can supply during discharge over a defined discharge period (nominal discharge period t_N) with the associated rated current (I_N) at nominal temperature, nominal density and nominal electrolyte status without going below the end-point voltage (U_{SN}).

The maxim is: $C_N = I_N \bullet t_N$

The n-hour capacities are associated with a battery if it can be discharged with currents different from the rated current. The index n gives the discharge time t_n in hours (e.g. C_3 = 3-hour capacity).

[1)] In international texts, C is the standard symbol for capacity.

End-point voltage:

The end-point voltage (U_S) is the set point below which the voltage must not fall during discharge with the assigned current.

The rated end-point voltage (U_{SN}) applies during draw with the nominal discharge current ($I_N = C_N/t_N$) for specifying the rated capacity C_N.

Gassing voltage:

The rated voltage (U_G) is the charging voltage above which a battery begins to discharge gas; in lead-acid batteries 2.40...2.45 V per cell, in nickel-cadmium batteries 1.50 -1.55 per cell.

Charging factor:

The charging factor $1/\eta_{Ah}$) is the ratio of the quantity of electricity required for full charge to the previously drawn quantity of electricity.
(Reciprocal efficiency of the charging η_{Ah}).

Internal resistance:

The internal resistance of a battery cell R/cell is dependent on the cell temperature and the charging or discharging status. The typical values given in Table 15-3 are based on a fully charged battery.

A contact resistance of 2 x 0.04 mΩ/cell can be assumed for the connections between cells.

Table 15-3

Specific properties of batteries.

Name	Dimension	Lead-acid batteries OPzS	GroE	GroE-H	NiCd batteries L	H
Rated capacity C_N	Ah	C_{10}	C_{10}	C_{10}	C_5	C_5
Rated discharge current I_N	A	$I_{10} = 0.1 \cdot C_{10}$	$I_{10} = 0.1 \cdot C_{10}$	$I_{10} = 0.1 \cdot C_{10}$	$I_5 = 0.2 \cdot C_5$	$I_5 = 0.2 \cdot C_5$
Rated end-point voltage U_{SN} at 20 °C	V/cell	to 1.80	1.80	1.80	1.00	1.00
Floating charging voltage U_{LE}	V/cell	2.23	2.23	2.23	1.4	1.4
Gassing voltage U_{LE}	V/cell	2.40	2.40	2.40	1.5	1.5
Charging factor $1/\eta_{Ah}$	—	1.2	1.2	1.2	1.4	1.4
Electrolyte density	kg/dm³	1.24	1.22	1.22	1.19	1.19
		± 0.01	± 0.01	± 0.01	± 0.02	± 0.02
Internal resistance R_i/cell (typical value)	mΩ/100 Ah	3.0	1.4	1.0	1.4	0.6
Load capacity[1)]	—	L	H	H	L	H
Approved temperature range		+ 5 °C to + 55 °C				– 20 °C to + 45 °C

[1)] Load capacity corresponds to:
H: high-current design for short-term load, i.e. for applications where the battery must cover a period of several minutes to a maximum of one hour if the power network fails.
L: for capacity load (long-term load), i.e. current draw for a period of 1 to 10 hours.

15.3.2 Charging and discharging batteries

All operation with batteries requires a regulated power source that recharges the battery. It must also be capable of supplying the consumers directly, depending on the operating mode. The required charging quantity for a lead-acid battery is 120%, and for a nickel-cadmium battery approximately 140 % of the previously drawn Ah. The self-discharge current of a lead-acid battery is about 0.2 % of the three-hour discharge current; that is about 1 % of the 10-hour capacity daily. The quantity of the charging current depends on the capacity of the battery and the charging time. This information is supplied by the manufacturer. In the case of lead-acid batteries the charging current is generally equal to the discharge current with a three- to five-hour discharge. In the case of nickel-cadmium batteries, the charging current should be equal to the discharge current of a five-hour discharge. Once the gassing voltage has been exceeded, it must be reduced to approximately one third of the above-mentioned charging current and should decrease further until charging is complete.

When batteries are fully charged, the charging voltage should be reduced to the floating charge voltage to prevent damage caused by continued gassing, temperature increase and water loss.

Lead-acid batteries can be fully recharged with the floating charge voltage and retain full capacity.

When NiCd batteries are charged with the floating charge voltage, they do not reach full capacity and therefore should always be charged at a higher voltage. Even if a NiCd has been previously fully charged, it still loses some capacity when receiving floating charging voltage. This loss of capacity under floating charging voltage depends on the load on the battery and can be up to 10% of the rated capacity.

For faster charging, all batteries should be charged at a higher voltage with a final automatic fallback to the floating charge voltage. When commissioning and servicing batteries, the charger should also have a boost charger device with automatic fallback to the floating charge voltage.

Battery charger:

If the battery cannot be isolated when charging with a higher characteristic but the charging voltage exceeds the maximum approved value at the consumer, the following actions may be taken in the charger:

– the use of counter-cells,
– main and end cells,
– DC stabilizer in the charger load-circuit output.

The following symbols apply for these load characteristics and for the off-switches and transfer circuit-breakers of the chargers with single or combined charging properties:

Charging characteristic for	Symbol
constant current	I
constant voltage	U
loading current falling	W
automatic tripping	a
limitation or switchover of the charging current to another charging characteristic	o (zero)
the sequence of combined symbols corresponds to the sequence of the charging process: e.g. constant current-constant voltage characteristic	IU
two sequential falling characteristics with switchover and automatic tripping	W0Wa

With automatic charging at constant voltage without tripping after reaching the fully charged state (e.g. charger with U, IU, IUW characteristic), the constant voltage must be retained as per DIN VDE 0510 with a permissible deviation of ± 1 %.

Therefore, the following applies for the output voltage of the charger:

$$U_d = n\,(U_{ZLE} \pm 1\,\%) + \Delta U.$$

n number of battery cells

U_d output direct voltage of the charger

ΔU voltage drop at the connection between charger and battery

U_{ZLE} floating charging voltage per cell

It should be possible to switch over manually to charge the battery with higher voltages.

In this case, the connected consumers or the consumer track must be switched off if the approved values are exceeded in modes deviating from the floating charge.

15.3.3 Operating modes for batteries

If consumers are supplied directly from a battery and the battery is disconnected from the consumers for charging, this is referred to as straight battery operation (Fig. 15-14a).

