SIEMENS

Totally Integrated Power

Application Models for Power Distribution

Data Centres

Answers for infrastructure.

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Data Centres – Definition

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In 1941, the successful revolution of data processing (DP) was started and hence the development of data centres (DaC). For the first time ever, engineer Konrad Zuse constructed an automatic computing machine – the Z3 – for the four basic arithmetic operations plus finding roots using electro-magnetic switches only from the world of telecommunications. This automatic machine in the "computing room", the living room of his parents, weighed more than a ton and had the gigantic power demand of 4,000 watts. The pioneer know-how of Zuse KG was integrated into the Siemens AG in 1967 and even today, it reflects our endeavour to push progress in DP technology and its related infrastructure.

The further development of information and communication technology (ICT) using electron tubes, magnetic storage devices and later semiconductor components has led to a world-spanning spread of data centres in science, industry and administration. In this way, the requirements regarding security and performance of the appertaining infrastructure were pushed upwards. The expansion of electronic data transfer, the networking of electronic media and, last but not least the spread of the Internet, in particular the "world wide web" developed at CERN (Conseil Européen pour la Recherche Nucléaire) – the European Council for Nuclear Research, at the end of the 1980ies generated a service sector in the field of data centres which grew dramatically and produced a growing demand for total availability and security of information.

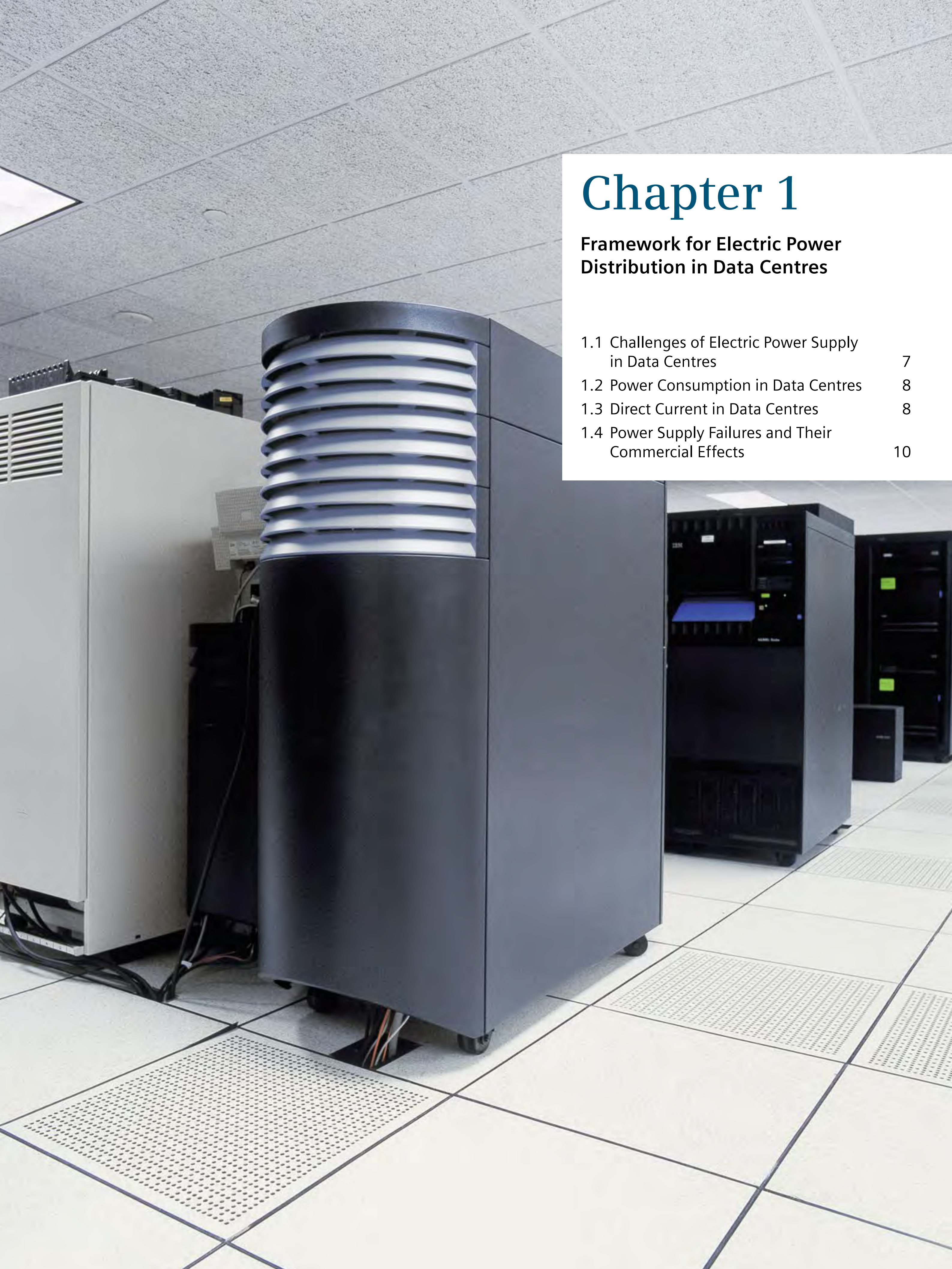
Wikipedia defines a data centre as "a facility used to house computer systems and associated components, such as telecommunications and storage systems. It generally includes redundant or backup power supplies, redundant data communications connections, environmental controls (e.g., air conditioning, fire suppression) and security devices" [1]. *SearchDataCenter.com* even includes the virtuality of this facility in the definition: "... a centralized repository, either physical or virtual, for the storage, management, and dissemination of data and information organized around a particular body of knowledge or pertaining to a particular business" [2].

Cremer et al. [3] differentiate between data centres in a narrower sense, the server farms, "in which data and services are stored and executed for Internet applications" and data centres in a wider sense, which means "buildings and parts of buildings which accommodate servers and similar ICT equipment and which are not located directly at the user's workplace".

Many different characteristics, like total area, floor area for ICT equipment, electric power demand of ICT equipment, or arithmetic operations per annum to be carried out in the data centre are used to classify data centres. A relatively common method is a classification of data centres by numbers of the ICT inventory, this refers in particular to servers. However, designations and size information may differ, as the table shows.

	U.S. EPA [4]	UBA [5]	IZE, TU Berlin [6]	IDC [7]
Server closet	1-2 servers, no external storage systems	3-10 servers	1-2 servers	
Server room	Up to some dozens of servers, no external storage systems	11-100 servers	3-10 servers	
Small DaC	A few dozens up to some hundreds of servers, moderate use of external storage systems	101-500 servers	11-50 servers	350-500 servers
DaC			51-250 servers	
Medium-size DaC	Several hundred servers, intensive use of external storage systems	501-5,000 servers	251-800 servers	1,500-1,700 servers
Large DaC		More than 5,000 servers		2,000-2,500 servers
Very large DaC/ mainframe computer centre/enterprise DaC	Thousands of servers, intensive use of external storage systems		More than 800 servers	Up to 25,000 servers

Classification of data centres by ICT equipment in different sources



Chapter 1

Framework for Electric Power Distribution in Data Centres

1 Framework for Electric Power Distribution in Data Centres

The data centre is a core facility which shall provide services in the range of data processing and communication, such as data transmission, data storage, data processing and conversion. In this context, the following may be required: the provision of a suitable room, a suitable ICT hardware, a suitable software or the execution of these types of ICT applications and the transmission of data and findings to the client in the desired format. A data centre can be built up within the organizational structure of a business enterprise; the appropriate services can also be acquired from external data centre operators.

1.1 Challenges of Electric Power Supply in Data Centres

Electric power supply is the prerequisite of all DaC operations, i.e. computers, screens, hard drives, network components and data lines. It is not only the ICT equipment for which electrical energy must be readily available, but also for infrastructure tasks which includes cooling, air conditioning, fire surveillance and fire fighting, security and access control, lighting, lifts, drives, motors and much more (see Fig. 1/1).

The following performance criteria are important for drawing up a concept of the power supply system:

- availability
- cost efficiency
- reliability
- environmental impact
- speed

It is the planner's task to optimally design the power supply. In this context he must consider both his customer's specifications and laws, directives, regulations and procedures.

Those general customer requirements which at all costs must be currently considered in planning the electrical power supply as conditioned by the deployment and environmental requirements are:

- Energy efficiency
- Redundancy
- Security
- Expandability
- Operational Management
- Quality

The specific characteristics of these factors influence the performance criteria called for, on the basis of which a power distribution infrastructure is planned. For example, additional redundancy integrated in power distribution may improve the availability and reliability of the data centre. However, the higher cost involved for redundant components may have a negative impact on cost efficiency, and an unfavourable utilisation of redundant components in operation may bring about drawbacks in efficiency and thus associated higher energy losses and an avoidable environmental burden.

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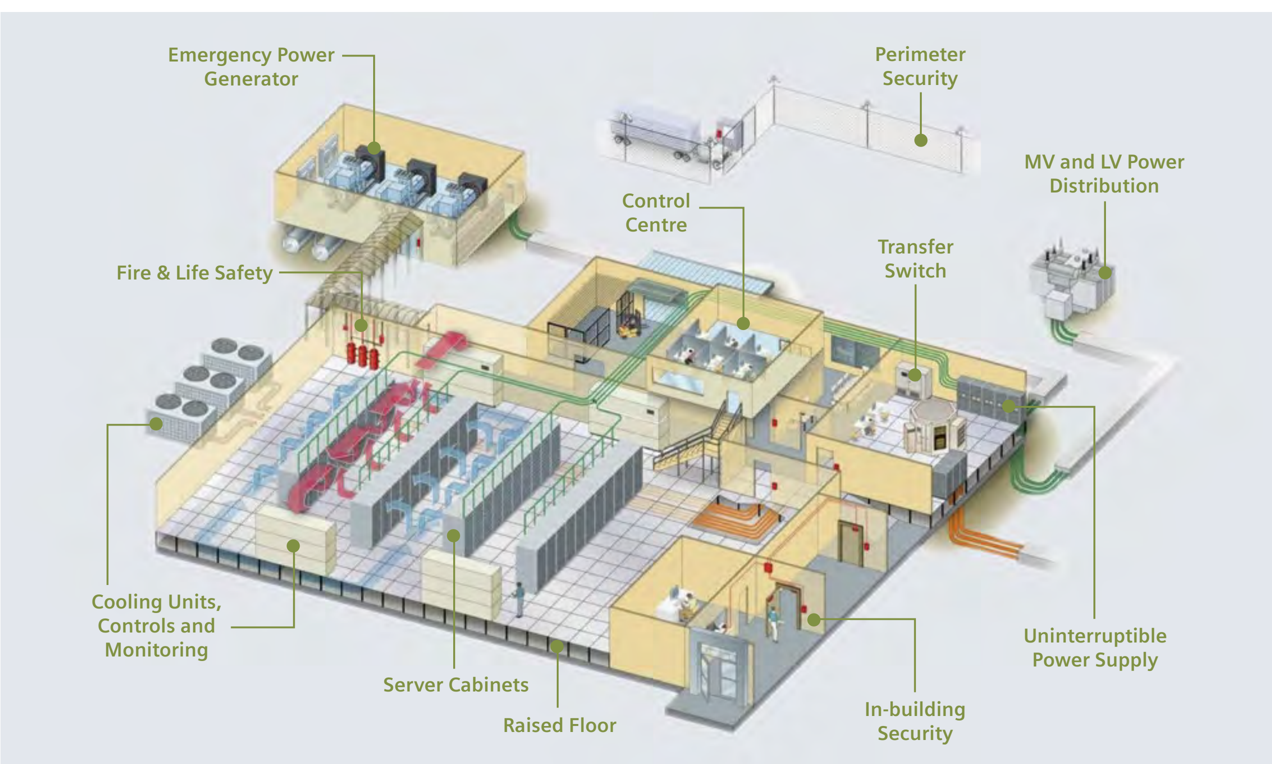


Fig. 1/1: **Power supply is an integral part of the infrastructure in data centres**

1.2 Power Consumption in Data Centres

The basic expectation is that the world-wide power demand of data centres will rise. Based on the assumptions of 2007, Microsoft [8], for example, forecasts a continuous rapid upsurge in power consumption, as shown in Fig. 1/2. The growth rates of previous years will be continued and the Power-Usage-Efficiency (PUE) factor of 2.0 (i.e. the ratio of the total power demand of a data centre compared to the power demand of its ICT components – see [9]) will remain unchanged.

1

In Western Europe, power consumption is set to nearly double from 56 TWh to 104 TWh between 2007 and 2020 according to the European Commission [10]. Even so, this correlates with the values in Fig. 1/2, since it can be expected that the development in aspiring countries such as China, India or Russia will speed up considerably over the next few years.

Other factors of uncertainty which may lead to deviations in estimates of future developments are for instance:
- the development of the global economy and competition
- protectionism, regulation or liberalisation of markets
- changes in the cost of power generation
- changes in the cost of labour and material
- impact of environmental issues in connection with power generation and consumption
- development trends in ICT and infrastructure components for data centres
- development trends in user behaviour with regard to DaC services such as cloud computing, network applications, security requirements

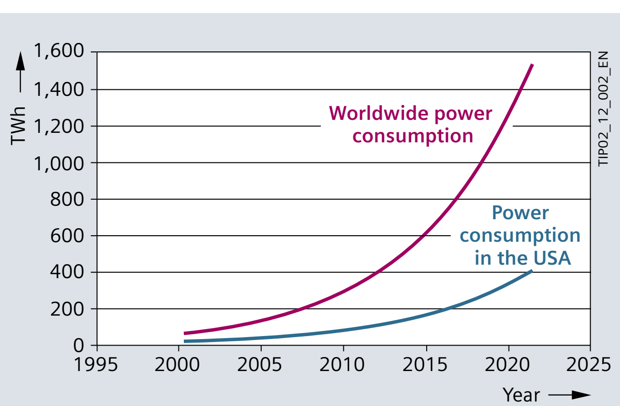


Fig. 1/2: **Power consumption trends of data centres [8]**

Considering the high requirements placed on the environment of a DaC, such as
- connectivity to the electric power distribution network and data transmission lines
- ambient climatic conditions
- avoidance of transportation hubs and industrial plants posing hazards
- distance away from military facilities, landfill sites, waste incineration plants and
- a low probability of natural catastrophes occurring,

it becomes increasingly difficult to find suitable localities for the construction of new data centres on green fields ("green field investments"). Therefore, the modification and extension of data centres ("brown field investments") as well as a consideration of the extendibility of modular systems will become more and more important. Likewise, in-plant power generation and its utilisation in the data centre can increasingly be factored into planning. In this context, a coincidence of power consumption and cooling demand would be advantageous conditional upon the required computation and communication capacity.

1.3 Direct Current in Data Centres

Of late IT experts have been discussing the use of electric power supply systems with direct current application for ICT components. Lawrence Berkeley National Laboratory (LBNL) predicted energy efficiency benefits of more than 28% for an average data centre, since the transformation steps from direct current (DC) to alternating current (AC) and vice versa would be avoided [11].

Without going into the findings and parameters in more detail which have been used to establish these values, it must be noted that a consequent use of state-of-the-art technology hardly gives rise to any efficiency benefits. Under European grid voltage conditions, modern UPS systems and high-quality power supply units in ICT components, the losses of AC and DC systems are equally large.

It must be possible for IT managers to handle the power supply for their equipment in a straightforward and safe manner. Safe disconnection and plugging of DC connections should just be as simple, cost-efficient and standardized as with AC connector systems. Since an energized disconnection of DC systems causes problems, safe isolation from supply must be ensured for DC connections.

Another problem of fault shutdown in higher voltage DC networks stems from arc detection in the distribution network. Traditional overcurrent protection devices (OPD) can only be applied here to a limited extent. On the one hand, limiting the arcing fault current may result in the OPD not tripping and on the other hand, the risk remains of the arc not being quenched in the OPD even if the fault is detected. This raises the fire hazard.

Moreover, it remains to be said that these considerations only envisage the ICT components being supplied with a high DC voltage, whereas the complete AC power supply structure must be maintained for the other power consumers. Thus it can be expected that besides a DC supply an AC supply also needs to be provided for the computer and telecommunication rooms.

Without considering the technical details, it can be assumed that owing to the current market situation for servers, storage system and network equipment, no abrupt turn-around towards a second product line of DC power supply components will take place. For this reason, this manual will present the state-of-the-art technology for the power supply of AC400/230-volt networks and development trends to be expected over the next few years.

Fig. 1/3: **Internal arc during an overvoltage test in the Siemens Switchgear Plant Berlin**

1.4 Power Supply Failures and Their Commercial Effects

In data centres, the relevant electrical components must be supplied with electricity with the utmost of reliability 24 hours a day. Malfunctions or even a power blackout and the resulting data losses and operational interruptions will cause substantial economic losses for a data centre operator (Fig. 1/4). Consequential damage owing to the loss of image and trust can be expected in addition.

Often, the consequences of IT failures are under-estimated since it is only the lost working time which is factored in the calculation of breakdown costs. Consequential damage, such as the loss of business and customer/investor confidence and possibly even contractual penalties, is not taken into account. The best examples are just-in-time deliveries given in contracts for work and services or building contracts. If delays are caused by IT failure, penalties for breach of contract may be claimed. At the same time, IT managers made the experience that the most frequent reason for operational downtimes is due to problems with the electrical power supply of the data centre (see Fig. 1/5).

1

Despite a high reliability of supply, it is the distribution system operator (DSO) who is responsible again and again for an interruption to the power supply. The majority of these failures lasts less than a second so that they are hardly noticed. But even interruptions of more than ten milliseconds and voltage dips can impair IT operations and result in financial losses (see Fig. 1/6). Therefore, precision planning of safety power supply (SPS) and uninterruptible power supply (UPS) is of vital importance for data centres.