During parallel operation (Fig. 15-14b), consumers, rectifiers and battery are continuously connected in parallel. In this case, a distinction is made between buffer operation (battery is used to keep constant voltage and to cover peaks) and parallel operation (battery supplies power only if the rectifier fails, Fig. 15-15b). Parallel operation predominates.

Under switchover mode, the battery is disconnected from the consumers; it is kept fully charged. If the standard power source fails, the consumers are switched to the battery (Fig. 15-14c).

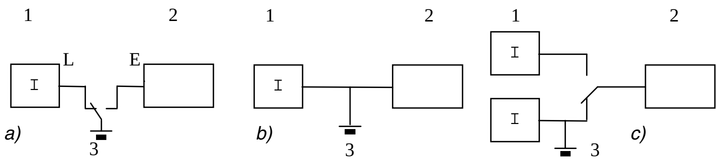

Fig.15-14

a) discharge-charge *b) parallel operation:* *c) switchover operation:*

1 DC source, 2 consumer, 3 battery

<u>Important note!</u>

During project planning of auxiliary installations in which the secure alternating voltage will be generated by rectifiers and inverters connected in series, the characteristics of both devices must be matched for each other for all loading cases. The selectivity of the two voltage potentials must be retained with load currents or short circuits. Correspondingly, the supplying device must be capable of supplying at five times the rated current for a short time while retaining the voltage drop approved by the VDE.

15.3.4 Dimensioning batteries

A large amount of data and operating conditions must be considered when dimensioning a battery.

It includes:
– load current,
– duration of load,
– impulse load,
– sequence of individual loads,
– permissible voltage tolerance of consumers,
– voltage drop on the connector cable,
– ambient temperature,
– end-point voltage of the battery,
– selected measures for retaining voltage tolerances
– proposed battery type.

Measures for retaining the voltage tolerances can include connecting of counter-cells, dividing a battery into main and end cells or using a stepup unit. A different procedure is used to determine the battery size depending on what measure is implemented. Battery manufacturers have suitable calculation programs. Detailed information can be found in IEEE 485 for lead-acid batteries and IEEE 1115 for Ni/Cd batteries.

Note:
It is never sufficient to calculate the capacity of a battery from the product of current x discharge time only.

15.3.5 Installing batteries, types of installation

Types of installation
Batteries are usually installed on steel racks.

The most convenient type of installation from the point of view of maintenance is on a tiered rack.

Stationary batteries are supplied in bolted or welded designs.

Inspection passages
DIN VDE 0510 specified that the rows of cells must be accessible by a passage. The width of the passage must be at least 500 mm for floor-mounted racks and at least 800 mm for tier racks. However, practice has shown that these aisle widths are too narrow, so the recommended widths for floor-mounted racks are at least 800 mm and 1000 mm for tier racks.

Battery rooms
The structural design of battery compartments is specified in worksheet J 31 of the working group for industrial structures (AGI: Arbeitsgemeinschaft für Industriebau). Battery compartments are accessible, enclosed compartments intended for installation of batteries for supplying electrical installations. As per DIN VDE 0510 and DIN VDE 0100 they are considered as

– *electrical premises/operator access area*, if the installation is designed for a nominal voltage of up to 220V
– *locked electrical premises/restricted access location,* if the installation is designed for nominal voltages over 220 V.

The requirements for the structural design of battery compartments are considered in more detail in Section 4.7.4.

15.4 Installations and lighting in switchgear installations

The operation, control and monitoring of switchgear installations inside and outside requires that they be supplied with energy (unit) and lighting.

15.4.1 Determining electrical power demand for equipment

The power demand P_{max} is calculated from the sum of the connected loads ΣP_i for the individual consumer groups and multiplied by the demand factor g.

$$P_{max} = \Sigma P_i \cdot g$$

The requirement factor is based on values derived from experience; see Table 15-4.

Table: 15-4

Typical values for demand factor g for:

installations	offices	switchgear installations
lighting	0.8	0.8
receptacles	0.1	0.1
air-conditioning, ventilation	1	1
heating	1	1
lifts	0.5 / 0.7	—
kitchen equipment	0.5	—
outside lighting (floodlight installations)	—	1
cranes	—	0.7
control and signalling equipment	—	0.5
data processing equipment	depending on the individual case	

See Table 6-6 for demand factors for other equipment.

Equipment for station services

The equipment for station services in switchgear installations is described in Section 7.1 and 7.2.

In most cases, low-voltage distributors in the form of switch cabinets or distributor boxes are used, with all requirements for maximum operational dependability regarding design and equipment selection being met.

Important consumers and functions are supplied with direct voltage, which also ensures an uninterrupted power supply even in the event of a malfunction with the use of stationary batteries.

15.4.2 Layout and installation systems

The complex cable and wiring networks comprise a significant portion of the entire installation system. For this reason, the correct selection of materials and systems appropriate for the application is particularly important. Installations with multiple fire compartments require appropriate barriers between them. If emergency exits are provided, they must be installed in F90; materials conforming to DIN 4102 must be used. Fasteners and installation materials that are easy to install must be selected to allow economical installation. Proper tools and construction equipment are also required to ensure rational installation work processes.

See Sections 6.1.7 and 13.2.4 for information on laying cables and wiring.

The manufacturer's working guidelines must also be observed.

There are single modules and complete layout systems for the various layout types.

The fastening methods and layout materials must be selected in accordance with the anticipated stresses caused by mechanical, thermal, chemical or other environmental effects. The following must also be taken into account:

- adequate heat dissipation,
- safe isolation of the power and communications circuits and the networks for stand-by power,
- open or covered configuration,
- sufficient flexibility for changes and retrofitting,
- technical fire protection measures.

The following are used for individual installation:

- plastic and metal nail, screw, bracket and glue clips,
- plastic and metal installation conduits, rigid and flexible (see Tables 15-5 to 15-9 for specifications).

The following are used for composite installation:

- plastic register clips and line-up saddles of plastic,
- plastic and metal bracket clips,
- plastic and metal strips and clamps,
- plastic and metal underfloor, wall and ceiling ducting,
- mesh cable racks of round steel bars,
- plastic and metal gutters and trays,
- metal racks and cable conduits.

Installation systems have been developed from the layout systems for interiors that not only protect and support elements for the wiring but also include tap boxes and terminal boards.

This development has been greatly assisted by construction technology which now offers not just the wall area but also the floor and ceiling for horizontal energy distribution. The window sill area is also available for this purpose.

Typical installation systems are:

The subfloor installation

with single- and multiple-duct metal or plastic conduits for laying power and communications wiring with floor-level or sub-floor connections for different components. The conduits can be laid in or on the unfinished floor, in the flooring material or flush with the floor.

Covered accesses for every terminal point must be included with a special design of the system. The wiring is run to the floor below on troughs or racks. The sub-floor installation is also suitable for double-floor systems.

Designs for every type of floor construction are available. The right design should be selected on the basis of the specific requirements and conditions and economy of installation.

The window-sill conduit installation (preferred for office space)

using plastic or metal conduits with built-in installation devices for power and communications wiring. The conduits are generally a component of the structural sill covering. Sufficient heat dissipation must be provided for installations adjacent to heaters and air-conditioning units.

In laboratories, the conduits are also used for utilities.

The terminal board installation

in the ceiling area, in combination with a suitable rack system. The terminal board consists of a plastic or metal housing with separate compartments for the power and communications circuits. Protection and switchgear is also included as well as terminals and terminal blocks. The terminal board can also be supplied as a complete module with added ceiling or built-in lights.

This installation system provides a wiring network without individual tapping boxes and is preferably used for decentralized supply of large spaces and anywhere that individual tapping boxes cannot be used for technical or structural reasons.

The busbar trunking system installation

in the vertical shafts of the central part of the building and as a connection between transformer and low-voltage main switchgear installation. This installation system has been developed from the classical plug-in busway installation used in industrial power supplies and has been switched from the horizontal to the vertical with slightly modified components.

The open or closed duct installation is preferably used for laying cables and wiring to individual consumers in the switchgear compartments and areas.

Plastic or steel conduits are used depending on the demands on the mechanical strength of the installation. They are installed in the ground, on and in the walls or ceilings of buildings and on structural framework.

See the following Tables 15-5 to 15-9 for data on installation ducts

Table 15-5

Electrical installation ducts as per DIN VDE 0605; non-threadable heavy-gauge steel conduits as per DIN 49 020 and flexible, corrugated steel conduits for heavy pressure loads as per DIN 49 023

Type	DIN 49 020 Steel conduits Non-threadable conduits, plug-in AS				DIN 49 023 Flexible, corrugated steel conduits for heavy loads AS			
	Diameter		Bundle Conduit length 3 m		Diameter		Ring	
	Interior mm	Exterior mm	Content m	Weight kg	Interior mm	Exterior mm	Content m	Weight kg Ω
9	13.2	15.2	90	33	10.0	14.7	25	4.5
11	16.4	18.6	60	30	14.0	18.4	25	5.5
13.5	18.0	20.4	60	32	16.0	20.2	20	7.0
16	19.9	22.5	30	20	18.0	22.3	25	7.5
21	25.5	28.3	30	27	23.5	28.0	25	9.0
29	34.2	37.0	15	18	31.5	36.7	25	15.0
36	44.0	47.0	15	26	41.0	46.6	25	19.0
42	51.0	54.0	15	32				
48	55.8	59.3	15	34	51.8	59.0	25	27.0

Application:
on concrete, in concrete, on plaster, in plaster, under plaster, on wood, on steel structures, in fill (flexible conduits not in hot fill).

Table 15-6

Electrical installation conduits DIN VDE 0605; flexible, corrugated, fire-retardant insulating conduits for light and medium pressure loads as per DIN 49018/1

Type	DIN 49 018/1 Flexible, corrugated, fire-retardant insulating conduits for light pressure loads B + C + F				DIN 49 018/1 Flexible, corrugated, fire-retardant insulating conduits for medium pressure loads A + C + F			
	Diameter		Ring		Diameter		Ring	
	Interior mm	Exterior mm	Content m	Weight kg	Interior mm	Exterior mm	Content m	Weight kg
9	9.9	13.0	50	1.1	9,6	13.0	50	1.3
11	11.8	15.7	50	1.5	11.3	15.8	50	2.1
13.5	14.5	18.6	100	3.7	14.3	18.7	100	5.2
16	16.6	21.1	50	2.4	16.5	21.2	50	3.0
23	23.8	28.5	50	4.0	23.6	28.5	50	5.0
29	29.6	34.5	25	2.5	29.0	34.5	25	3.3
36	36.8	42.5	25	4.0	36.6	42.5	25	4.6
48	48.5	54.5	25	6.0	48.3	54.5	25	6.5

Application:
in plaster, under plaster for prefabricated timber construction

Application:
on plaster, in plaster, under plaster in poured concrete

Table 15-7

Electrical installation conduits DIN VDE 0605; flexible, corrugated, fire-retardant insulating conduits for heavy pressure loads as per DIN 49 018/2 and flexible, smooth, non-fire-retardant insulating conduits for medium pressure loads as per DIN 49 019/2

Type	DIN 49 019/2 Flexible, corrugated, fire-retardant insulating conduits for heavy pressure loads B + C + F				DIN 49 019/2 Flexible, smooth, non-fire-retardant insulating conduits for medium pressure loads A + C			
	Diameter		Ring		Diameter		Ring	
	Interior mm	Exterior mm	Content m	Weight kg	Interior mm	Exterior mm	Content m	Weight kg
11	13.8	18.5	50	5.4	13.7	18.6	50	5.1
13.5	14.4	20.4	50	6.8	14.9	20.4	50	6.4
16	16.0	22.5	50	7.9	16.6	22.5	50	7.3
21	22.0	28.3	25	5.2	21.2	28.3	25	5.8
29	29.8	36.5	25	7.6	29.2	37.0	25	9.0
36	38.5	46.4	25	9.9	36.0	47.0	25	14.0
48	50.1	58.4	25	17.9				

Application:
on plaster, in plaster, under plaster,
in poured, vibrated and tamped concrete
for prefabricated concrete buildings
for machine terminals and industrial installations

Application:
in plaster, under plaster,
in concrete
outdoors and in ground

Table 15-8

Electrical installation conduits DIN VDE 0605; rigid, smooth, fire-retardant insulating conduits for medium and heavy pressure loads as per DIN 49016