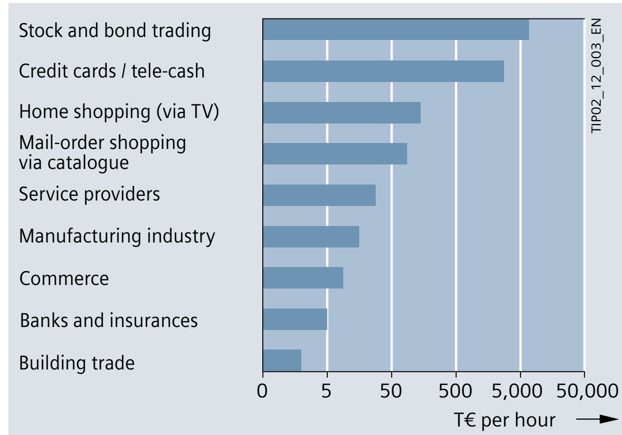


Fig. 1/4: **Damage costs caused by IT breakdowns [12]**

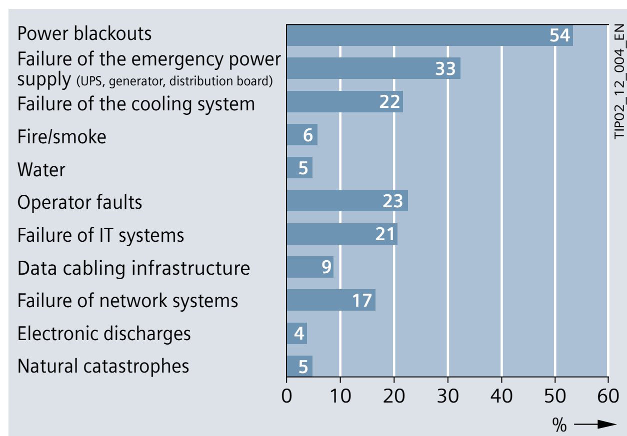


Fig. 1/5: **Percentage frequency distribution answering the question: Which factors have caused operational interruptions in your data centre within the last 24 months? [13]**

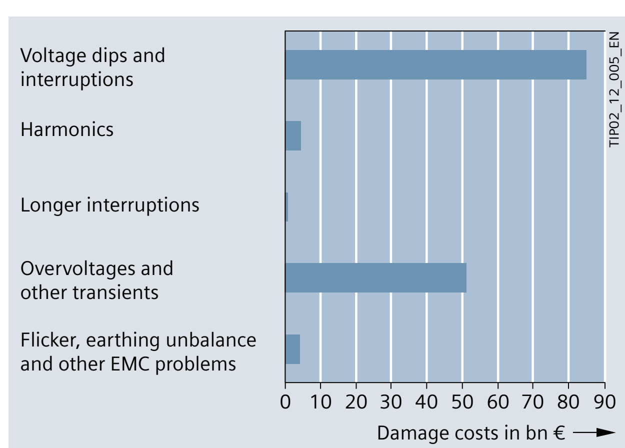
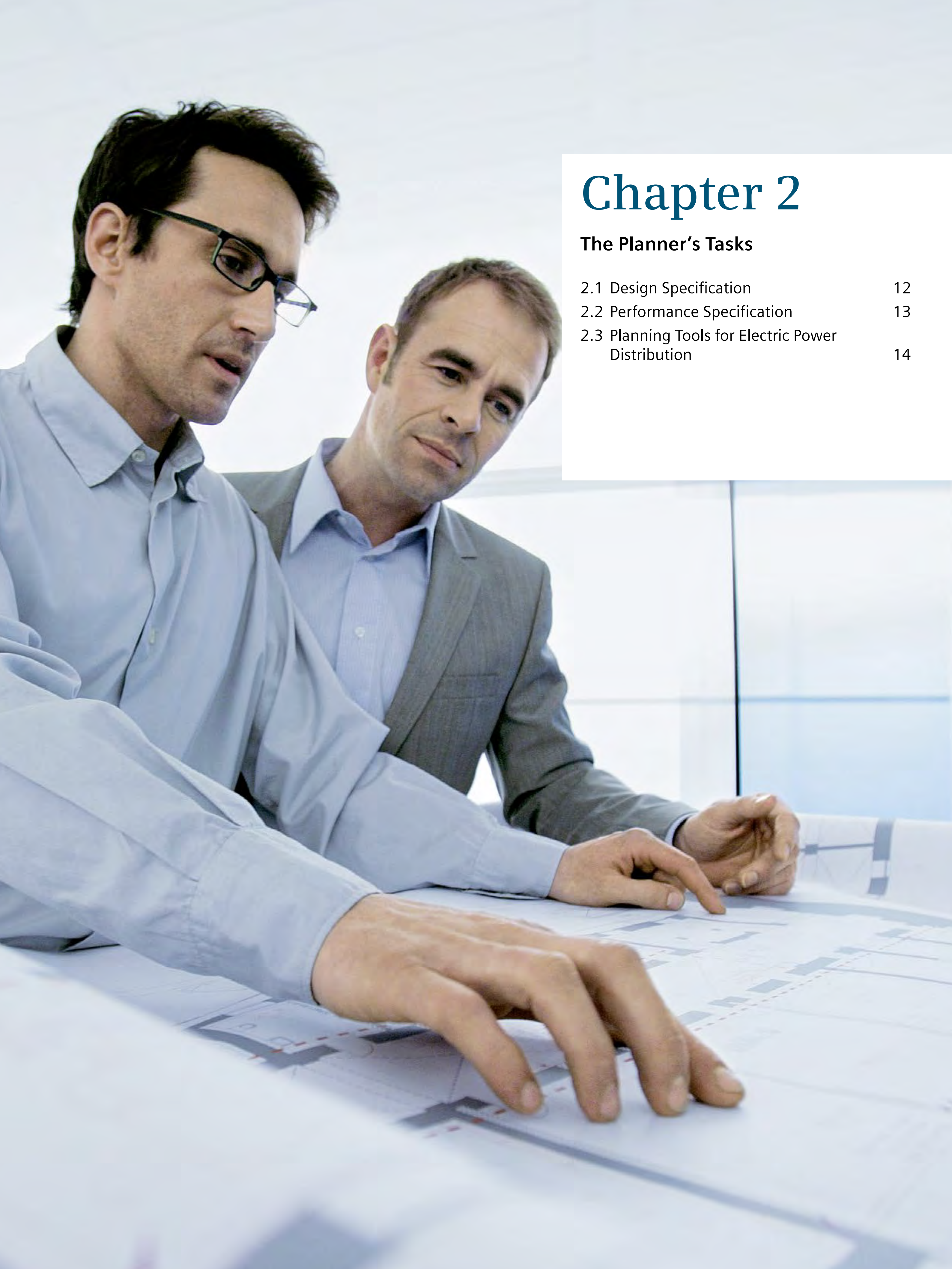


Fig. 1/6: **Annual losses due to lack of good voltage quality exemplified for industrial applications in Europe [14]**

Chapter 2

The Planner's Tasks



2 The Planner's Tasks

It is up to the planner on the one hand to win an edge over his competitors and gain unique selling points by offering modern, innovative concepts for the layout of power supply systems and the selection of equipment. But on the other hand, he is also responsible for his planning work, which means that he may be held liable for damages. Therefore it is important to clarify the project scope and the economic conditions with the owner/developer at an early stage. Integrated planning in the sense of Totally Integrated Power ranging from medium-voltage feed-in to the server rack (see Fig. 2/1) starts from a holistic approach, which takes these conditions into account and delivers a profitable and safe solution.

The intial phases of planning the electric power distribution of a data centres are already of vital importance. They determine the basic set-up and guidelines for the further course of the project. Wrong assumptions and imprecise specifications may result either in system oversizing and, consequently, in unnecessary costs, or in undersizing and, consequently, in equipment overloading and failure. The design specification and built on that the performance specification are the basis for the creation of a custom-er-specific project.

2

2.1 Design Specification

The design or product specification describes the "What?" and "For which purpose?" and outlines the basic require-ments. For the contractor it is the basis for drawing up a performance specification.

- It describes the direct requirements and the desires placed in a planned product or project from the user's point of view.
- It serves as a basis for the invitation to tender, the tender or quotation, and the contract.
- It represents the scope of requirements defined by the contract awarding party as regards the deliveries and services to be performed by the contractor within the scope of the contract.
- The questions as to "What?" and "For which purpose?" shall be answered in the design specification.
- The requirements shall be quantified and verifiable.
- The design specification is drawn up by the (external or in-house) awarding party, and it is addressed to the contractors.
- In software development, the design specification consti-tutes the result of the planning phase and is usually worked out by the developers as a first stage to the performance specification.

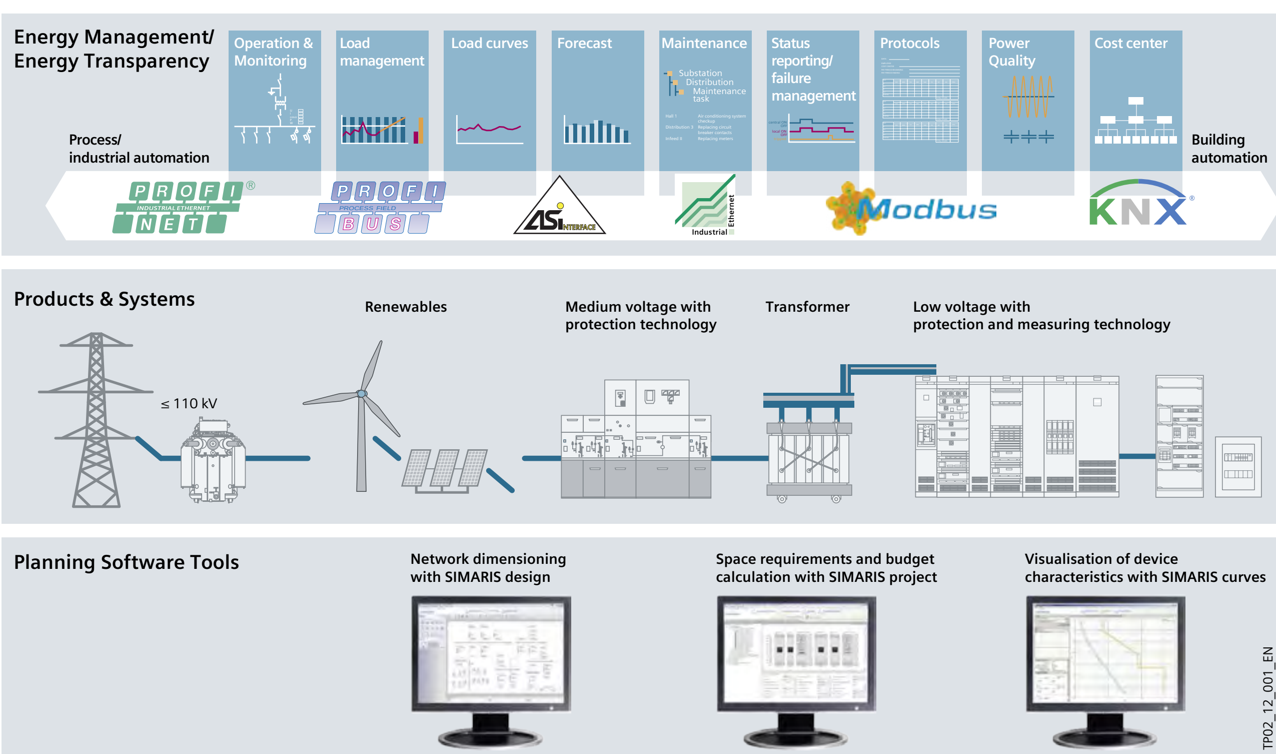


Fig. 2/1: **Totally Integrated Power – integrated solutions for electrical power distribution**

2.2 Performance Specification

The performance or feature specification represents the concept to be put into practice and is technically detailed in so far that it can act as the basis for contract awarding.

It is a detailed description of a service to be performed, for example, the erection of a technical plant, the construction of a tool, or the creation of a computer program.

- It describes the solutions which the contractor has worked out for how to implement the project on the basis of the design specification defined by the customer.
- The questions as to "How" a project should be put into practice and "Which tools or resources" are to be employed are dealt with in the performance specification.
- The contents of the design specification are described in more detail, completed and written into a plausible implementation concept and combined with technical operating and maintenance requirements.

Usually, each of the requirements of the design specification can be assigned to one or more services defined in the performance specification. This also illustrates the order of the two documents in the development process: A requirement is fulfilled, when the corresponding feature is implemented.

When a design or performance specification is drawn up, it must be considered that subordinate targets such as investment, losses, reliability, quality, and much more may mutually influence one another. Listing up such conflicting relations and weighing them in the project context will foster planning decisions and hence the focus that is placed on the design and performance specification. Weighing in the context of design or performance specification must be based on different questions posed. Tab. 2/1 shows a simple correlation matrix in which the competing situation of individual sub-targets is assessed. For example, sub-target 2 – Low power losses – is strongly influenced by sub-target 1 – Cost of investment – whereas sub-target 4 – High reliability of supply – has no immediate interrelation with power losses.

Subgoals		1	2	3	4	5	6	7	8	9
1	Low investment costs	–	■	■	■	■	□	○	□	□
2	Low power losses	■	–	○	○	○	○	□	○	○
3	Process-compliant coverage of the power demand	■	○	–	○	○	○	■	○	○
4	High reliability of supply	■	○	○	–	○	○	■	○	○
5	High voltage quality	■	○	○	○	–	○	□	○	○
6	Low hazard for man and machine	□	○	○	○	○	–	○	○	○
7	Low maintenance and repair expense	○	□	■	■	□	○	–	□	○
8	Ease of operation	□	○	○	○	○	○	□	–	○
9	High environmental compatibility	□	○	○	○	○	○	○	○	–

■ Strong competition □ Competition ○ No or irrelevant competition

Tab. 2/1: **Competitive situation during planning decisions [14]**

2.3 Planning Tools for Electric Power Distribution

Since the requirements for the equipment of data centres as well as the expectations with regard to system safety and documentation are constantly increasing, the planning of electric power distribution becomes more and more demanding and complex. The SIMARIS software tools support the planning of power distribution systems in buildings and allow for convenient and easy operation thanks to a well designed user interface and functions which can be used intuitively. Frequently required modules, devices and systems can be saved as favourites and integrated in later planning files again. The planning expense can thus be further reduced by using the SIMARIS software tools. The user can update the stored product data in an uncomplicated way by means of online updates. The data is, of course, synchronised between the programs.

2.3.1 Dimensioning with SIMARIS design

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In accordance with the conditions resulting from the project requirements, SIMARIS design can be used to dimension the equipment according to the accepted rules of good installation practice and all applicable standards (VDE, IEC), from medium-voltage supply up to the consumers. SIMARIS design thus supports the calculation of short-circuit currents, load flow and distribution, voltage drop and energy report. Moreover, SIMARIS design assists in the selection of actually required equipment, e.g. medium-voltage switching and protective devices, transformers, generators, low-voltage switching and protective devices, and the sizing of cables, wires and busbar systems. In addition, the lightning and overvoltage protection can be included in the dimensioning process.

The power supply system to be planned can be designed graphically in a quick, easy and clear way with the help of the elements stored in the library (Fig. 2/2). Subsequently, the planner defines the operating modes required for the project. This definition can be more or less complex, depending on the project size and the type and amount of load feeders and couplings used. However, with SIMARIS design this definition is quite simple, since the relevant devices and their switching conditions required for the respective operating modes are presented graphically in a clear and well structured manner. All common switching modes can be mapped and calculated thanks to the option of representing directional and non-directional couplings and load feeders at the sub-distribution level and isolated networks.

Sizing of the complete network or of subnetworks is done automatically according to the dimensioning target of "selectivity" or "backup protection". The calculation results can be documented with various output options. With the "professional" version of the software, it is even possible, among other things, to perform a selectivity evaluation of the complete network.

From experience, planning an electric power distribution system is always subject to considerable changes and adaptations both in the planning and in the implementation stage, for example also due to concept changes on part of the customer forwarded at short notice. With the help of the software, adaptations of the voltage level, consumer capacities or the technical settings for medium or low voltage can be quickly and reliably worked into the supply concept, for example; this includes an automatic check for permissibility in accordance with the applicable standards integrated in the software.

2.3.2 Determining the space requirements with SIMARIS project

When using the "professional" version of SIMARIS design, an export file can be generated, which contains all the relevant information on the established equipment. This file can be imported in SIMARIS project for further processing of the planning scheme. Here, the established devices and other equipment can be allocated to the concrete systems. Thus, the space requirements of the planned systems can be determined and the budget be estimated.

If an export file from SIMARIS design is not available, the electrical designer can determine the required medium-voltage switchgear, transformers, busbar systems and devices for the low-voltage switchboards and distribution boards directly in SIMARIS project on the basis of the given technical data and defined project structure.

Depending on the type of system, the systems are represented graphically (see Fig. 2/3) or in list form. For example, the planner can directly select and graphically place the panels required for the medium-voltage switchgear, whereas selected transformers and the components required for the busbar trunking systems are presented in list form. For low-voltage switchboards and distribution boards in SIMARIS project, the devices are compiled in a list at first and then automatically placed in the plants. The device arrangement created in this process can then be modified in the graphic view (see Fig. 2/3).