Type	DIN 49 016 Rigid, smooth, fire-retardant insulating for medium pressure loads A + C + F				DIN 49 016 Rigid, smooth, fire-retardant insulating conduits for heavy pressure loads AS + C + F			
	Diameter		Bundle Conduit length 3 m		Diameter		Bundle Conduit length 3 m	
	Interior mm	Exterior mm	Content m	Weight kg	Interior mm	Exterior mm	Content m	Weight kg
9	12.6	15.2	120	10.8				
11	16.0	18.6	120	12.0				
13.5	17.5	20.4	120	16.5	16.0	20.4	120	21.6
16	19.4	22.5	60	8.0	18.1	22.5	60	12.9
21	24.9	28.3	60	12.2	22.1	28.3	60	20.4
29	33.6	37.0	30	8.0	30.8	37.0	30	14.6
36	42.8	47.0	15	5.5	39.0	47.0	15	11.6
42	49.6	54.0	15	6.0				
48	54.7	59.3	15	7.5	51.3	59.3	15	16.3

Application: on plaster, in plaster, under plaster
on concrete, in concrete
for industrial installations

on concrete
in poured and tamped concrete
for prefabricated concrete construction
in industrial installations

Table 15-9

Electrical installation conduits DIN VDE 0605, flexible, corrugated, non-fire-retardant insulating conduits for light pressure loads and heat resistance to 105 °C as per DIN 49019/3 and flexible, corrugated cable conduits of rigid PVC, compressive strength as per DIN 1187 (not as per VDE 0605)

Type	DIN 49 019/3 Flexible, corrugated, non-fire-retardant insulating conduits for light pressure Heat resistance to 105 °C B + C + 105				not as per VDE 0605 Flexible, corrugated cable conduits of rigid PVC Compressive strength as per DIN 1187			
	Diameter		Ring			Diameter		Weight each 100 m
	Interior mm	Exterior mm	Content m	Weight kg	NW	Interior mm	Exterior mm	kg
11	11.5	15.6	50	2.0	40	36.5	42.5	13.2
13.5	14.0	18.6	100	4.8	50	43.9	50.5	15.0
16	16.0	21.1	50	3.1	65	58.0	65.5	22.0
23	22.9	27.7	50	4.6	80	71.5	80.5	30.0
29	28.4	33.6	25	2.7	100	91.0	100.5	45.0
36	35.9	41.5	25	4.0	125	115.0	126.0	62.0
48	47.7	53.5	25	5.5	160	148.5	160.0	90.0
					200	182.0	200.0	140.0
Application:	in concrete and prefabricated construction in plaster, under plaster				in ground in concrete construction as lost sheathing			

There is a direct relationship between the internal diameter of the conduit, the approved space factor of the wiring in the conduit and the maximum permissible conduit length between the cable insertion points. This must be considered when planning the installation.

The limited options for pulling wiring and cables into the conduits require that some selection criteria be met:

– external diameter of cable,
– number of cables per conduit,
– permissible cable bending radii (see Table 13-64)
– permissible cable pull force (see Table 13-63)
– internal diameter of conduit,
– permissible conduit length between two cable pull points,
– number of conduit bends between two cable pull points,
– permissible space factor of the conduits based on heat given off by cables.

The cable data can be found in the manufacturers' lists.

Table 15-10 shows an overview of typical values for space factors, for pull lengths of 3-35 m with various conduit types and various installation types for single cables and bundled cables.

Table 15-10

Selection of conduits and conduit filling factor, typical values for space factors with manual insertion

Approved space factors of conduits with a max. draw length	3 m	6 m	9 m	12 m	20 m	25 m	30 m	35 m
PVC/steel conduit in open conduit installation, single cable								
D_{Ri} = 18 – 44 mm	0.7	0.7	0.5	0.5	—	—	—	—
≥ 45 mm	0.4	0.4	0.4	0.4	0.4	0.4	0.4	—
PVC/steel conduit in open conduit installation, bundled cable								
D_{Ri} = 18 – 44 mm	0.6	0.5	0.4	0.3	—	—	—	—
≥ 45 mm	0.3	0.3	0.3	0.3	0.3	0.3	—	—
PVC/steel conduit in closed conduit installation, single cable								
D_{Ri} = 18 – 44 mm	0.4/0.3	0.4/0.3	0.3/0.2	0.3/0.2	—	—	—	—
≥ 45 mm	0.2/0.2	0.2/0.2	0.2/0.2	0.2/0.2	—	—	—	—
½ conduit bend								
PVC/steel conduit in closed conduit installation, bundled cable								
D_{Ri} = 18 – 44 mm	0.4/0.3	0.4/0.3	0.3/0.2	0.3/0.2	—	—	—	—
≥ 45 mm	0.2/0.2	0.2/0.2	0.2/0.2	0.2/0.2	—	—	—	—
½ conduit bend								
PVC/concrete conduit in ground or concrete, single cable								
D_{Ri} ≤ 50 mm	0.5	0.5	0.5	0.5	0.5	—	—	—
> 50 mm	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
PVC/concrete conduit in ground or concrete, bundled cable								
D_{Ri} ≤ 50 mm	0.4	0.4	0.4	0.4	0.4	—	—	—
> 50 mm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

D_{Ri} = interior conduit diameter (mm)

The effective space factor is calculated from the square of the interior diameter of the conduit (D_{Ri}) and the sum of the squares of the external diameter of all cables (ΣD_{KA}^2) that will be pulled into the conduit according to the following formula:

$$P_r = \frac{\Sigma D_{KA}^2}{D_{Ri}^2} \leqq P_r \text{ approved}$$

Conduits with an interior diameter of less than 18 mm (in ground and concrete less than 50 mm) should generally not be used.

If the cables are pulled in by machine, as is often the case with conduit installations in ground or concrete, the max. draw length may not exceed 100 m.

15.4.3 Lighting installations

Installations for lighting indoor and outdoor switchgear installations and their auxiliary equipment are subject to very varied requirements regarding intensity of lighting, limiting glare, colour and colour reproduction.

Table 15-11 lists recommendations conforming to ASR 7/3 and DIN 5035 Part 2.

Workplace directive ASR 7/3 and DIN 5035 specify nominal lighting intensities for illuminating workplaces. ASR 7/3 was released by the Federal Minister for Labor and Social Affairs and therefore forms the legal basis for lighting workplaces.

DIN 5035 Part 3 (hospitals), Part 4 (educational institutions), Part 5 (emergency lighting) and Part 7 (computer workstations) are subject to additional regulations.

Planners of lighting installations should take into consideration that lights become dirty and that they deteriorate with age. For this reason, a planning factor is calculated into new installations.