In the further course of the project, the planning can be adapted to current requirements over and again and become more and more detailed according to the project progress. The result which the user gets is concrete technical data as well as dimensions and weights for all

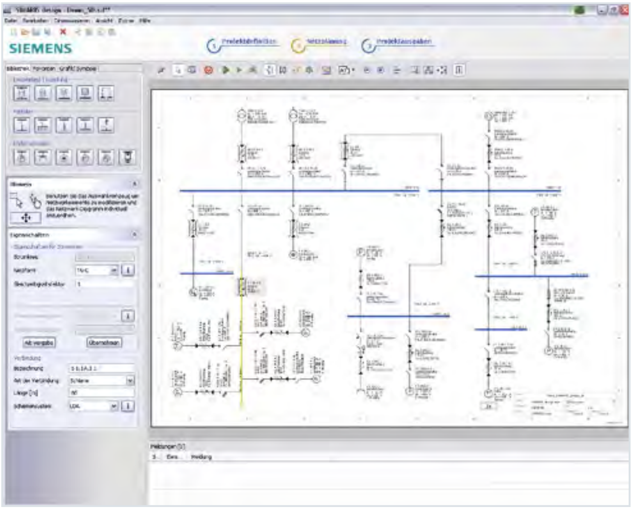

Fig. 2/2: **Network design with SIMARIS design**

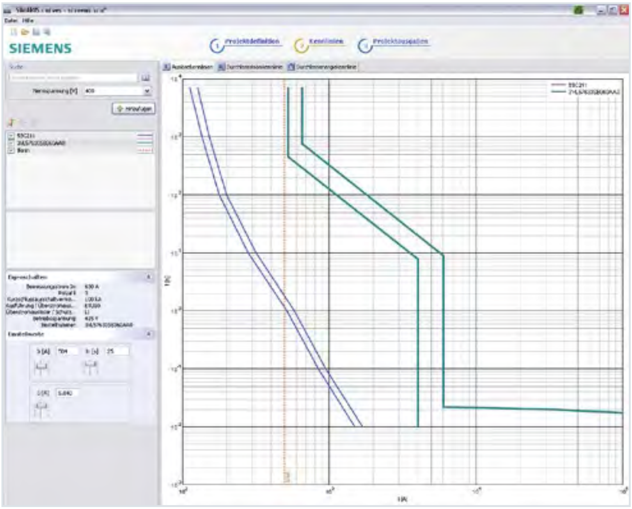

Fig. 2/4: **Characteristic curves (fuse, moulded-case circuit-breaker) in SIMARIS curves**

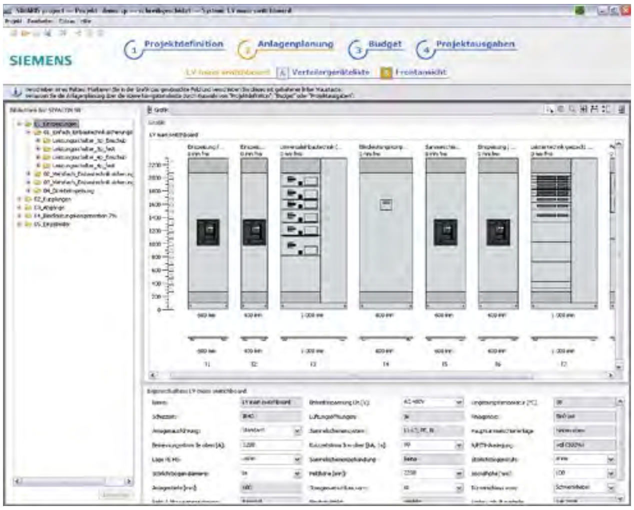

Fig. 2/3: **SIVACON S8 system planning with SIMARIS project**

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components in the power distribution system. For the documentation of the planned systems, SIMARIS project also allows the creation of view drawings, technical descriptions, component lists and even technical specifications.

The budget for the planned systems can either be obtained by sending the project file to the responsible Siemens contact or, you can perform the calculation yourself. To support your own calculation, a list of the configured systems is created in SIMARIS project as a summary, in which every system can be assigned a price as well as additions and reductions.

Displaying characteristic curves with SIMARIS curves

If detailed information on the tripping performance of individual devices is required for planning preparations or for documentation purposes, SIMARIS curves can be used to visualise and assess tripping curves and their tolerance ranges; the curves can be adapted by simulating parameter settings (see Fig. 2/4) . Moreover, SIMARIS curves can also be used to display and document let-through current and let-through energy curves for the devices.

For more information see *www.siemens.com/simaris*

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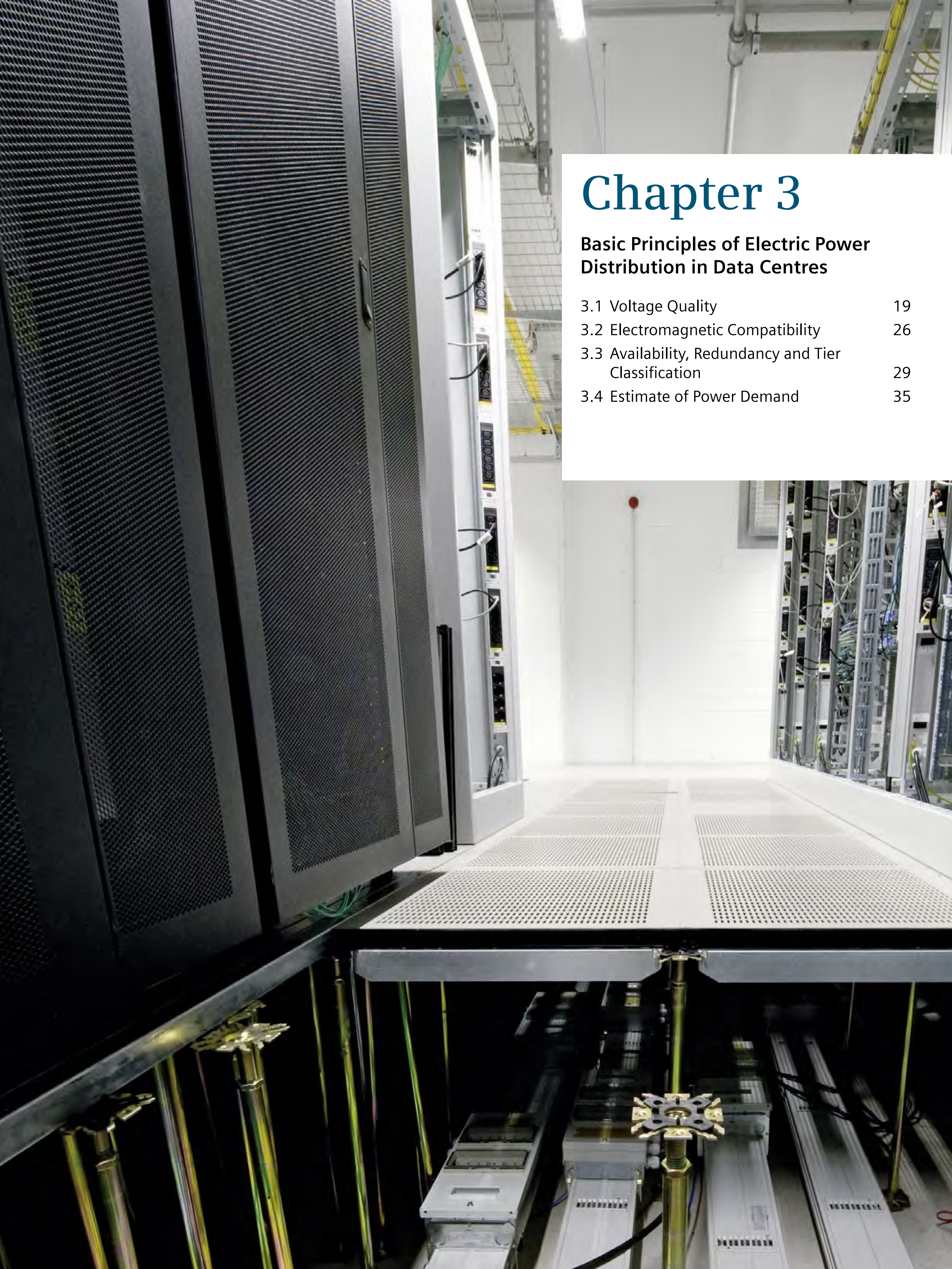


Chapter 3

Basic Principles of Electric Power Distribution in Data Centres

3 Basic Principles of Electric Power Distribution in Data Centres

A high availability of supply is of fundamental importance to data centre operation. In combination with the voltage and service quality, availability of electric power supply characterizes supply quality in the data centre. The basic challenge in planning now is to find the optimum of investment and operating costs on the one hand and risk estimation (frequency and effects of failures) on the other (Fig. 3/1).

Supply quality =
voltage quality + availability + service quality

The plus sign symbolizes the linkage of the individual factors. Voltage quality does not mean pure line voltage quality in the narrower sense but also includes power quality, reactive power and failures caused by power consuming equipment in the data centre. In the planning process, the question of how supply quality is desired inevitably leads to a cost analysis, since investments made for risk minimisation must be compared to and assessed with the consequential costs from operational downtimes possibly resulting from a server crash or outages of one rack or even the entire IT room.

A cost estimate of supply problems should at least take into account the costs of interruptions, failures and putting the hardware into service again. Indirect costs, such as costs incurred due to a deterioration of customer loyalties or even contract losses are practically non-assessable as cost factors during the planning stages.

3

The specific usage of the data centre plays an important part in a cost estimate. It is helpful for the desired degree of operational flexibility to be considered as early as in the planning stages. To this end, the data centre operator must determine which usage and outfit options shall be permitted in the pre-planning phase. If the user is offered electric power supply down to the rack level, planning must pay attention to a variable design structure to a much greater extent than if the user is only offered supply to the IT room with a defined amount of power output. In any case, much shorter innovation cycles of ICT components than those of infrastructure components must be observed. Higher packing densities, for example, will result in greater performance requirements in the IT room and hence a bigger sizing of cables and wires and changed safety requirements.

The electrical designer will indirectly factor in the aspect of service quality by considering the functionality and quality aspects of the products and systems involved in the project. Components of electric power distribution that show appropriate quality features are introduced in chapter 4.

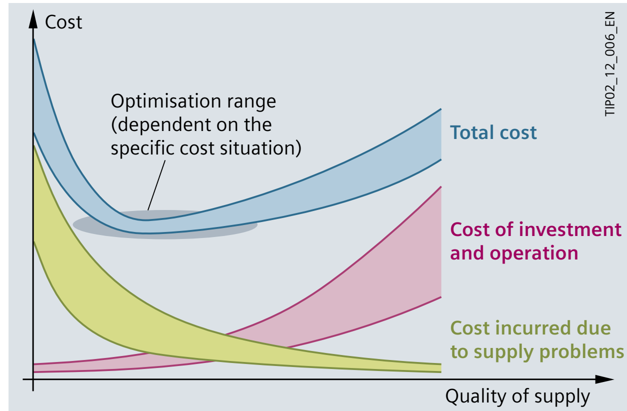


Fig. 3/1: **Diagram of cost optimisation conditional upon supply quality**

In order to specify the required product quality of connected consumers in the data centre with regard to their supply voltage, the curve of the "Information Technology Industry Council" (ITIC), previously called "Computer and Business Equipment Manufacturers Association" (CBEMA) as shown in Tab. 3/2, is used. In this context, it must be noted that the data is based on an manufacturer agreement concerning power supply units for computers and 120-volt/60-hertz power supplies. Within the sphere of influence of the American National Standards Institute (ANSI), this curve is based on IEEE 446. The ITIC curve is shown in Annex B of the IEC 61000-2-4 (VDE 0839-2-4) standard. However, special emphasis is laid on the 120-volt/60-hertz single-phase network and the limitation on IT facilities.

Today, many single-phase power supply units in ICT hardware are used for the wide input voltage range of 120 V to 240 V. As such, the curves provide a good starting point for the protective measures to be chosen. The parameters of

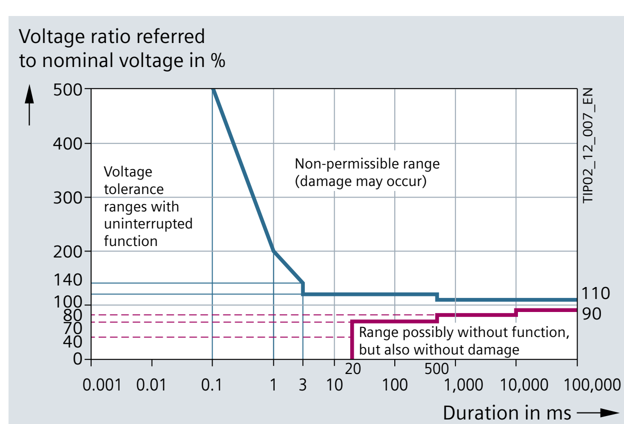


Fig. 3/2: **ITIC curve for computer power supply units acc. to [15]** voltage quality and availability will be discussed in the next two sections and rounded off by an estimate of the power demand. Basically, the entire infrastructure chain in the data centre must be included in such a consideration, in particular the cooling and air conditioning processes.

3.1 Voltage Quality

The voltage quality characterizes the conformity of important criteria of electric power supply for the operation of equipment with the voltage properties assured by the supplier. In this context it must be observed that the consumers also meet the requirements set up by the supplier. Thus a mix of faults in the power supply and line perturbations arise which are caused by the connected appliances, plants and equipment. EN 50160 describes the requirements placed on the main characteristics of the supply voltage for connection to the public grids:

- Voltage magnitude, slow voltage changes
- Fast voltage changes, flicker
- Voltage dips
- Supply interruptions
- Voltage unbalance
- Harmonic voltage and interharmonic component
- Line-frequency and transient overvoltages
- Frequency variations

In many European countries, this standard serves as a guideline or reference for parameter adaptation to the characteristics of national power systems in order to create national standards. The establishment of such standards is normally performed on the basis of the experience gained by local initiatives from the implementation of monitoring systems for power quality which allow the appropriate voltage parameters to be determined. Tab. 3/1 shows a more detailed subdivision with appropriate level and guidance values.

The fault parameters described in EN 50160 affect data centre operation. Tab. 3/2 allocates possible causes and consequences to the individual voltage problems. This issue is now increasingly becoming the focus of the planner's attention, since the restructuring of the power generation concept based on controlled power stations in the vicinity of load centres towards decentralized power supply dependent on local conditions has the effect of intelligent concepts such as the Smart Grid, being based, for instance, on the efficient use of measuring and automation technology, storage technologies and uninterruptible power supply systems.

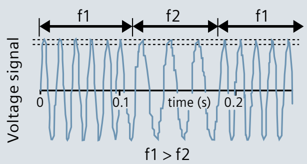
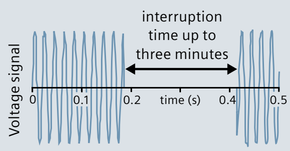
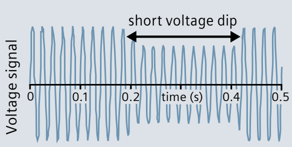
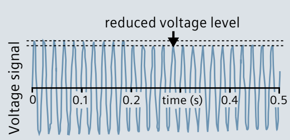
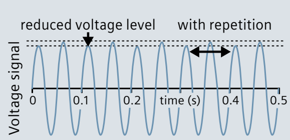
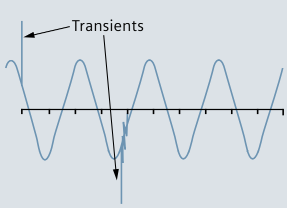
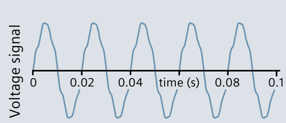
EN 50160 does not specify any values for electromagnetic compatibility (EMC) or limit values for the emission of interferences. It describes the characteristics of the supply voltage and related requirements for general operation.

3

Characteristic	Requirements	Measurement interval	Period under consideration
System frequency	Interconnected grid: 50 Hz + 4 % / –6 % continuously; 50 Hz ± 1 % during ≥ 99.5 % of a year Isolated operation: 50 Hz + 15 % / –6 % continuously; 50 Hz ± 2 % during ≥ 95 % of a week	10 sec average	1 year 1 week
Slow voltage changes	U_{rated} + 10 % / –15 % continuously U_{rated} ± 10 % during ≥ 95 % of a week	10 min average	1 week
Flicker / fast voltage changes	Long-term flicker severity P_{lt} < 1 during ≥ 95 % of a week and ΔU_{10ms} < 2 % U_{rated}	2 h (flickermeter in acc. with IEC 61000-4-15)	1 week
Voltage unbalance	U (negative phase-sequence system) / U (positive phase-sequence system) < 2 % during ≥ 95 % of a week	10 min average	1 week
Harmonics U_{n2} … U_{n25}	< limit value in acc. with EN 50160 and THD < 8 % during > 95 % of a week	10 min average of each harmonic	1 week
Subharmonics	being discussed		1 week
Signal voltages	< standard characteristic curve = f(f) during ≥ 99 % of a day	3 sec average	1 day
Voltage dips	Number < 10 … 1,000 / year; thereof > 50 % with t < 1 s and ΔU_{10ms} < 60 % U_{rated}	10 ms r.m.s. value U_{10ms} = 1 … 90 % U_{rated}	1 year
Short voltage interruptions	Number < 10 … 1,000 / year; thereof > 70 % with a duration of < 1 s	10 ms r.m.s. value U_{10ms} = 1 … 1 % U_{rated}	1 year
Long voltage interruptions	Number < 10 … 50 / year; thereof > 70 % with a duration of < 3 min		1 year
Temporary overvoltage (L-N)	Number < 10 … 1,000 / year; thereof > 70 % with a duration of < 1 s	10 ms r.m.s. value U_{10ms} = 1 … 110 % U_{rated}	1 year
Transient overvoltage	< 6 kV; µs … ms		No data

Tab. 3/1: **Voltage characteristics of electricity supplied by public grids in accordance with EN 50160**