Standard planning factor for contamination and deterioration:

1.25	standard,
1.43	enhanced,
1.67	strong.

These factors are multiplied with the rated value of the required illumination intensity to find the required installation intensity.

The set rated lighting intensities E_n are rated values of the average lighting intensity. They must not be below these values. The quality criteria of lighting colour, colour reproduction and limitation of glare are covered in ASR 7/3 and DIN 5035.

Table15-11

Lighting with artificial light.
Recommendations for various lighting tasks
(extracts from ASR 7/3 and DIN 5035 Part 2)

Type of space or activity	Rated lighting intensity E_n lx	Light colour	Stages of colour reproduction properties	Quality class of glare restriction
General spaces				
Traffic zones in storage rooms, warehouses	50	ww, nw	3	3
Warehouses for similar or large items	50	ww, nw	3	3
Warehouses with search tasks among dissimilar storage items	100	ww, nw	3	3
Warehouses with read tasks	200	ww, nw	3	2
Automatic high-rack warehouses, aisles	20	ww, nw	3	3
Operator station	200	ww, nw	2A	1
Shipping	200	ww, nw	3	2
Lunchrooms, sanitation rooms and canteens	200	ww, nw,	2A	1
Other rest areas and sleeping rooms	100	ww, nw	2A	1
Changing rooms, bathrooms, toilets	100	ww, nw	2A	2
Sanitation rooms, rooms for first aid and medical treatment	500	ww, nw	1A	1
Passageways in buildings				
For persons	50	ww, nw	3	3
For persons and vehicles	100	ww, nw	3	3
Stairs, escalators, inclined passageways	100	ww, nw	3	2
Loading ramps	100	ww, nw	3	3

(continued)

Table 15-11 (continued)

Lighting with artificial light.
Recommendations for various lighting tasks
(extracts from ASR 7/3 and DIN 5035 Part 2)

Type of space or activity	Rated lighting intensity E_n lx	Light colour	Stages of colour reproduction properties	Quality class of glare restriction
Offices and similar spaces				
Supplementary daylight lighting for offices with workstations exclusively adjacent to windows	300	ww, nw	2A	1
Offices	500	ww, nw	2A	1
Open-plan offices high reflection	750	ww, nw	2A	1
Open-plan offices moderate reflection	1000	ww, nw	2A	1
Technical drafting	750	ww, nw	2A	1
Conference and meeting rooms	300	ww, nw	2A	1
Rooms open to the public	200	ww, nw	2A	1
Rooms for data processing	500	ww, nw	2A	1 for 750 lx
Work on CAD devices	500	ww, nw	2A	1 for 1000 lx
Exclusively for viewing television images, e.g. process monitoring	200	ww, nw	2A	1 for 1000 lx
Power plants				
Loading systems	50	ww, nw, tw	3	3
Boiler house	100	ww, nw, tw	3	3
Machine sheds	100	ww, nw, tw	3	2
Control rooms with CRT monitors	300	ww, nw, tw	2A	1 for 1000 lx
Repairs and maintenance work on turbines and generators	500	ww, nw, tw	2B	2

(continued)

Table 15-11 (continued)

Lighting with artificial light.
Recommendations for various lighting tasks
(extracts from ASR 7/3 and DIN 5035 Part 2)

Type of space or activity	Rated lighting intensity E_n lx	Light colour	Stages of colour reproduction properties	Quality class of glare restriction
Switchgear installations – values from in-house experience				
Switchgear installations in buildings	100	nw	2	2
Switchgear installations outdoors	20	ww, nw	3,4	3
Control rooms	300	ww, nw	2	1
Electrical engineering industry				
Cable and wiring manufacture, coating and impregnating coils, assembly of large machines, simple assembly work, winding coils and armatures with coarse wire	300	ww, nw, tw	3	1
Assembly of telephone sets, small motors, winding coils and armatures with medium wire	500	ww, nw, tw	3	1
Assembly of precision devices, radio and television equipment, winding fine wire coils, manufacturing fuses, adjusting, testing and calibrating	1000	ww, nw, tw	3	1
Assembly of high-precision parts, electronic components	1500	ww, nw, tw	2A	1
Assembly of high- and very high-precision parts with CRT monitors	1000	ww, nw, tw	2	1 for 1500 lx

In addition to the lighting intensity the colour and colour reproduction determine the selection of lights for the required purpose (Table 15-12).

Table15-12

Colour and colour reproduction properties of light sources

Stages of colour reproduction properties	Light colour	Typical light sources	Remarks	Typical applications
1	daylight white (tw)	xenon lamps, fluorescent lights (daylight) and halogen metal-vapour lamps with very good colour reproduction properties		textile industry, graphical commercial, factory sheds, outdoor manufacturing halls, sales rooms
	neutral white (nw)	fluorescent lights (white) with very good colour reproduction properties	can be combined with daylight	offices, schools, laboratories, sales rooms, art galleries
	warm-white (ww)	incandescent lights, halogen incandescent lights, fluorescent lights (warm tone) with very good colour reproduction properties	can be combined very well with incandescent lights	mood lighting, living area, restaurants, sales rooms
2	daylight white (tw)	fluorescent lights (daylight) and halogen metal-vapour lamps with good colour reproduction properties		factory halls, exhibition halls
	neutral white (nw)	fluorescent lights (white) with good colour reproduction properties	can be combined with daylight	offices, schools, laboratories, sales rooms, show window, industrial commercial work rooms
	warm-white (ww)	fluorescent lights (warm tone) with good colour reproduction properties	can be combined well with incandescent lights	hallways, stairwells houses, lighting outdoors

Table 15-12 (continued)

Colour and colour reproduction properties of light sources

Stages of colour reproduction properties	Light colour	Typical light sources	Remarks	Typical applications
3	neutral white (nw)	fluorescent lights (white) with few good colour reproduction properties, mercury vapour high-pressure lamps with fluorescent material, mixed lamps	can be combined with daylight	industrial and commercial work rooms, lighting outdoors
	warm-white (ww)	fluorescent lights (warm tone) with few good colour reproduction properties		warehouses lighting outdoors
4		sodium-vapour lamps mercury vapour high-pressure lamps without fluorescent material		floodlighting, lighting outdoors

Three quality classes are distinguished with very individual criteria with the requirements for the glare limitation:

Quality class 1: high demands, ca. 10 % of persons surveyed still detect distracting glare.