3

Problem	Description	Cause	Effect
	**Frequency variation:** A frequency variation involves variation in frequency above or below the normally stable utility frequency of 50 or 60 Hz	• Start-up or shutdown of very large item of consumer equipment, e.g. air conditioning equipment • Loading and unloading of generator or small co-generation sites • Unstable frequency power sources	• Maloperation, or even damage to IT equipment • Data loss • System crash
	**Supply interruption:** Planned or accidental total loss of power in a specific area; momentary interruptions lasting from a half second to 3 seconds; temporary interruptions lasting from 3 seconds to 1 minute; long-term interruptions lasting longer than 1 minute	• Switching operations attempting to isolate an electrical problem and maintain power to affected area • Accidents, acts of nature, etc. • Fuses, actions by a protection function, e.g. automatic recloser cycle	• Sensible software process crashes • Loss of computer/controller memory • Hardware failure or damage
	**Voltage dip / sag or swell:** Any short-term (half cycle to 3 seconds) decrease (sag) or increase (swell) in voltage	• Start-up or shutdown of very large item of consumer equipment, e.g. air conditioning equipment • Short circuits (faults) • Underdimensioned power supply • Owing to utility equipment failure or utility switching	• Memory loss, data errors, shrinking display screens • Lighting variations • Motors stalling or stopping and decreased motor life
	**Supply voltage variations:** Variation in the voltage level above or below the nominal voltage under normal operating conditions	• The line voltage amplitude may change due to changing load situations	• Equipment shutdown by tripping due to undervoltage • Overheating and/or damage to equipment due to overvoltage • Reduced efficiency or life of electrical equipment
	**Flicker** Impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time	• Intermittent loads • Motor starting of fans and pumps • Arc furnaces • Welding plants	• Rapid variations in the luminance of lamps causing headaches on people, disturbing their concentration; defective products caused by production shortcomings
	**Transient** A transient is a sudden change in voltage up to several thousand volts. It may be of the impulsive or oscillatory type (also termed impulse, surge, or spike) **Notch:** This is a disturbance of opposite polarity from the waveform	• Utility switching operations, • Starting and stopping heavy equipment and lifts • Static discharge • Strikes of lightning	• Hardware damage • Data loss • Burning of circuit boards and power supply units
	**Noise:** This is an unwanted electrical signal of high frequency from other equipment **Harmonic:** Distortion of the pure sine wave due to non-linear loads on the power supply network	• Noise is caused by electromagnetic interference from appliances, e.g. microwave, radio and TV broadcast signals, or improper earthing • Harmonic distortion is affected by UPS systems, for instance	• Noise interferes with sensitive electronic equipment • Data loss • Harmonic distortion causes motors, transformers, and wiring to overheat • Improper operation of circuit-breakers, relays, or fuses

Tab. 3/2: **Main problems of power quality**

IEC 61000	Electromagnetic compatibility (EMC)			
	-2	EMC- Ambient conditions		
		-2	VDE 0839-2-2	EMC – Ambient conditions – Compatibility level for low-frequency, line-conducted disturbances and signal transmission in public low-voltage grids
		-4	VDE 0839-2-4	EMC – Ambient conditions – Compatibility level for low-frequency, line-conducted disturbances in industrial plants
		-12	VDE 0839-2-12	EMC – Ambient conditions – Compatibility level for low-frequency, line-conducted disturbances and signal transmission in public medium-voltage grids
	-3	EMC- Limit values		
		-2	VDE 0838-2	EMC – Limit values – Limit values for harmonic currents (equipment input current lower or equal to 16 A per phase)
		-3	VDE 0838-3	EMC – Limit values – Limiting voltage changes, voltage variations and flicker in public low-voltage supply grids for equipment with a rated current of 16 A per phase)
		-11	VDE 0838-11	EMC – Limit values – Limiting of voltage changes, voltage variations and flicker in public low-voltage supply grids for equipment with a rated current of 75 A per phase)
		-12	VDE 0838-12	EMC – Limit values – Limit values for harmonic currents caused by equipment and facilities with an input current of 16 A and 75 A per phase which are intended for connection to the public low-voltage grid
	-4	EMC – Testing and measuring procedures		
		-7	VDE 0847-7	EMC – Testing and measuring procedures – General guide for procedures and equipment measuring harmonic content and interharmonic components in power supply grids and connected equipment
		-15	VDE 0847-15	EMC – Testing and measuring procedures – Flickermeter, functional description and design specification
		30	VDE 0847-30	EMC – Testing and measuring procedures – Procedures for measuring the voltage quality

Tab. 3/3: **Structure of the standard series IEC 61000 (VDE 0838, VDE 0839, VDE 0848)**

Whereas the D-A-CH-CZ guideline [16] defines EMC as "the capacity of an electrical appliance to function in a satisfactory manner in its electromagnetic environment without unpermissibly affecting this environment, which may also include other appliances." This kind of reciprocal impact of equipment in the distribution network and its effects on the distribution network are called system perturbations.

A classification of different operational environments, the assignment of appropriate characteristic parameters and compatibility levels are described in the standard series IEC 61000 (VDE 0838, VDE 0839, VDE 0848). Tab. 3/3 gives an overview of the contents of the individual standards.

According to IEC 61000-2-4 (VDE 0839-2-4), equipment and devices responding very sensitively to interference parameters of power supply, such as the data processing facilities in the data centre, are to be assigned to electromagnetic Environment Class 1. Protection by uninterruptible power supply systems (UPS), filters, or surge arresters is common for this class. The classification in accordance with IEC 61000-2-4 (VDE 0839-2-4) is shown in Tab. 3/4.

According to [14], voltage dips and fluctuations can therefore be ruled out for the "white space" in data centres, i.e. those areas in which servers, routers, switches and ICT data storage facilities are used. However, influences on all powered infrastructure components in the data centre as regards interference emission and susceptibility to interference must be taken into account. Besides the voltage stability, voltage unbalance and harmonics play an important part in assessing malfunctions and voltage quality.

Class 1	This class applies to protected supplies, having compatibility levels which are lower than for public grids. It refers to the operation of equipment which responds in a very sensitive manner to disturbances in the power supply, for example the electrical equipment of technical laboratories, certain automation and protection gear, certain data processing facilities etc.
Class 2	This class generally applies to points of common coupling (PCC) with the public grid and for in-plant points of coupling (IPC) with industrial and other non-public power supply networks. The compatibility levels for this class are generally identical with those applying to public grids. Therefore, components which were developed for use in public grids can also be employed in this class for industrial environments.
Class 3	This class only applies to in-plant points of coupling (IPC) in industrial environments. For some disturbances, it comprises higher compatibility levels than those in Class 2. This class should be considered, for example, if one of the following conditions is true. • A major load share is fed by the power converter. • Welding machines exist • Large motors are frequently started • Loads vary quickly

Tab. 3/4: **Electromagnetic compatibility levels in accordance with IEC 61000-2-4 (VDE 0839-2-4)**

3

3.1.1 Voltage unbalance

Uneven loading of the phase conductors in a three-phase system causes unbalances. Since the servers in the data centre are supplied from single-phase power supply units, unbalance prevails practically at all times. However, a fine subdivision of single-phase loads in operation will lead to a symmetrisation. In line with the specifications of IEC 61000-2-4 (VDE 0839-2-4) for the protected supply of data centres, unbalance for stationary network operation must not exceed the permissible level of voltage unbalance of 2 % as given for Environment Class 1. As a rule,

$$k_U \approx S_A / S_{kV} \leq k_{U,\,perm} = 2\,\%$$

(S_A = connected load as single-phase or two-phase load)

3.1.2 Harmonics

Harmonics are overladen oscillations deviating from the 50-hertz fundamental frequency of the power grid with an integer multiple of the fundamental. Every periodical oscillation curve can be represented as an overlay of the sine-shaped basic curve and harmonic oscillations. They are generated by equipment with non-linear current-voltage characteristics such as transformers, gas-discharge lamps, and power electronic devices.

Important harmonic generators are:

- Power electronic devices, such as converter drives, static UPS systems, rectifier systems, dimmers
- Fluorescent lamps
- Power supply units for the DC voltage supply of ICT components
- Motors with non-linear current-voltage characteristics

Harmonics can, for instance, produce the following effects:

- Heating of three-phase and alternating current motors
- Overheating of transformers
- Fault tripping of circuit-breakers and miniature circuit-breakers and malfunctions of ripple control receivers
- Overloading and destruction of capacitors as a result of thermal overloading
- Skin effects of cabling resulting in higher temperature loads and a greater voltage drop
- Malfunction of electronic devices and control units as a result of zero-crossing faults
- Problems with the compensation of earth faults
- Overloading of the N conductor

Uneven harmonics				Even harmonics	
No multiples of 3		Multiples of 3			
Order h	Relative voltage in %	Order h	Relative voltage in %	Order h	Relative voltage in %
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.5	6 to 24	0.5
13	3	21	0.5		
17	2				
19	1.5				
23	1.5				
25 *	1.5				
* No values are given for h > 25, since they are normally very small					

Tab. 3/5: **Electromagnetic compatibility levels in accordance with EN 50160 for line voltages up to 35 kV**

Uneven harmonics				Even harmonics	
No multiples of 3		Multiples of 3			
Order h	Relative voltage in %	Order h	Relative voltage in %	Order h	Relative voltage in %
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.4	6	0.5
13	3	21	0.3	8	0.5
17 ≤ h ≤ 49	2.27 x (17/h) – 0.27	21 ≤ h ≤ 45	0.2	10 ≤ h ≤ 50	2.25 x (10/h) – 0.25

Tab. 3/6: **Electromagnetic compatibility levels in accordance with IEC 61000-2-2 (VDE 0839-2-2) up to 1 kV**

The compatibility levels to be observed by the distribution system operator are defined in EN 50160 (see Tab. 3/5). When connecting to the public supply grid, the user must ensure that compatibility levels in accordance with the D-A-CH-CZ guideline [16] corresponding to EN 50160 and IEC 61000-2-2 (VDE 0839-2-2) are observed at the connecting points to the public distribution grid (see Tab. 3/6). Concerning the harmonic voltages of plant-internal connecting points in the non-public networks of a data centre, reference can be made to IEC 61000-2-4 (VDE 0839-2-4). The assumption for data centres is a very sensitive environment according electromagnetic compatibility. Hence the overview in Tab. 3/7 only gives values for Environment Class 1.

Uneven harmonics				Even harmonics	
No multiples of 3		Multiples of 3			
Order h	Relative voltage in %	Order h	Relative voltage in %	Order h	Relative voltage in %
5	3	3	3	2	2
7	3	9	1.5	4	1
11	3	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2			10	0.5
17 ≤ h ≤ 49	2.27 × (17/h) – 0.27	21 ≤ h ≤ 45	0.2	10 ≤ h ≤ 50	2.25 × (10/h) + 0.25

Tab. 3/7: **Electromagnetic compatibility levels in accordance with IEC 61000-2-4 (VDE 0839-2-4) up to 35 kV**

The values specified in the standards are for forming a reference level in a defined environment which only with a low probability (< 5 %) exceeds the actual interference level. They are used for a metrological inspection of the user's systems. Monitoring systems can be used for measuring which provide more extensive options for data processing and analysis than required by EN 50160. The SICAM Q80 Power Quality Recorder (Fig. 3/3) uses the principle of “complete recording“ so that even events in which the defined thresholds are not reached will still be used for power quality analyses or for recording such events at the relevant locations in the distribution systems.

Fig. 3/3: **SICAM Q80 power quality recorder**

SICAM Q80 meets the precision requirements of a Class A measuring device in accordance with IEC 61000-4-30 (VDE 0847-30) for testing voltage quality. Harmonics are of course detected in accordance with the specifications made in IEC 61000-4-7 (VDE 0847-7) (Fig. 3/4) and flickers are calculated as described in IEC 61000-4-15 (VDE 0847-15).

The identification, determination and profile formation of the measuring points for power system monitoring play an important part in project design. Since the supply network in the data centre is a dynamic system, the optimisation of the measuring points is based on the insights gained in day-to-day operation. Besides the selection of measuring points, the determination of system quality requires a definition and determination of the evaluation criteria at the individual measuring points.

In order to estimate harmonic voltage interferences properly during the planning of a data centre in line with the D-A-CH-CZ guideline [16], it is important to consider the functioning principles of the UPS systems used. According to [16] harmonic voltage generators need to be divided into two groups (also see Tab. 3/11):

Group 1: Equipment with a low emission of harmonic content (10 % ≤ THDi ≤ 25 %)

Group 2: Equipment with medium-range and high emission of harmonic content (THDi > 25 %)

If new double-converter UPS systems (see section 4.4) are operated using a transistor-controlled or power-factor-compensated rectifier, the expectation is for hardly any system perturbations and thus for hardly any harmonic interferences for the upstream network. Therefore, they needn't be factored in for estimating the harmonic interferences in the UPS input network. However the ICT consumers connected to the UPS system may interfere with each other. The same applies to dynamic diesel UPS systems which act like an active line filter owing to the combination of synchronous generator and reactor coil.

If these UPS systems are operated in double-converter mode using a 12-pulse thyristor inverter with smoothing choke they can normally be assigned to Group 1. UPS systems using 6-pulse rectifier circuits in double-converter mode usually correspond to Group 2 according to [16].

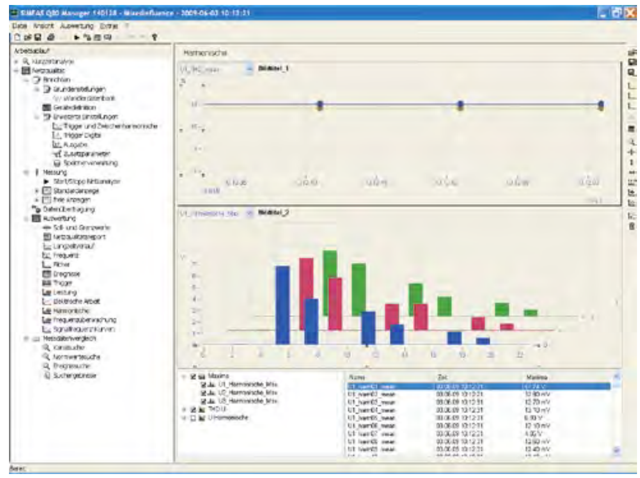


Fig. 3/4: **Overview of harmonics, SICAM Q80 Power Quality Recorder**

The intended operating mode of the UPS systems must be observed for fault assessment purposes. If it is not the double-converter line which is used for load supply, but, for instance, the so-called eco mode for reasons of efficiency, then the connected equipment will feed faults into the supply network via the electronic bypass line. To assess harmonic interferences, an assignment of the connected loads to these interference groups is necessary here.

For example, pumps, ventilators, compressors, air conditioning appliances, DC-controlled fans and compact fluorescent lamps with electronic ballast belong to Group 2 (whereas compact fluorescent lamps with inductive ballast are assigned to Group 1). Finally, the load simultaneity to be expected per group must be factored in to estimate the harmonic load of the plant S_{OS} from the two group-specific shares ($S_{Gr.1}$, $S_{Gr.2}$) according to

$$S_{OS} = 0.5 \times S_{Gr.1} + S_{Gr.2}$$

The quotient S_{OS}/S_A (S_A = connected load of the plant) can be used graphically from the relation to the quotient from short-circuit power at the linking point S_{kV} and plant connected load (see Fig. 3/5) to assess the harmonic load content:

$$\frac{S_{OS}}{S_A} = b \times \sqrt{\frac{S_{kV}}{S_A}}$$

(b = 0.082 for low voltage, or b = 0.058 for medium voltage)

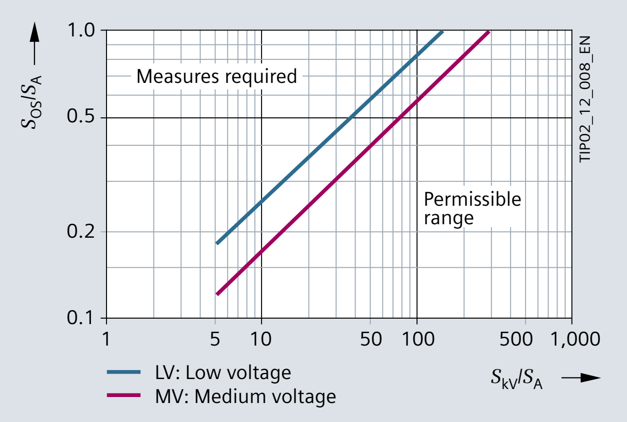


Fig. 3/5: **Graphical assessment of the harmonic content**

If the limit lines of Fig. 3/5 for S_{OS}/S_A are exceeded, passive or active filters can be used as an effective means to limit harmonic content. While the use of passive filters only cause harmonics of the matched frequencies to be affected, an active filter performs an analysis of the interference and emits a "negative" (i.e. phase-shifted by 180°) harmonic range to eliminate interferences as far as possible.

When an active filter is connected in parallel, the upstream line current is optimized, whereas the series connection is largely utilized for a targeted improvement of the voltage quality of individual loads. However, even active filters cannot simultaneously make current and voltage curves nearly sinusoidal

An important use of active filters is the reduction of summated N conductor currents produced, for instance, by the phase angle control of many power supply units of energy-saving lamps. In particular, the interferences of the third harmonic with a frequency of 150 Hz are summated in the N conductor. Do note that high N conductor currents may possibly require the larger dimensioning of switchgear and transformers in addition to cables, as described in DIN VDE 0298-4. You may then consider the use of power converters for transformers. Or, the cost of oversizing transformers is balanced by reduced energy losses during operation (see section 5.4).

3.2 Electromagnetic Compatibility

The so-called EMC Directive of the European Union [17] defines electromagnetic compatibility (EMC) as "the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment".

An electric current which flows is linked to a magnetic and an electric field. These fields affect the environment and other equipment. Two factors play a major part in spreading the fields and thus for EMC:
- Cable routing and screening
- Power supply system/ connection to earth

3.2.1 Cable routing and screening

The spreading of interference currents and the electric and magnetic fields linked to them depend both on the cable type and their arrangement. Generally speaking and in accordance with EN 50174-2 (VDE 0800-174-2), signal and data cables should be routed well away from power supply leads. The requirements placed on this separation depend on the following:
- the EMC characteristics of the IT cables
- the design, dimensions and geometrical arrangement of the power supply cables
- the type of circuits supplied
- possibly existing isolation devices.

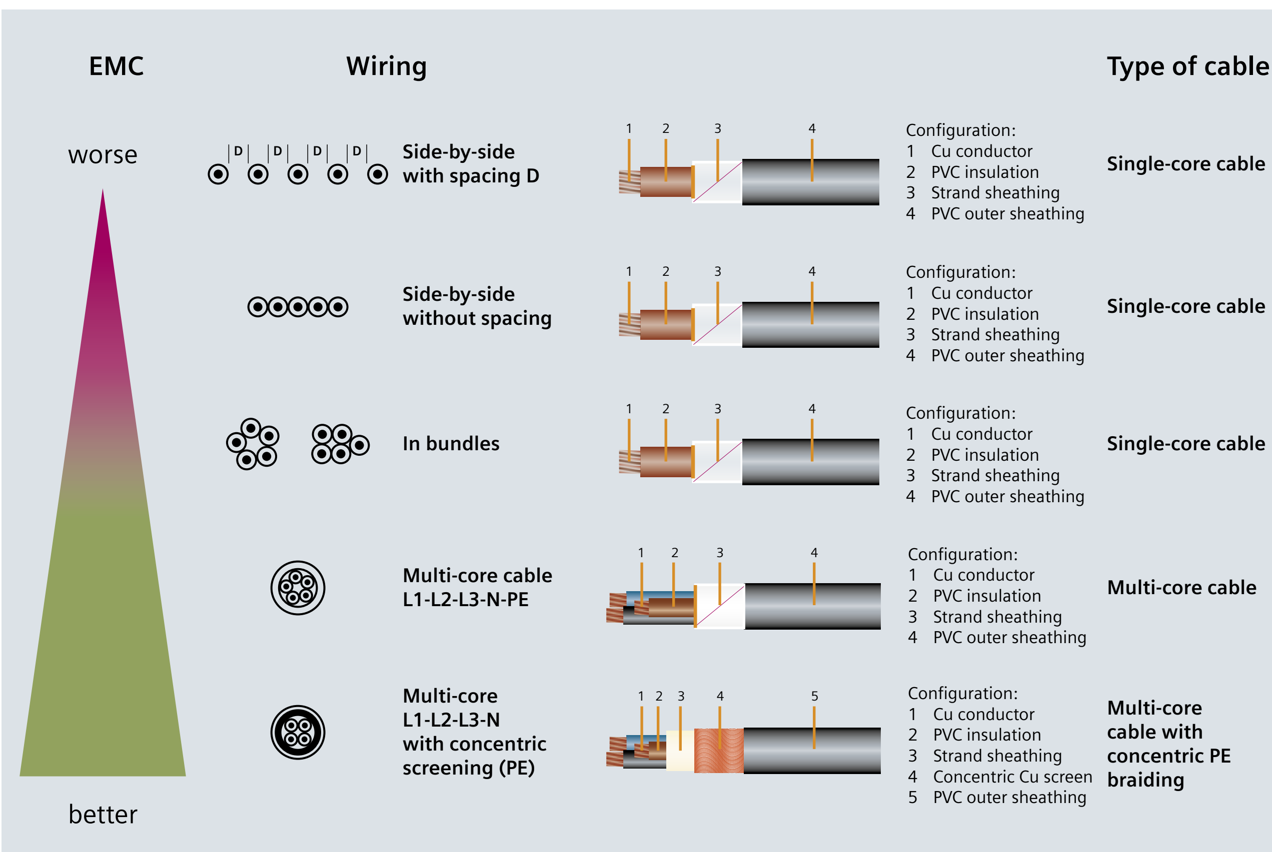


Fig. 3/6: **Classification of simple cable types and wiring with regard to EMC**

The procedure how to define isolation/separation requirements is described in EN 50174-2 (VDE 0800-174-2). In particular for data centres, it is recommended doubling the value established for the (isolating) distance between IT cabling and power supply leads.

Bundling into cable groups and twisting phase and return conductor is beneficial for electric power supply. The different bundlings of conductors and the use of cable screens are arranged in an EMC-quality-significant manner in Fig. 3/6.

Commonly, busbar trunking systems are better than cables in terms of EMC in case of equal currents. The influence of conductor arrangement both in cables and in busbar trunking systems must be added to the above. A symmetrical splitting of conductors in the busbar trunking system – assuming equal currents – has a significant advantage with regard to EMC. The Siemens LD busbar trunking system (LDA/LDC) with its symmetrical conductor splitting is thus particularly suitable for the transmission of high currents with a favourable EMC characteristic. Fig. 3/7 also reveals that an asymmetrical loading of conductors leads to a deterioration of EMC conditions.

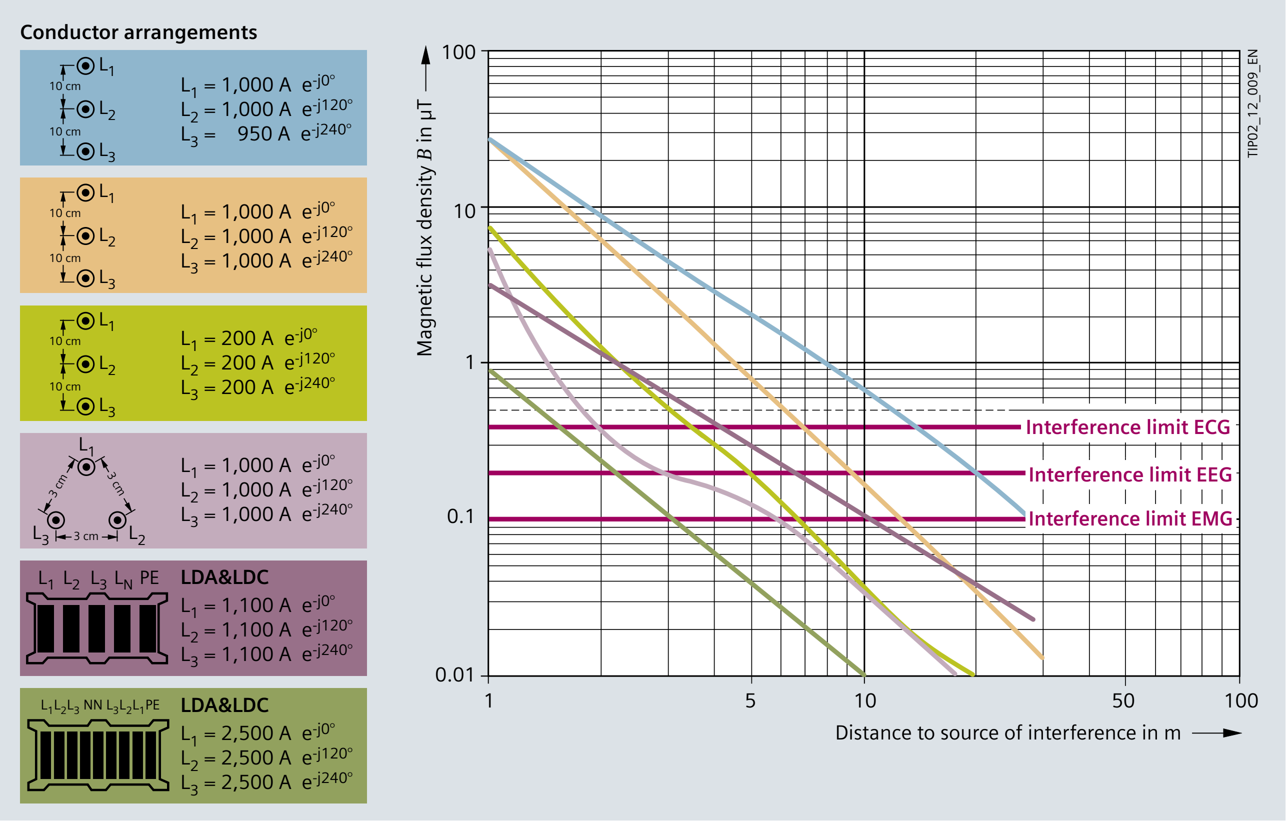


Fig. 3/7: **Cable configuration and suitability with regard to EMC (the interference levels for electromyograms (EMG), electrocardiograms (ECG) and electroencephalograms (EEG) are specified in IEC 60364-7-710 (VDE 0100-710))**

3

3.2.2 Earthing and equal potential bonding

Stray currents may prove a severe problem in data centres, in particular. Currents flowing through the protective conductor and the screening of data and IT cables cause failures, malfunctions and even damage. In the low-voltage network, it is the connection to earth conditions in the power system which are decisive for this cable-bound EMC. The strict separation of the protective conductor from the neutral conductor in the TN-S network helps to avoid these kinds of stray currents.

For each functional unit, a central earthing point (CEP) should be additionally formed in the TN-S network. 4-pole switching devices must be used for a changeover connection in case of a supply from two networks each with their own CEPs (in the Fig. 3/8 example the transformer and generator feed into separate distribution boards in a distributed layout). In addition, the PEN must be wire- insulated over its entire course - this also applies to its route in the switchgear assemblies.

The earthing concept must also be thoroughly examined for UPS feed-in purposes. Particularly with static UPS systems which feature different feed-ins for the rectifier input and connection of the static bypass switch (see chap. 4.4.2) it must be kept in mind that neutral conductors are connected in parallel. Only that neutral conductor whose associated phase conductors carry currents may be connected. For more information, please contact your TIP expert.

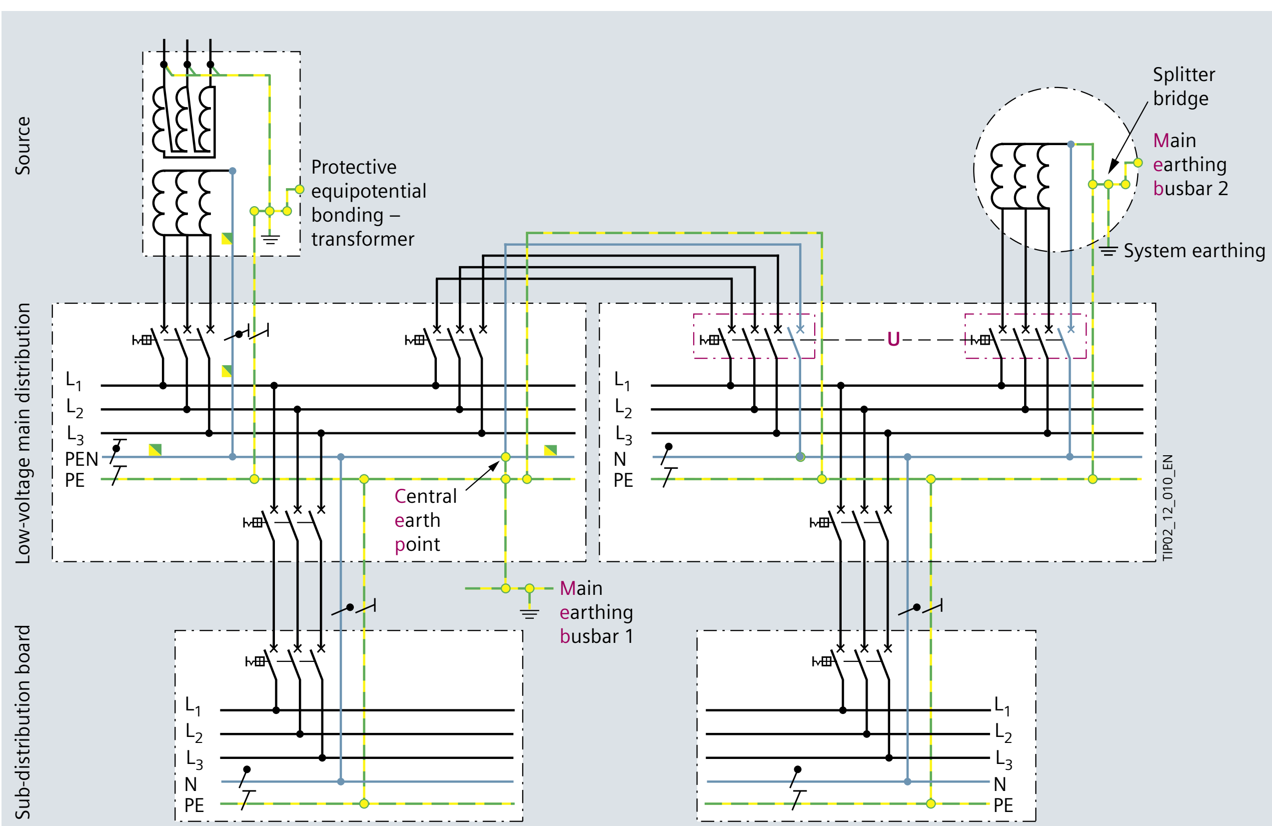


Fig. 3/8: **Earthing concept for coupling distributed feed-in systems**

3.3 Availability, Redundancy and Tier Classification

Although there are no binding standards with regard to reliability of supply at the moment, the permissible duration of interruption and corresponding redundancy requirements should be considered in the planning phase. Adapted to DIN 40041 (comparable to the international standard IEC 60050-191), redundancy in data centres is defined as the existence of more functional power supply components in one unit than required for maintaining this function (here: electric power supply of the ICT hardware and critical infrastructure components). The DIN standard explicitly notes that maintenance, i.e. monitoring, servicing and restoring (in case of failure) proper functioning, is required for maintaining the redundancy.

3.3.1 Classes of availability

Based on the classification performed by the Harvard Research Group (HRG) in 2002, several grades of availability have been established (Tab. 3/8). In its High-availability Compendium, The German Federal Agency for Safety in Information Technology (Bundesamt für Sicherheit in der Informationstechnik (BSI)) presents a classification quoting downtimes corresponding to the respective status of non-availability (Tab. 3/9).

As a mathematical term, availability is defined as the quotient from the "mean time between failure" (MTBF) and the sum of all MTBF and "mean time to repair" (MTTR):

Availability A = MTBF/(MTBF + MTTR)

HRG class	Designation	Explanation
AEC-0	Conventional	Function can be interrupted, data integrity is not essential.
AEC-1	Highly Reliable	Function can be interrupted, but data integrity must be ensured.
AEC-2	High Availability	Function may only be interrupted within defined times or minimally during the main operating time.
AEC-3	Fault-resilient	Function must be maintained without interruption within defined times or during the main operating time.
AEC-4	Fault-tolerant	Function must be maintained without interruption, 24/7 operation (24 hours, 7 days a week) must be ensured.
AEC-5	Disaster-tolerant	Function must be available under all circumstances.

Tab. 3/8: **Availability Environment Classification (AEC) acc. to [19]**

However, availability only becomes significant if the magnitudes of MTBF and MTTR are known. Tab. 3/10 shows three comparable figures for the availability in different fault scenarios.

The percentages of availability differ only in the sixth digit after the decimal point – this is marginal, but the significance of a long uninterrupted phase of operation is obvious. Nobody wants to be disturbed by frequent minor interruptions in the data centre. Some guidelines can be derived from this:

- Preference should be given to high quality of the products applied.
- The number of components should not be unduly enlarged, since every component must be regarded as a potential source of trouble.
- Repeated interference and switching operations, in particular in connection with modularisation and load-dependent operation, should be avoided.
- A dependency on single components should be avoided, since their failure, or switching off such a "single point of failure" (spof)[1] would affect the whole system.

On top of this, a power supply failure in the data centre means that a DaC restart cannot be expected within seconds but more likely after many hours or even days. If a defect concerns special components such as the transformers, UPS, or switchgear panels, their replacement may take several days or weeks.

3

3.3.2 Redundancy

The availability of a system is influenced by the quality of its components (the availability of the individual components) on the one hand and redundancy configuration on the other. Generally speaking, redundancy characterizes the use of multiple technical resources which are technically identical or at least functionally identical. Another basic principle to be adhered to in planning should be endeavouring to come up with a preferably straightforward plant configuration.

It should be mentioned here that though the (n-1) concept in network design and the (n+1) concept known from redundancy considerations follow the same basic idea, they proceed from a different number of "n" resources or components of the same design or function.

1 The term "single point of failure" (spof) refers to system components or system paths whose failure would make the whole system inoperable. This is always true if one component adopts a central function in the whole system, is not redundant and in cases of failure impairs the other components in their functioning. Moreover, a spof-component is imperative for the safe and reliable functioning of the whole system. According to http://www.itwissen.info/definition/lexikon/single-point-of-failure-SPoF.html

Availability Class (AVC)	Designation	Minimum availability	Non-availability	Downtime per month	Downtime per year
AVC 0	Standard IT system without requirements on availability	~95 %	~5 %	1 day	Several days
AVC 1	Standard safety based on basic IT protection with normal demand for availability	99 %	1 %	< 8 h	< 88 h
AVC 2	Standard safety based on basic IT protection with increased demand for availability	99.9 %	0.1 %	< 44 min	< 9 h
AVC 3	High-availability basic IT protection for specific IT resources; 100-3*	99.99 %	0.01 %	< 5 min	< 53 min
AVC 4	Highest availability	99.999 %	0.001 %	< 26 s	< 6 min
AVC 5	Disaster-tolerant	Max. availability	0	0	0

* Supplementary risk analysis acc. to BSI Standard 100-3)

Tab. 3/9: **Typical availability classes acc. to the High-availability Compendium of the BSI [18]**

MTBF	MTTR	A	Operational compatibility
1 day	1 second	86,400 s / 86,401 s = 99.999 %	Not acceptable
1 month	30 seconds	2,592,000 s / 2,592,030 s = 99.999 %	Still acceptable
10 years	1 hour	87,600 h / 87,601 h = 99.999 %	User-friendly

Tab. 3/10: **Availability A for different interruption characteristics**

- (n-1) concept: "n" components are available, with "n-1" components being sufficient to ensure full functioning ("n" items available, "n-1" items are sufficient)
- (n+1) concept: One component may fail or be removed to the extent that "n" components are sufficient for full functioning ("n+1" items available, "n" items are sufficient)

In order to avoid complete failure from system-related faults, so-called "diversified" systems (different technology or design for the same function) are used in a redundant manner. Electric power distribution in data centres may involve consideration being given to a very diversified range of redundancy configurations in planning. Caution! The names for these configurations may easily lead to mix-ups.