Quality class 2: moderate demands, ca. 30 % of persons surveyed still detect distracting glare.

Quality class 3: low demands, ca. 40 % of persons surveyed still detect distracting glare.

The requirements for a lighting installation are determined by the following criteria:
- horizontal lighting intensity,
- if applicable, vertical lighting intensity,
- even lighting distribution,
- limitation of glare,
- colour reproduction stage.

The following must also be considered:
- room dimensions,
- colour of the reflecting surfaces around the outside of the room,
- mounting height above working plane.

The vertical lighting intensity is significant where vertically mounted instruments and devices need to be continuously monitored.

Refer to the “Manual for Lighting”, published by the “technical lighting associations (Lichttechnischen Gesellschaften)” and “working group (Arbeitsgemeinschaft)” of Switzerland, Austria and Germany, for descriptions of the calculation procedures. An explanation of the two calculation procedures is given there as follows:

– efficiency method

and

– point calculation method.

The point calculation method is generally recommended for outside lighting systems and for demanding interior applications (such as control rooms, network control rooms).

The efficiency method is generally sufficiently accurate for offices and workshops, switchgear rooms and access passages.

The requirements for lighting emergency and escape paths are described in DIN 5035 Part 5. The Workplace Directive ASR 7/4 “Emergency Lighting” must also be taken into account.

15.4.4 Fire alarm systems

Fires can occur even in installations that are protected by structural measures.

An important component of preventive fire protection (see Section 4.7.6) is fire alarm equipment that is automatically or manually activated in accordance with DIN VDE 0833 Parts 1+2. Both the directives of the VdS (association of property insurers) and the structural fire regulations must be observed.

If a fire can be detected early and action to extinguish it taken quickly and directly, the damage caused by the fire or the process of extinguishing it can be reduced.

Automatic fire alarm systems are recommended for switchgear installations, control rooms and data processing systems that are not continuously staffed.

Switchgear installations supplying hospitals and other critical installations must be equipped with fire alarm systems or be included in the general fire alarm system.

Fire alarms are forwarded to a central monitoring site. An incoming fire alarm automatically initiates the appropriate firefighting measures. Fig. 15-15 shows a circuit diagram of an automatically or manually actuated alarm system.

Smoke, temperature or the optical appearance of flames are the quantities for early detection of fires that set off the alarm when maximum values are exceeded. These alarms actuate stationary extinguishing systems and also alert the fire department through a central monitoring system.

A fire alarm system generally consists of the following components

– automatic fire alarms (heat, smoke, flames) installed in groups,
– central fire alarm,
– secure power supply from power system or battery,
– alarm equipment such as sirens, horns, flashing lights,
– actuation, tripping,
– transmission equipment for fire alarms to a continuously staffed monitoring centre (fire department),
– non-automatic manual alarms for less important areas.

The design of an automatic fire alarm system should also include any existing air intake and exhaust systems (corresponding placement of the spot alarms, otherwise an alarm may be delayed).

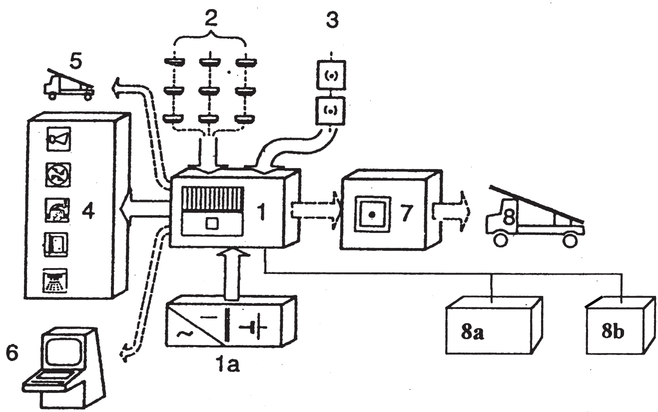

Fig.15-15

Circuit diagram of a fire alarm system

1 Central fire alarm,
1a Power supply (power system and battery)
2 Automatic fire detectors
3 Non-automatic fire alarm (manual alarm)
4 Alarms and actuation/tripping
5 Plant fire department
6 Building services (fault alarms)
7 Transmission equipment for fire alarms (main fire alarm)
8 Public fire department
8a Fire department control panel
8b Fire department key compartment

15.5 Compressed-air systems in switchgear installations

15.5.1 Application, requirements, regulations

Because air is available everywhere and can be compressed, dehumidified and stored, compressed air was long considered a particularly economical power source for equipment and machines. It has been used in switchgear installations for the following purposes:

– actuation force for mechanisms,
– arc-extinguishing medium for current interruption,
– dielectric in the interrupter chambers of circuit-breakers,
– ventilation of busbars for cooling and to prevent condensation.

The introduction of new technologies (SF_6 as extinguishing and insulating gas, mechanical spring energy storage, hydraulic power transmission) has greatly reduced the importance of compressed air for new systems. However, because a large number of switchgear installations with compressed-air systems are still in operation, the following deals with the basic principles.

The following standards are among those used as the basis:

DIN 1314 – Pressure, basic terms, units
DIN 43 609 – Graph. symbols for compressed-air system diagrams
DIN 43 615 – Rated pressures and pressure ranges for compressed-air systems
DIN 43 691 – Pressure terms
DIN 43 903 – Moisture in compressed air, terms, measurement methods
DIN 43 690 – Air compressors for compressor systems in electrical switchgear installations
DIN 43 686 – Pressure tanks for compressor systems in electrical switchgear installations

Reference is also made to the "directives for compressed-air systems in electrical switchgear installations from the association of German electricity companies (Vereinigung Deutscher Elektrizitätswerke), Frankfurt, 3rd edition 1985".

15.5.2 Physical basis

Atmospheric air consists of approximately 21 % oxygen and 79 % nitrogen and also traces of other gases. It also has a specific moisture content in the form of vapour. The moisture per unit of space is determined by the atmospheric conditions and the temperature. Atmospheric air has a moisture content that nears saturation point only in foggy and rainy conditions. Absolute moisture is the quantity of water in grams in one m^3 of air.

Compressed air is produced in compressors which draw in the atmospheric air with all the moisture it contains. The compression process reduces the volume of air in inverse proportion to the increase of pressure at a constant temperature (isothermal). With increasing compression pressure, the water vapour partial pressure and the relative humidity increase at constant saturation pressure.

The quantity of water Q is automatically separated by oil and water separators (between the individual compression stages) and can be calculated with the formula shown below.

$$Q = V_a \left(\frac{U}{100\ \%} \cdot f_{sn1} - \frac{p_1 (T_0 + t_2)}{p_2 (T_0 + t_1)} \cdot f_{sn2} \right)$$

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The following letters are used:

f_{sn1} maximum possible moisture content at intake temperature t_1 (g/l),
f_{sn2} maximum possible moisture content at discharge temperature t_2 (g/l),
V_a volume of intake air (l/min),
U relative humidity (%),
p_1 pressure of intake air (bar),
p_2 pressure of compressed air (bar),
t_1 temperature of intake air (°C),
t_2 temperature of compressed air (°C).

Example:

V_a = 500 l/min,
p_1 = 1 bar,
p_2 = 200 bar,
t_1 = + 10 °C, according to Table 15-13: f_{sn1} = 0.0094 g/l,
t_2 = + 25 °C, according to Table 15-13: f_{sn2} = 0.023 g/l,
U = 60 %.
Q = ?

Separated water:

$$Q = 500\,\frac{\mathrm{l}}{\mathrm{min}}\left(\frac{60\%}{100\%}\cdot 0.0094\,\frac{\mathrm{g}}{\mathrm{l}} - \frac{1\ \mathrm{bar}}{200\ \mathrm{bar}}\cdot\frac{(273+25)\ \mathrm{K}}{(273+10)\ \mathrm{K}}\cdot 0.023\,\frac{\mathrm{g}}{\mathrm{l}}\right) = 2.76\,\frac{\mathrm{g}}{\mathrm{min}}$$

Water separators in the compressor only removed the condensed water in the compressed air but not the moisture content in the form of vapour. If compressed air is to be used to actuate switchgear, the moisture content must be reduced. This is generally done by reducing the pressure and cooling the pressure tanks, or if this is not sufficient, by using air dryers.

The requirements for air quality regarding moisture content vary for indoor and outdoor installations. A moisture reduction to 40 % is sufficient for indoor installations but air-blast breakers for outdoor installations require a reduction to ca. 15 . . . 20 % to go below the dew point and thereby to prevent condensation in the switching device. In general, this means a pressure-reduction ratio of 5:1. This reduction ratio assures protection even in case of a fall in temperature of ca. 20 K over the temperature range –35 °C ... +50 °C. As can be seen in Table 15-13, even at low temperatures the air contains a small quantity of moisture. Air heated by compression should therefore be cooled to the ambient temperature of the switchgear if at all possible.

Table 15-13

Water content of air at various temperatures for standard pressure p_n (atmospheric pressure)

Dew point temperature °C	Saturation moisture f_{sn} g/m³	°C	g/m³	°C	g/m³
– 30	0.33	+ 5	6.790	+ 35	39.286
– 20	0.88	+ 10	9.356	+ 40	50.672
– 15	1.38	+ 15	12.739	+ 45	64.848
– 10	2.156	+ 20	17.148	+ 50	82.257
– 5	3.230	+ 25	22.830		
0	4.860	+ 30	30.878		

Fig. 15-16 shows the relationship between saturated moisture content f_s, pressure dew point t_{pd} and compression pressure p.

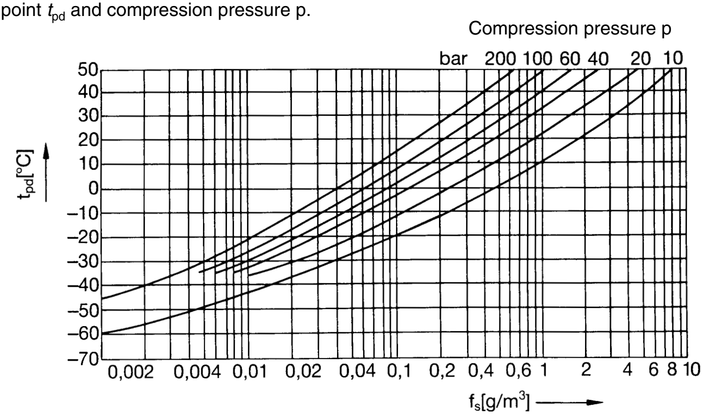

Fig. 15-16

Saturated moisture content of compressed air

Definitions of some important compressed air quantities:

f = absolute moisture content, in g/m³ or ppm, the quantity of moisture present at a specified temperature

f_{sn} = saturated moisture content, in g/m³ or ppm, is the maximum quantity of water vapour that can be absorbed by one m³ of dry air at atmospheric pressure

f_s = saturation moisture content of compressed air, in g/m³ or ppm, is dependent on temperature and pressure

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k = saturation compensation factor takes into account the non-proportional change of the saturation moisture of compressed air to the saturation moisture content of air at standard pressure p_n.

$$f_s = k \cdot \frac{f_{sn}}{p}$$

$$U = \frac{\text{absolute moisture content}}{\text{saturation moisture content}} 100\ \% = \frac{f}{f_{sn}} 100\ \% = \text{relative humidity}$$

ppm = parts per million, $1\ \text{ppm} = \dfrac{1\ \text{cm}^3\ \text{water vapour}}{1\ \text{m}^3\ \text{dry air}}$

t_d = dew point temperature = dew point in °C

t_{pd} = pressure dew point is the dew point of compressed air in °C

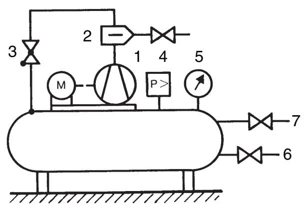
15.5.3 Design of compressed-air systems

A compressed-air system for supplying electrical switchgear consists of compressors, storage tanks and the distribution system with the pipes, pressure reducers and the control, protection and monitoring equipment. A distinction is made between working compressed-air systems and storage compressed-air systems.

In working compressed-air systems, the equipment is supplied with air at the compressor output pressure. It is only used in switchgear installations with low air requirements.
The compressor units are supplied as modules installed on a horizontal tank of 125 ... 500 l; see Fig. 15-17.

Fig.15-17

Pneumatic circuit diagram of a small compressed-air system:
1 Compressor
2 Water separator
3 Pressure valve
4 Pressure switch
5 Manometer
6 Drainage
7 Distribution system



Storage compressed-air systems

The air is compressed to a higher pressure than the operating pressure of the equipment and is stored. To supply the equipment in high-voltage installations, the air pressure is mostly reduced in the switchbay on an individual basis and centrally in medium-voltage substations.