Standby redundancy

A component is operated in idle mode side by side with the active component. It only becomes active should the primary component fail. Therefore this type of redundancy is often called "cold" redundancy or "hot" redundancy depending on the duration of readiness. Basically, a spare tyre is a "cold" redundancy, since refitting takes quite a time. Fig. 3/9 exemplifies the output of the standby UPS being connected to the input of the static bypass line of the primary UPS. Only when we switch over to the bypass line, does the standby UPS become active. In some texts, standby redundancy is also called "isolated redundancy".

Parallel redundancy

For a certain function of power distribution, one component more than is necessary for functional endurance is employed. To this end, components must be operated in parallel. Since the spare component is ready immediately, we also refer to this as "hot" redundancy.

In the UPS example of Fig. 3/10, two of the three systems connected in parallel are sufficient to safely supply the connected load. In case of maximum utilisation of redundancy, each of the connected UPS systems supplies two-third of the power required.

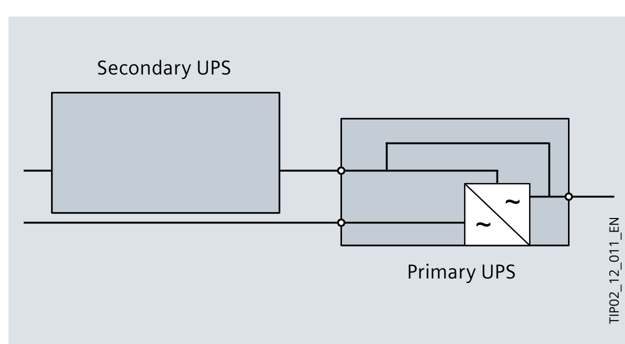


Fig. 3/9: **Schematic illustration of the standby redundancy for a single UPS system**

As described above, we speak of an (n+1) redundancy if "n" items of equipment are sufficient in parallel operation to ensure undisturbed operation so that an item of equipment may fail or be switched off. Thus, no further redundancy exists.

Similarly, (n+2) redundancy could be achieved in case of reduced load requirements if it would be possible for one or two items of equipment to fail or be switched off. This means that in case of an original (n+2) redundancy, redundancy is reduced to (n+1) if one item of equipment fails. In the example of Fig. 3/10 this means that in case of a load of 50 kVA or less, a redundancy of (n+2) – thus here (1+2) – would be on hand. Please note that output synchronisation must be ensured in order to avoid equalizing currents.

The common output busbar is a spof, which is avoided by a second busbar system as described below. Likewise, a battery should not be shared between the individual UPS systems for reasons of availability. This would turn the DC link circuit into a spof. Or generally speaking, components or facilities should preferably not be shared in parallel systems.

System redundancy

The configuration of two parallel supply systems allows system redundancy to be obtained. At the same time, parallelism should be maintained as far as possible down to the load be supplied. Ideally, electric power supply of ICT components is ensured by at least two redundantly usable, separate power supply units.

The worst case in which a consumer can only be supplied from one power supply unit only seldom occurs in data centres today. Only a very few routers, switches or memory drives are without any second power supply unit. For these types of consumers, electric power distribution can be routed on two different paths to the static transfer switch, as shown in Fig. 3/12, Diagram A. This switch and the individual line to the power supply unit then constitute more spofs in the distribution.

A) For consumers having just one power supply unit;
B) For consumers with two redundant power supply units

In case A) the static transfer switch is an additional component whose availability must be considered. Both the connection of the power supply unit and singularity of this power supply unit represent significant limitations of the system redundancy.

In Fig. 3/11, diagram B, both redundant power supply units of the ICT components are supplied via separate paths. Hence no static transfer switch is required. This extends redundancy up to the ICT components.

Sometimes, static transfer switches are taken into consideration in case of three mutually redundant power supply units. The reason lies in being able to switch over between two existing "power sources" (here UPS systems) in case of a fault. The intention here is that even in case of one power supply failure, a redundancy is still maintained behind the one and only power source now available. A second fault – after the failure of one UPS system – would not lead to an interruption of supply. In this case a switch-over – using a central static transfer switch – is to be sought as close to the power sources as possible Fig. 3/12.

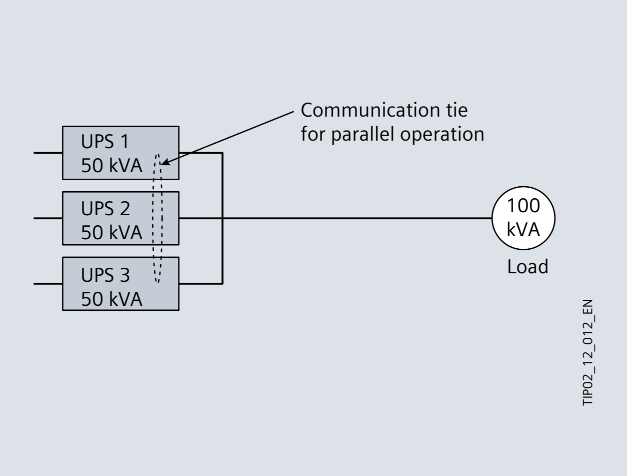


Fig. 3/10: **Parallel-redundant UPS system with (n+1) equal to (2+1)**

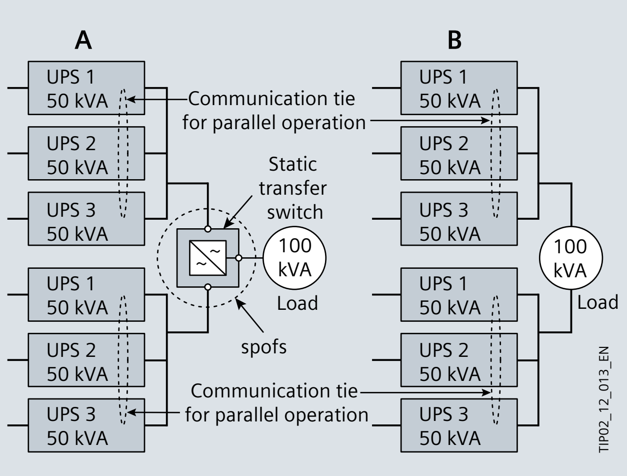


Fig. 3/11: **System-redundant UPS system with (n+1)+(n+1) for two different load configurations A and B**

But as is quite clear, this makes the system setup more complicated and causes the number of components to increase. Moreover, notice must be taken in operations of the switch positions and present current routes, before switching operations, servicing or repair can be performed. Therefore, the use of static transfer switches, which certainly cannot replace any stand-alone supply, must be viewed critically in planning.

All of the above described cases include the fact that each one of the UPS systems has its own parallel-redundant system (n+1) setup. This results in a total redundancy of (n+1)+(n+1). To sum up, it becomes clear that each step to improve redundancy must involve planning scrutinizing the relation between outlay and secured function. Effective documentation and description of operating procedures and switching sequences helps to avoid many difficulties from the outset.

Isolated-parallel redundancy

To cut back somewhat on the equipment outlay which would be necessary to attain a higher degree of system redundancy, parallel-operating components are used redundantly (n+1) and the consumers are divided into several groups supplied in different ways. Put simply, the simultaneous modularity of systems and loads is utilized and the system redundancy of (n+1)+(n+1) is the special case for (1+1)^(n+1) – that is: One plus one subsystems – for an isolated-parallel redundancy, where each subsystem is characterized by a redundancy of (n+1).

3

Using four subsystems, this will produce a (1+1+1+1)^(n+1) isolated-parallel redundancy, where each of the four supply systems is then connected to each load group via a path of its own. But usually such a complex design is not put into practice. It is more common to connect the individual load groups using two paths – hence two different groups of supply components.

This is better illustrated in an example. In Fig. 3/13, three subsystems are complemented by a fourth redundant supply system. Since power supply is performed using two power supply units, there is no need for a static transfer switch. The advantage is that there is no mutual relation between two identical UPS systems. These (m+1) existing (n+1) systems are always divided into two load subsystems. For the example shown in Fig. 3/13 this is m = 3 and n = 2. Each load system is supplied from two different paths (for the electric power supply these are the paths for cables and/or busbar trunking systems including the matching components for measuring, protection and switching). This means that both the components and consumers are divided into groups and the paths are modularized, too. This helps to avoid oversizing and curb and parry the consequences of failures.

For example, in case of a complete failure of the parallel UPS system, i.e. UPS 1 through 3 in Fig. 3/13, another single UPS system could also break down (UPS 4 or 5 or ... 12) without the supply being impaired. In case of more faults, the summated nominal power of the UPS systems would no longer be capable of supplying 100 % of the load.

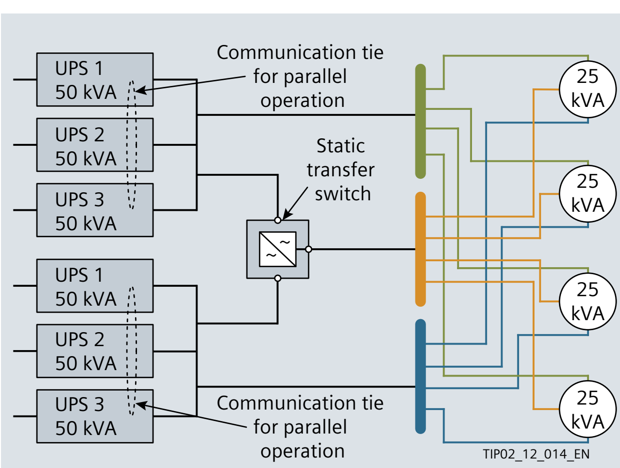


Fig. 3/12: **Use of static transfer switches for ICT components using three power supply units**

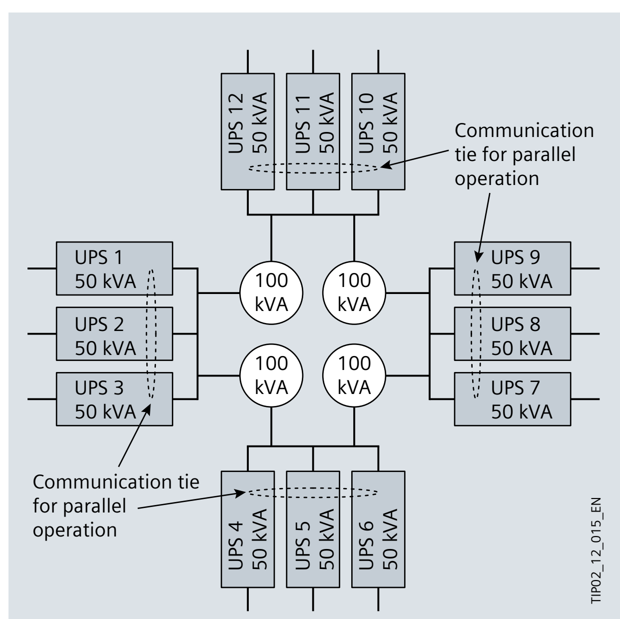


Fig. 3/13: **Isolated-parallel UPS system with a link through two independent power supply units acc. to (m+1)^(n+1) – here: (3+1)^(2+1)**

But restricted operation or limited overload operation might still be possible.

Linking the individual UPS systems with a static transfer switch would mean a redundancy in keeping with (m+1)^(n+1) up to the switches, but would also entail a correspondingly substantial outlay.

3.3.3 Tier classification

Based on a "white paper" by the Uptime Institute [20] a classification of data centres according to availability levels has generally prevailed. The availability is defined through the relationship between the total duration of operational interruptions relative to the total operating time of the data centre. It should be noted that the calculated availability data of equipment manufacturers for individual products based on MTBF and MTTR values – but only for this one product – is pure window dressing, considering the fact that the restoration of controlled IT operation in the data centre – assumed as a realistic mean value by the Uptime Institute – is about four hours and in the assumption of the repair time the probability of human error in trouble-shooting is completely neglected.

Likewise the Uptime Institute emphasizes again and again that intermediate tiers, such as "Tier 2.5" simply cannot arise or that an averaging between diverging layouts of parts of the infrastructure are not permissible. Grading electric power supply as Tier IV and classifying cooling as Tier II in no way yields a "mean" classification acc. to Tier III. Here the weakest point of protection determines the tier classification of the whole data centre. Likewise the Uptime Institute makes clear that the use of static transfer switches can in no way remedy the weaknesses of IT power supply using one power supply unit given the fault tolerance and alternately usable maintenance paths. Put simply, a data centre may in the best case attain Tier II when using critical ICT components in non-redundant design which are only supplied by one power supply unit. Therefore with co-location operation, only a classification can and should be undertaken that limits responsibility to that part or installation in the data centre for which the co-location operator signs responsible. This again points to the fact that a customer-oriented concept including modular systems is to be preferred in data centre planning. Holistic solution approaches should be established in this context which integrate intended user applications.

In their statements on availability for tier classifications, the assumption of the Uptime Institute given a case of failure is that of the above-mentioned four hours until data centre operation is resumed. The "white paper" did not focus on a calculation of availability but on a correlation between tier classification, availability and the data centre concept:

Tier I – Basic Data Centre Site Infrastructure:

Data centres need two shut-downs of about twelve hours each for repair and maintenance work and the long-term mean shows 1.2 outages per year. Since the data centre stands still for four hours in case of downtime, these stand-still times amount to 28.8 hours per year - corresponding to an availability of 99.67 %.

Tier II – Redundant Site Infrastructure:

Operational experience with data centres yields a second level where two to three maintenance and repair cases occur within two years and with only one downtime a year owing to the redundancy of individual components. This results in a mean standstill time of 22 hours per year, which corresponds to an availability of 99.75 %.

Tier III – Concurrently Maintainable Site Infrastructure:

Operators appreciate a concurrently maintainable supply path in data centres to rule out shut-downs for maintenance or repair. In addition this means a downtime just once in 2.5 years. This produces an overall standstill time of 1.6 hours per year. This corresponds to an availability of 99.98 %.

Tier IV – Fault Tolerant Site Infrastructure:

Robustness and a fault-tolerant design halve the failure rate again compared to Tier III, so that the standstill time for Tier IV is a mere 0.8 hours a year. This increases availability to 99.99 %.

A characterisation of redundancies to attain a certain level of availability is given by the well known "Tier structure" [17] of the Uptime Institute. This structure has practically established itself as the standard for data centres. The Tier classes of Tab. 3/11 can also be graphically illustrated with regard to air conditioning and power distribution in the data centre (see [21]).

It would be advantageous not to be dependent on a single supply network connection. Unfortunately, it is only rarely possible to create two independent supply network connections for a data centre so that improvements in the data transmission network make the concept of a mirrored data centre a more feasible solution. Similar to a backup system with mirrored disks, two data centres work here in parallel.

The idea in future is for applications to be controlled by "cloud computing"[2] independently of the hardware location. This concept is also interesting with regard to locally different degrees of utilisation conditional upon normal local hours of work. In addition, the data centre environment can be integrated into energy considerations. Lower outside temperatures during night times or as a result of the season can simplify cooling and thus reduce the energy demand. And the merging of Cloud Computing and Smart Grid might result in further advantages in energy use. The increasing interrelation between data processing, data traffic and electric power distribution will require paying special attention to the communication capability and controllability of the components in electric power distribution.

2 This term describes the approach to make abstracted IT infrastructure systems (such as computing capacity, data storage, network capacities, or ready-to-use software) available in a dynamically demand-oriented manner using a network.

	Tier I	Tier II	Tier III	Tier IV
Active components to supply the IT load	n	n+1	n+1	n After any fault
Supply paths	1	1	1 active and 1 alternative path	2 simultaneously active paths
Alternating servicing is possible	No	No	Yes	Yes
Fault tolerance (single fault event)	No	No	No	Yes
Physical separation	No	No	No	Yes
Continuous cooling	Load density dependent	Load density dependent	Load density dependent	Class A*

* Uninterruptible cooling: Fans of the cooling equipment and water pumps for the chillers are supplied from the UPS systems; there is a temperated cooling water reservoir; temperature and relative humidity stay "normal" even in case of events that would cause a cooling stop

Tab. 3/11: **Overview of the requirements corresponding to the four Tier classes [20]**

3

3.4 Estimate of Power Demand

To determine the technical supply conditions, it is necessary to estimate the future power demand as precisely as possible in the preliminary planning stage. The more precisely this power demand can be estimated, the better the power supply system can be sized as well. This applies as much to the components in normal power supply (NPS) as to the safety power supply (SPS) components. Specifications for the technical equipment rooms are also derived from the sizing data for electric power distribution. Considering the importance of high availability for the data centre, as demonstrated above, the sizing of the uninterruptible power supply (UPS) and its connection to NPS and SPS is of special significance (see Tab. 3/12).

In NPS, feed-in is from
- direct connection to the public grid: normally up to 300 kW at 400 V
- a transfer from the medium-voltage grid (max. 52 kV) using distribution transformers – usually with a power demand of more than 300 kW.

For SPS and UPS, power sources are selected in dependency of regulations and the permissible interruption time:
- Generators for general emergency standby power systems (ESPS) and/or SPS
- Uninterruptible power systems
  - static UPS comprising a rectifier/inverter unit with battery or flywheel energy storage for buffering
  - motor/generator set and flywheel energy storage or rectifier/inverter unit and battery for buffering.

A constellation as described in Fig. 3/14 has proven itself in the infrastructure.

Since the circuits for SPS consumers must be laid separately, their placing inside the building is relevant for budget considerations. In Germany, certain statutory regulations and specifications are additionally applicable, which demand the functional endurance of cables and wires in case of fire.

In general, circuits for safety purposes routed through fire-threatened areas must be designed fire-resistant. Never must they be routed through explosion-prone areas.

Usually, safety-purpose facilities receive an automatic power supply whose activation does not depend on operator personnel. According to IEC 60364-1 (VDE 0100-100), automatic supply is classified by its maximum change-over time:

Type	Example
Normal power supply	Supply of all installations and power consumers available in the building
Safety power supply	Supply of life-protecting facilities in case of danger, e. g.:
	• Safety lighting
	• Fire fighting lifts
	• Fire extinguishing systems
Uninterruptible power supply	Supply of sensitive power consumers which must be operated without interruption in the event of an NPS failure/fault, e.g.:
	• Control systems
	• Servers/computers
	• Communication systems

Tab. 3/12: **Type of feed-in**

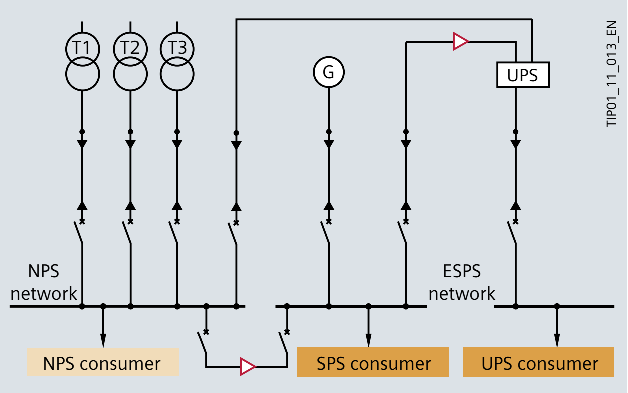


Fig. 3/14: **Supply structure based on the type of feed-in**

- Without interruption: automatic supply which can ensure continuous supply during transfer under defined conditions, e.g. with regard to voltage and frequency fluctuations
- Very short interruption: automatic supply which is available within 0.15 s
- Short interruption: automatic supply which is available within 0.5 s
- Mean interruption: automatic supply which is available within 15 s
- Long interruption: automatic supply which is available after more than 15 s.

3

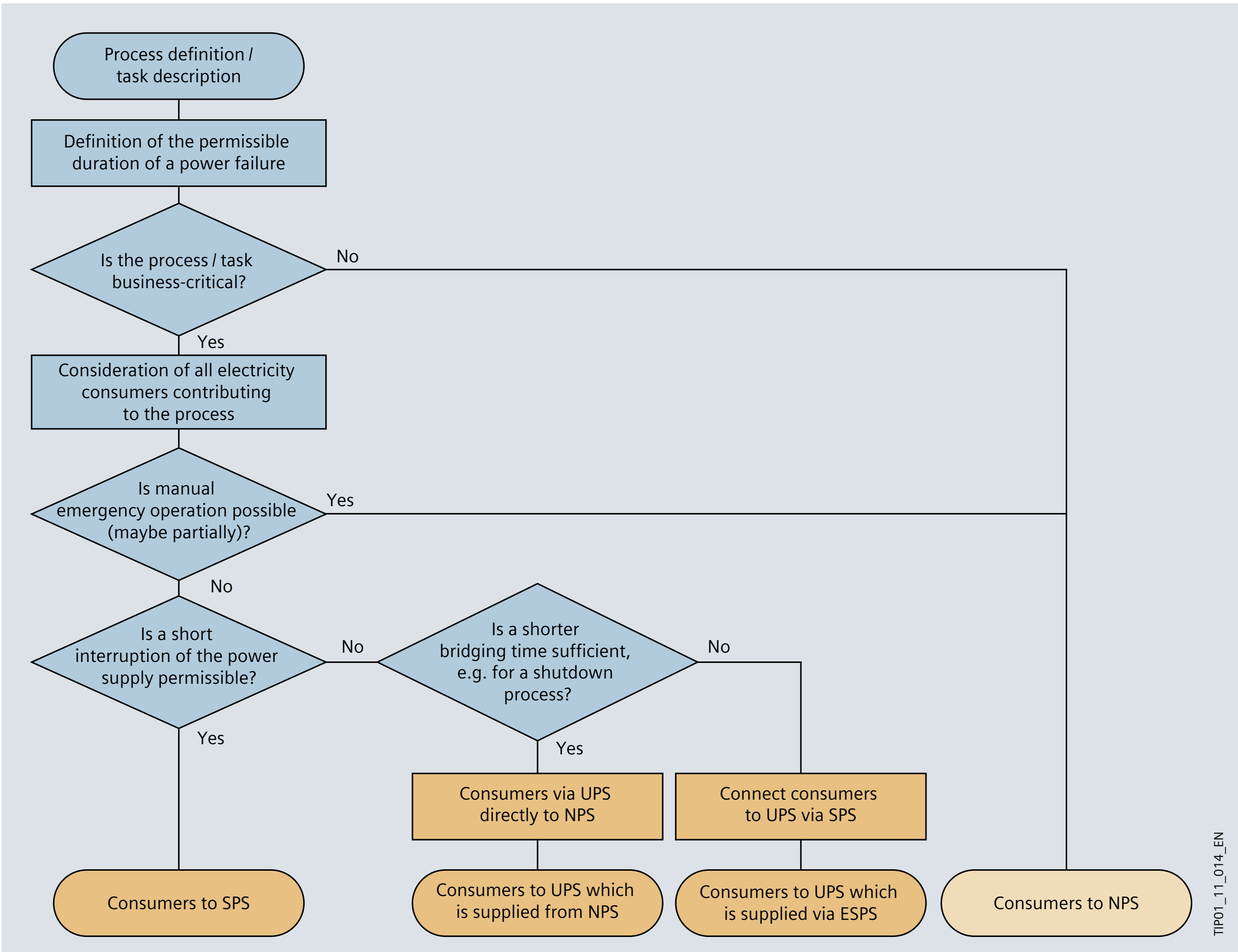


Fig. 3/15: **Flow chart for estimating NPS, SPS and UPS**

In IEC 60364-5-56 (VDE 0100-560) the following examples of safety installations are given:
- Emergency lighting (safety lighting)
- Fire extinguishing pumps
- Fire fighting lifts
- Alarm systems such as fire alarm systems, carbon monoxide (CO) alarm systems and intruder detection systems
- Evacuation systems
- Smoke evacuation systems
- Important medical systems

The procedure shown in Fig. 3/15 can be carried out by customers and/or planners for a use-specific classification of different power consumers and the associated corporate-sensitive tasks.

Criteria for the determination of business-critical processes might be the following:
- Effects on life and health
- Protection of important legal interests
- Infringements of laws and regulations
- Loss of reputation of the institution

Chapter 4

The Main Components of Power Supply

4 The Main Components of Power Supply

Operating the data centre infrastructure requires the planning of electric power supply based on qualitative specifications and safety requirements. It is a particular challenge to coordinate electric power supply for the individual technical installations. Basically, this means air conditioning and cooling systems, lighting, fire protection and control systems need to be power-supplied reliably (Fig. 4/1). In modern planning, these requirements cannot simply be broken down to the individual installations separately, but mutual influences must be recognized and taken into consideration.

Regarding the planning concept for power supply, it is not only imperative to observe standards and regulations, it is also important to discuss and clarify economic and technical interrelations. To this end, electrical equipment such as UPS, distribution boards and transformers is selected and rated in such a way that an optimum result for the power system as whole is achieved rather than focusing individual components. All components must be sufficiently rated to withstand normal operating conditions as well as fault conditions.

It is common practice during the initial planning phases to assess the energy efficiency of some components with higher operational losses only, such as the UPS and the power supply for the cooling system. Redundancy and networking concepts are not included in such an assessment. But in integrated planning, expense and safety should be balanced. On the one hand, the power consumers must be assigned to suitable supply paths (see Fig. 4/2). The "swing" generator in Fig. 4/2 represents a method of redundancy with a supply path of its own. This avoids oversizing the number of components, i.e. building up a chain of components in any length and width for mutual failure safeguarding. After all, the generators serve

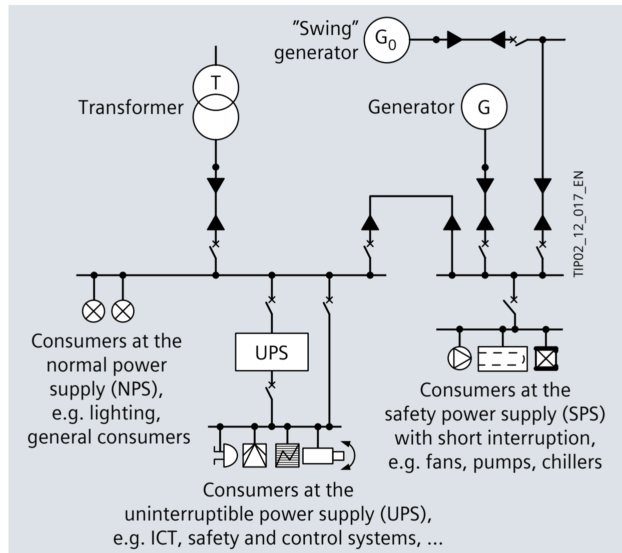


Fig. 4/2: **Types of power supply for the data centre infrastructure (normal power supply – NPS, safety power supply – SPS, uninterruptible power supply – UPS)**

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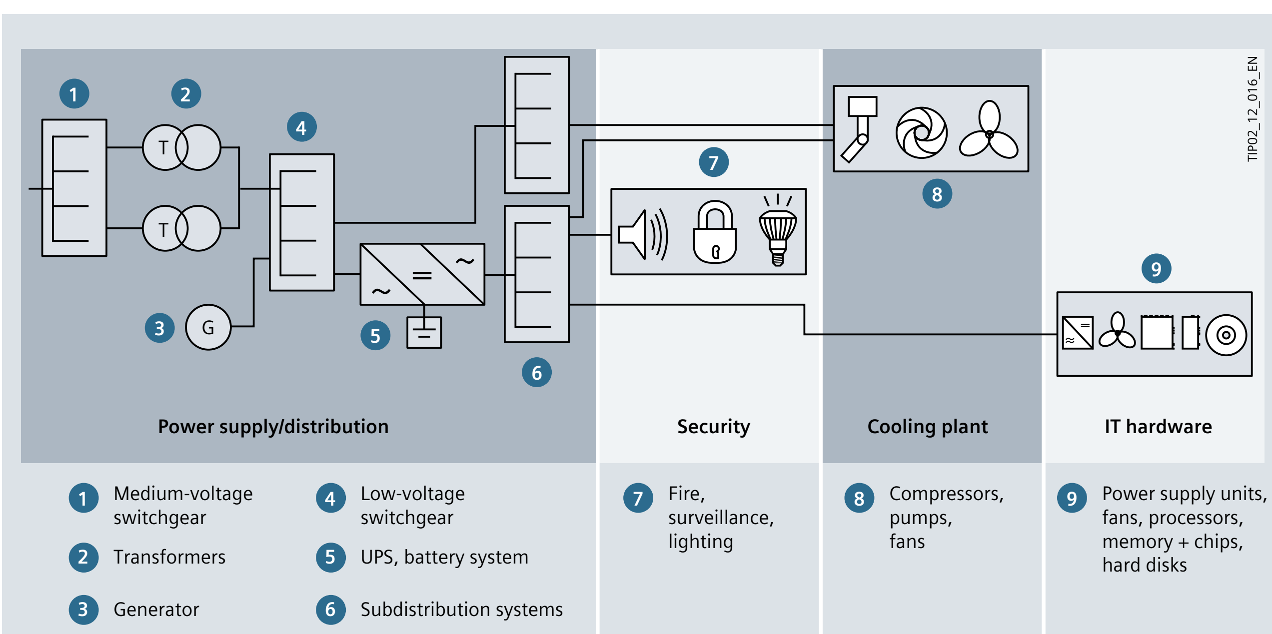

Fig. 4/1: **Power distribution components in the data centre**

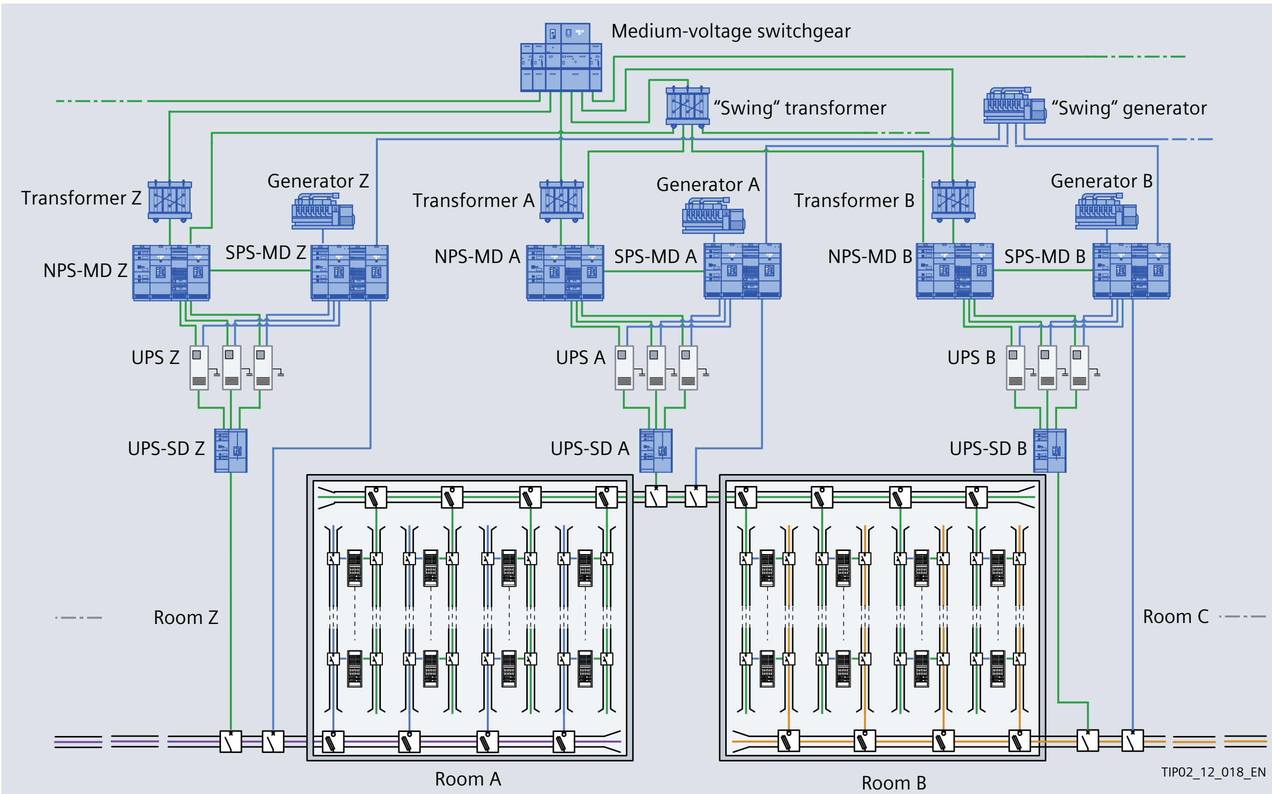

Fig. 4/3: **Example of a power supply for critical consumers in more than one "white space" (a link of the white spaces – Room 1, Room 2 – pointing to redundant power distribution is schematically indicated and corresponds to a Tier IV Green structure. MD = main distribution, SD = sub-distribution)**

as redundancy in case of a failure of normal power supply. On the other hand, a clever method of power distribution by way of jointly utilizing systems – as exemplified in Fig. 4/3 for isolated-parallel redundancy of several "white spaces" in the data centre – can reduce the purchase and operating costs without any impairments in availability and servicing options. Distribution helps improve utilisation and efficiency. This single-line diagram of power distribution and usage in the data centre demonstrates the interdependencies between redundancy and distribution (also see chapter 5). Owing to improved efficiency, this can be defined as "Tier IV Green" in the sense of the Tier structures.

4

4.1 Medium-voltage Switchgear

Depending on the DSO and the required transformer power, there are certain standards for medium-voltage switchgear which must be observed when planning and/or sizing utility substations. These standards are described in the Technical Supply Conditions of the respective distribution system operator. The IEC 62271 (VDE 0671) standard series applies to the implementation with medium-voltage switchgear (MV switchgear) systems.

These influencing factors and stresses as listed in Tab. 4/1 determine the selection parameters and rated quantities of the switchgear. They are briefly described below.

Line voltage

The line voltage determines the rated voltage of the switchgear, switches and other installed components. The maximum line voltage at the upper tolerance limit is the deciding factor.

Assigned configuration criteria for switchgear
- Rated voltage U_r
- Rated insulation voltage U_d; U_p
- Primary rated voltage of voltage transformers U_{pr}

Short-circuit current

The short-circuit current is characterized by the electrical quantities of surge current I_p (peak value of the initial symmetrical short-circuit current) and sustained short-circuit current I_k. The required short-circuit current level in the system is specified by the dynamic response of the loads and the power quality to be maintained, and determines the make and break capacity and the withstand capability of the switchgear and switching devices (Tab. 4/2).

Power system parameters	• Rated voltage • Short-circuit current • Operating current • Load flow	• Neutral earthing • Cable/overhead line • Overvoltage protection • Power quality
System protection & measurement	• Protective functions • Selectivity • Measurement	• Redundancy • Tripping times • Metering
Feeder lines	• Public grids • Distributed generation	• Emergency power • Redundancy
Operating area	• Installation site • Utilities (technical equipment) room • Transport	• Accessibility • Buildings • Installation
Environmental conditions	• Indoor climate • Temperature	• Altitude • Humidity
Sector-specific application	• Switching duty • Busbar change	• Switching frequency • Availability
Sector-specific operating procedures	• Operation • Work • Inspection	• Operator protection • Operator instructions • Maintenance
Standards and regulations	• Standards • Association guidelines	• Statutory regulations • Company regulations

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Tab. 4/1: **Influencing factors and stresses on the switchgear**

Attention: The ratio of surge current and sustained short-circuit current in the system can be $2 \times \sqrt{2} = 2.83$, thus being slightly higher than the standardized factor $I_p / I_k = 2.5$ (50 Hz), for which switches and installations are built. A possible cause, for example, are motors that feed power back to the system when a short circuit occurs, thus increasing the surge current significantly.

Operating current and load flow

The operating current refers to current paths of the feed-in units, busbar(s) and load feeders. Because of the spatial arrangement of the panels, the current is also distributed and therefore there may be different rated current values next to one another along a conducting path; typically there are different values for busbars and feeders. Reserves must be planned when dimensioning the installations, for example:
- corresponding to ambient temperature variations,
- for planned overload,
- for temporary overload during faults.