Fig. 15-18 shows the general design of storage compressed-air systems with the preferred storage, reduction and distribution methods.

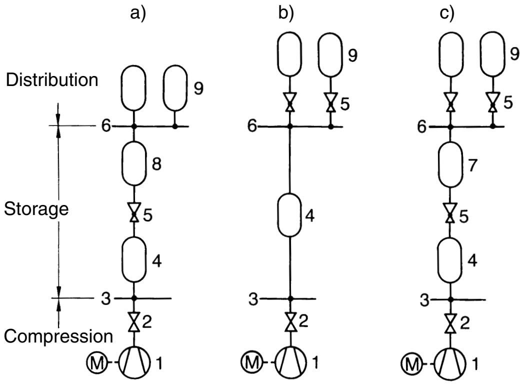


Fig.15-18

Storage compressed-air systems, schematic design:

a) central reduction to breaker pressure b) local reduction, storage at distribution pressure.
c) central/local reduction, storage at high pressure and distribution pressure.

1 Compressor, 2 Pressure valve, 3 Combined line for compression, 4 Storage tank (high-pressure), 5 Pressure reduction valve, 6 Combined line for distribution, 7 Storage tank (distribution pressure), 8 Storage tank (operating pressure), 9 Tanks at the switching device

15.5.4 Rated pressures and pressure ranges

Compressed air generating and distribution systems for specialized applications consist of compressor, storage, reduction equipment and distribution. Table 15-14 shows an overview of the pressure ranges of the various sections of the system.

Table 15-14

Rated pressures and pressure ranges for compressed-air systems as per DIN 43 615

Rated pressure bar	Compression pressure[1)] bar	Storage pressure bar	Distribution pressure bar	Rated breaker pressure bar
10	5… 10	5… 10		
40	25	25		
64	30… 44	30… 44	5, 15, 20,	5, 15, 20,
64	60… 64	60… 64	40, 60, 160,	25, 30, 35
100	100…120	100…120	200	
250	200…250	170…200		

[1)] The compressor pressure may be higher when pressure valves are used.

The selection of pressure levels depends largely on the breaker operating pressure, air requirements, required storage volume, repressurizing times and the permissible moisture in the breaker tank. To meet all possible daily and seasonal temperature variations, pressure levels must be selected to ensure that no condensation occurs in the breaker tank or in the interior of the breaker at even the maximum possible fall in temperature. Fig. 15-19 shows an overview of the connections between the air temperature t, fall in temperature Δt and the expansion ratio ε.

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Example:
Δ t = 23 K
t = 35 °C
ε = 6:1

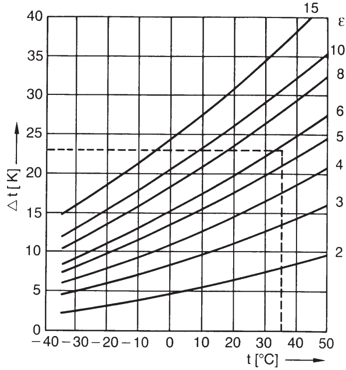

Fig. 15-19

Temperature fall diagram

15.5.5 Calculating compressed air generating and storage systems

Calculation quantities:

a	air requirement of a switch for CO
a_1	air requirement for O-CO
b	leakage air requirement/h
n	number of generator circuit-breakers/high-current bus ducts
n_1	number of switching cycles/day
n_2	number of switching cycles in the event of a fault
p	rated pressure of the high-pressure storage
p_1	breaker blocking pressure
p_2	compressor starting pressure or repressurizing valve "Open"
p_3	minimum tank storage pressure or rated breaker pressure
p_4	opening pressure of charging valve (high-pressure reduction)
p_5	rated breaker operating pressure +5 bar
q	effective output of compressor
t	compressor operating time/day
t_1	fill time for CO
t_2	fill time to autoreclosure block
V	total air quantity/day
V_G	volume/high-current bus duct
V_M	medium pressure storage volume
V_H	high-pressure storage volume
z	percentage air loss of V_G/h

Calculating the compressor output

The size of a compressed-air system is determined by the number of switching cycles occurring in practice. Table 15-15 shows an overview.

Table 15-15

Switching cycles of circuit-breakers, typical values

Number of circuit-breakers when fully installed in the installation	power plant, transformer substation 10 ... 30 kV Number of switching cycles: in 24 h	immediately on faults
n	n_1	n_2
1	2	1
2	5	2
4	9	4
6	11	6
8	13	8
10	15	9

The compressor output is derived as follows:

$$q = \frac{n_1 \cdot a + n \cdot b}{t}$$

For switchgear "b" takes the leakage losses over 24 hours into account. They are included in the circuit-breaker datasheets.

With high-current bus ducts $b = \dfrac{z \cdot V_G \cdot 24}{100}$

The storage volume of the compressed-air systems is calculated for medium- and high-pressure storage as follows:

Medium- and high-pressure storage

$$V_H = \frac{2\, n_2 \cdot a}{3\,(p_2 - p_3)}$$

$$V_M = \frac{n_2 \cdot a}{3\,(p_4 - p_5)}$$

If high-pressure storage only is used, then

$$V_H = \frac{n_2 \cdot a}{p_2 - p_3}$$

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15.5.6 Compressed air distribution systems

Copper and steel pipes are used for the compressed air distribution system. The joints are designed with soldered fittings for an operating pressure of up to 60 bar. A soft solder with 95% Sn + 5% Sb is used for copper pipes at a working temperature of approximately 245 °C.

A hard solder with 40% Ag can be used for applications with severe mechanical stresses. Because the melting point of this solder is over 600 °C, the pipes are heated during soldering. They must therefore only be stressed with the load value of the next lower strength class of the soft state.

At an operating pressure of over 60 bar, cutting ring screws as per DIN 43685 or 2353 are generally used.

The lines between the compressor system and the switchgear are either radial lines or ring lines, depending on the size of the system.

Copper pipes with external diameters of 6, 8, 10, 12, 18, 20 and 28 mm and steel pipes of 6, 8, 10 and 12 mm are used.

The wall thickness and pressure ranges of the compressed air lines in switchgear installations are specified in DIN 43614.

Changes in the length of the pipes caused by changes in temperature must be compensated by installing expansion loops. Pipes must be able to move slightly when installed.