Large cable cross sections or several cables in parallel must be connected for large operating currents; the panel connection must be rated accordingly.

Assigned configuration criteria for switchgear are:
- Rated current of busbar(s) and feeders
- Number of cables for each conductor in the panel (parallel cables)
- Rating of the current transformers

The smallest possible standardized grading of the switchgear rated values should be selected for a cost-optimized dimensioning of the medium-voltage switchgear, whereby the operating current conditions and the short-circuit current conditions must be satisfied.

Operating current condition:

$I_{b\text{-}max} \leq I_{perm}$

(The maximum operating current must be less than or equal to the continuous current-carrying capacity)

Assigned configuration criteria for switchgear	
Main and earthing conducting paths	• Rated peak withstand current I_p • Rated short-time current I_k
Switching devices	• Short-circuit making current I_{ma} • Rated short-circuit breaking current I_{sc}
Current transformer	• Rated peak withstand current I_{dyn} • Thermal rated short-time current I_{th}

Tab. 4/2: **Configuration criteria for short-circuit current**

Short-circuit current condition:

$I_a \leq I_{sc}$

(the symmetrical AC breaking current must be less than or equal to the rated short-circuit breaking current of the feeding system)

$i_p \leq I_{ma}$ (for switches), or
$i_p \leq I_{pk}$ (for switches and switchgear)

(the peak short-circuit current must be less than or equal to the rated short-circuit making current, or the rated peak short-circuit current)

$I_{th} \leq I_{thr}$ (for $t_k \leq t_{thr}$), or $I_{th} \leq I_{thr} \times \sqrt{t_{thr} / t_k}$ (for $t_k > t_{thr}$)

(The thermally equivalent short-circuit current is less than or equal to the rated short-time current if the maximum short-circuit duration t_k is less than or equal to the rated short time t_{thr}, or less than or equal to the rated short-time current weighted with a factor derived from the root of the quotient t_k and t_{thr}, when the maximum short-circuit duration is longer than the rated short time)

A gas-insulated switchgear plant (e.g. 8DJH by Siemens) should be used for the medium-voltage utilities substation (see Tab. 4/3). The advantages of gas-insulated switchgear are:
- Low space requirements (up to approx. 70 % savings with 20 kV) compared to air-insulated switchgear
- Smaller transportation size and consequently easier shipping
- Increased reliability of operation due to hermetically sealed primary switchgear section (adverse impact such as from contamination, small animals, contact, condensation are excluded due to the encapsulation)
- Maintenance-free primary section (lubrication and re-adjustment is eliminated; maintenance-free gas compartment for the entire service life thanks to stainless steel tank)
- Better eco balance than air-insulated switchgear with regard to the service life
- When a pressure absorption system is used, the rise in pressure when a fault occurs is significantly less than with air-insulated switchgear, which means that a smaller room is possible

Operator protection:

- The gas-insulated switchgear is safe to touch thanks to its grounded metal enclosure.
- HV HRC fuses and cable terminations are only accessible if branch circuits are earthed.
- Operation is only possible if the enclosure is fully sealed.

8DJH switchgear							
Rated insulation level	Rated voltage U_r [kV]	7.2	12	15	17.5	24
	Rated short-duration power-frequency withstand voltage U_d [kV]	20	28	36	38	50
	Rated lightning impulse withstand voltage U_p [kV]	60	75	95	95	125
Rated frequency f_r		50/60 Hz				
Rated operating current I_r	for branch circuits	up to 400 A or 630 A				
	for busbar	max. 630 A				
Rated short-time current I_k	for installations with t_k = 1 s [up to kA]	20 25	20 25	20 25	20 25	20
	for installations with t_k = 3 s (option) [kA]	20 –	20 –	20 –	20 –	20
Rated peak withstand current I_p	[up to kA]	50 63	50 63	50 63	50 63	50
Rated short-circuit making current I_{ma}	[up to kA]	50 63	50 63	50 63	50 63	50
Ambient temperature T	without secondary equipment	– 25/– 40 to + 70 °C				
	with secondary equipment	– 5 to + 55 °C				

Tab. 4/3: **Electrical data of gas-insulated 8DJH switchgear**

- A maintenance-free pressure absorption system, laid out as a "special cooling system", reduces pressure-related and thermal effects of an arc fault. This keeps the personnel and the building protected (Fig. 4/4).

Protection of medium-voltage switchgear:

- Protection devices (e.g. SIPROTEC) detect faults in the power system and disconnect the respective installation parts safely and quickly
- In a radial network, a grading of non-directional time-overcurrent protection relays is sufficient
- Flexibility achieved from a variety of protocols, such as those based on IEC 61850, IEC 60870-5-103, PROFIBUS-DB, Modbus RTU or DNP 3.0 should be kept in mind

Substation control:

Linking the switchgear to a substation control system has the following advantages:
- High degree of availability and safety
- Short response times
- Central operator control and monitoring

The switchgear acquires and transmits switching states, messages, operating conditions and measured values. If an integrated energy automation system like SICAM is used as substation control system, all field levels can be connected:
- Process level
- Field control level
- Substation control level
- Network control level

SICAM uses specially tested components and standards to ensure the above advantages are maintained.

An extension to integrated automation solutions is possible from interfacing the building automation, for instance via OPC (OLE for Process Control; OLE (object link environment)) to higher-level control systems, which in turn are in accordance with the communication standard IEC 60870-5-101 or IEC 60870-5-104.

Extendibility

The switchgear should be extendible with a minimum time expense. A modular system with the following characteristics provides the best conditions:
- Busbar extension optionally on the right, on the left or at both ends
- Individual panels and panel blocks can be mounted side-by-side and extended as desired – no gas work required on site
- Low-voltage cubicle is available in two heights, wired to the switchgear panel by means of plug connectors
- All panels can be replaced at any time

Installation site

The switchgear is to be used indoors in compliance with IEC 61936 (Power installations exceeding 1 kV a.c.) and VDE 0101. We distinguish between:
- Switchgear types in locations with no access from the public, outside closed off electrical operating areas. Switchgear enclosures can only be removed with the aid of tools and operation by ordinary persons must be prevented.
- Installations in locked electrical operating areas: A closed electrical operating area is a room or location used solely for the operation of electrical switchgear and is kept locked. Access is only granted to electrically skilled per-

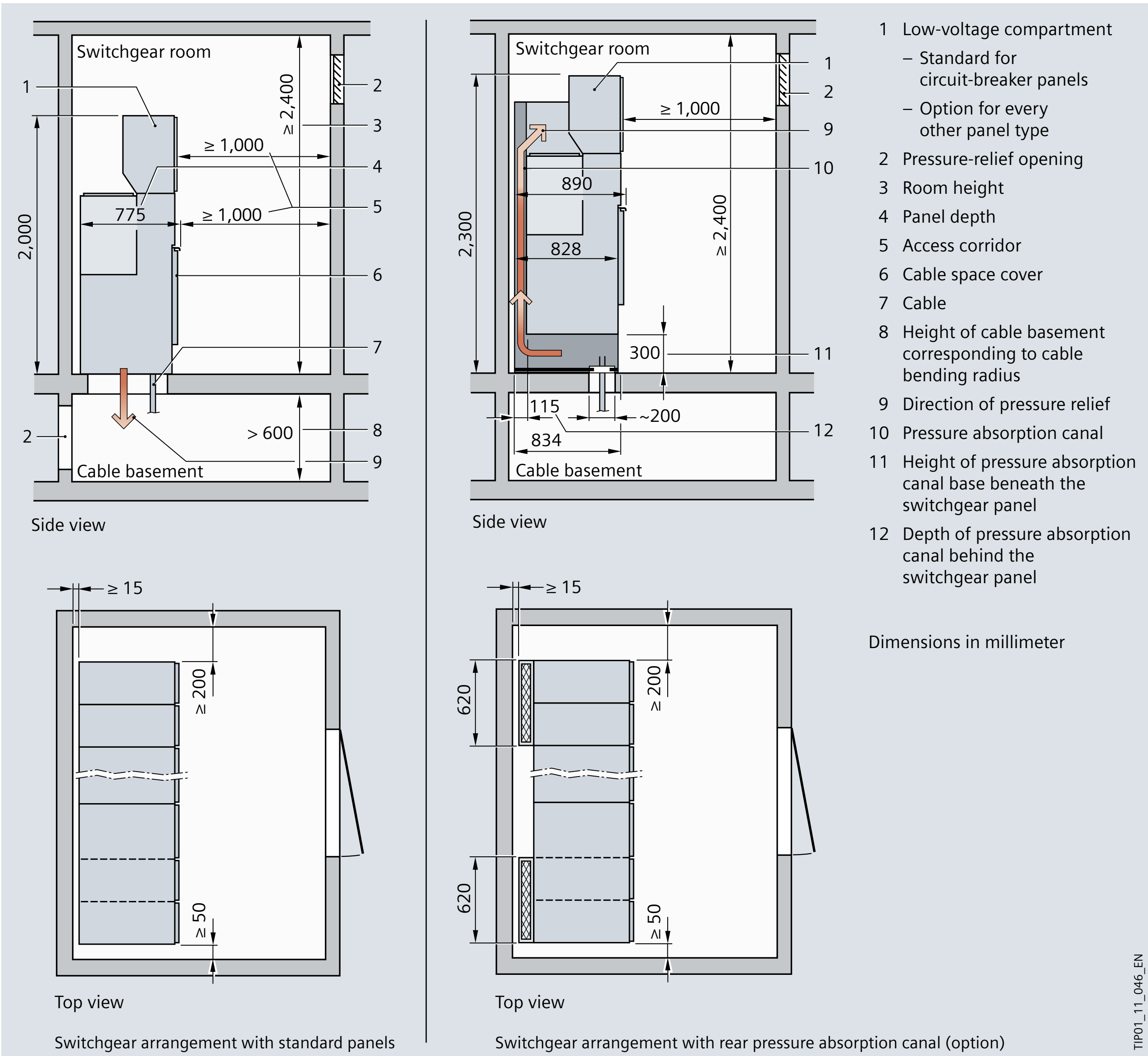

Fig. 4/4: **Room layout for switchgear with pressure relief downward (left) and with pressure absorption duct**

sons and electrically instructed persons; for ordinary persons only when accompanied by electrically skilled or instructed persons.

Operating and maintenance areas

These are corridors, connecting passages, access areas, transportation and escape routes.

- Corridors and access areas must be sufficiently dimensioned for work, operation and transportation of components.
- The corridors must have a minimum width of 800 mm.
- Corridor width must not be obstructed by equipment protruding into the corridor, such as permanently installed drives or switchgear trucks in disconnected position.
- The width of the escape route must be at least 500 mm, even if removable parts or fully open doors protrude into the escape route.
- Switchgear panel or cubicle doors should close in the direction of escape.
- For mounting and maintenance work behind enclosed units (stand-alone) a passage width of 500 mm is sufficient.

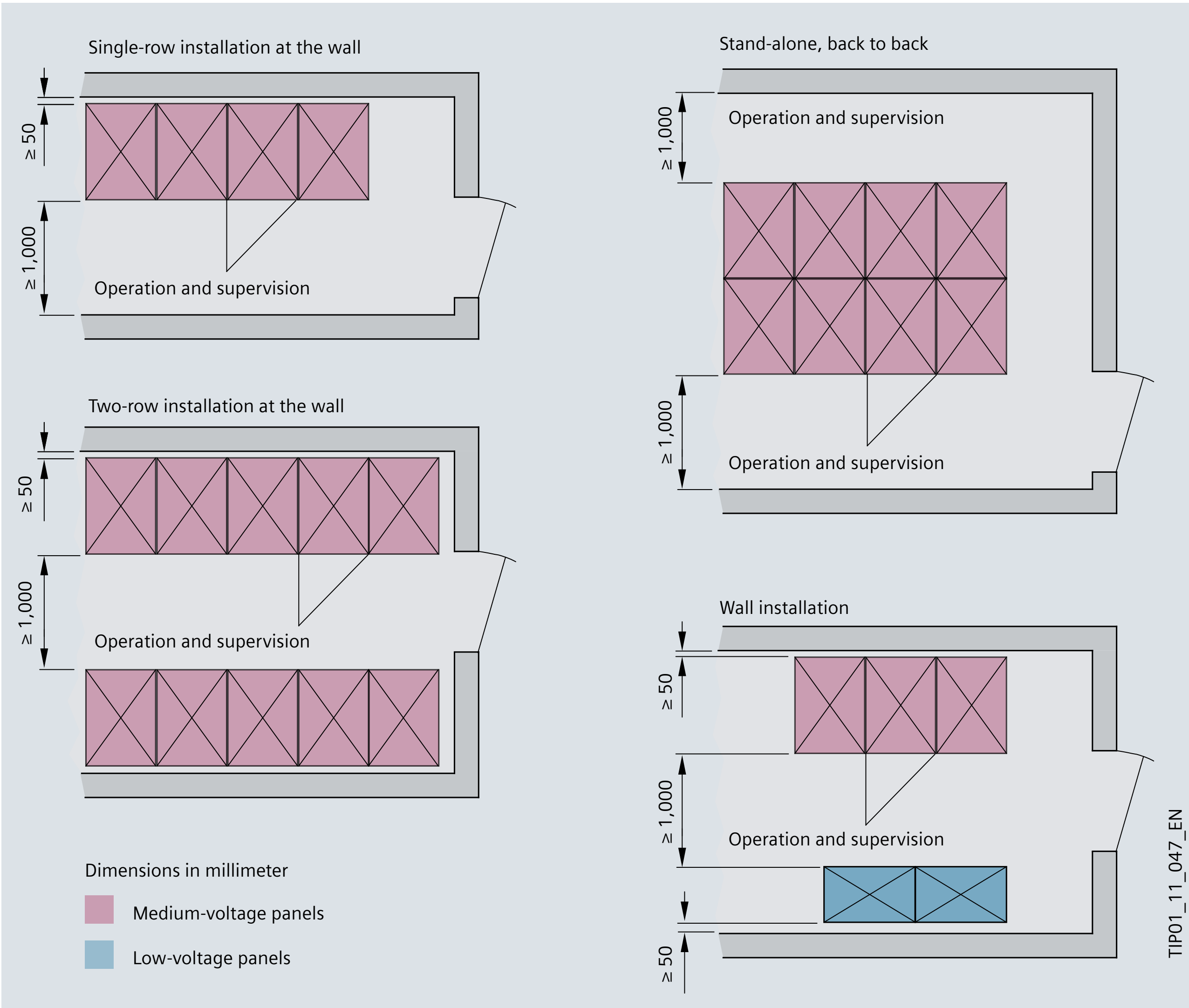

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Fig. 4/5: **Examples for the arrangement of panels and corridors (acc. to [22])**

- A minimum height of 2,000 mm below ceilings, covers or enclosures, except for cable basements is required.
- For rated voltages up to 52 kV, installations must be spaciously arranged in such a way that the length of the escape route inside the room does not exceed 20 m (40 m for operating voltages above 52 kV). This requirement does not apply to walk-in busbar or cable conduits or ducts.
- If operator corridors do not exceed a length of 10 m, one exit is sufficient. If the escape route is longer than 10 m, an (emergency) exit is required at both ends.
- Fixed ladders or similar facilities are permissible as emergency exits in escape routes.

4.2 Distribution Transformers

A secure power supply requires a well-developed power supply network with powerful transformers. Distribution transformers are designed for a power range from 50 to 2,500 kVA and maximum 36 kV. In the last stage, they feed electrical energy into the consumer networks by transforming it from medium voltage into low voltage. They are designed either as liquid-insulated transformers or as cast-resin dry-type transformers.

Power transformers, including distribution transformers, must comply with the relevant specifications such as IEC 60076 (VDE 0532-76) for "Power transformers" and the requirements of the standards and specifications of the European Union (DIN EN 50464 for "Oil-immersed AC distribution transformers, 50 Hz, ..." or HD538 revised for "AC dry-type transformers, 50 Hz, ...").

4.2.1 GEAFOL cast-resin transformers

Cast-resin dry-type transformers (e.g. GEAFOL) are the solution wherever distribution transformers in the immediate proximity to people must guarantee the greatest possible safety. Requirements for the site of installation in accordance with pre-2000 version of DIN VDE 0101 (water protection, fire protection and functional endurance, see Tab. 4/5) suggest the use of such transformers. Compared to transformers using mineral oil, silicone oil or diester oil as insulation liquid, the requirements in terms of installation site, personal protection and low fire load can be more easily fulfilled. Cast-resin transformers should at least meet the requirements C2 (Climate Category), E1 or E2 (Environment Category) and F1 (Fire Safety Category) as defined in IEC 60076-11 (VDE 0532-76-11) (see Tab. 4/4).

Important!
In accordance with IEC 60076-11 (VDE 0532-76-11), the required classes may be defined by the operator.

Standard GEAFOL cast-resin transformers are suitable for the E2 environment category. Transformers of the GEAFOL Basic series can be optionally re-equipped from the E1 to the E2 environment category. GEAFOL Basic offers an optimal cost-benefit ratio, with a corresponding compromise involved of smaller dimensions and slightly higher power losses than the standard version.

Environment category	
Category E0	No condensation, pollution can be neglected
Category E1	Occasional condensation, limited pollution possible
Category E2	Frequent condensation or pollution, also both at the same time
Climate category	
Category C1	Indoor installation not under –5 °C
Category C2	Outdoor installation down to –25 °C
Fire safety category	
Category F0	There are no measures to limit the danger of fire
Category F1	The fire risk is limited by the properties of the transformer

Tab. 4/4: **Environment, Climate and Fire Safety Categories in accordance with IEC 60076-11 (VDE 0532-76-11)**

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Transformer design	Type of cooling acc. to IEC 60076-2 (VDE 0532-76-2)	General	In closed electrical operating areas	Outdoor installations
Mineral oil *	O	a Oil sumps and collecting pits b Discharge of liquid from the collecting pit must be prevented c Water Resources Act and the state-specific regulations must be observed	Impermeable floors with sills are permitted as oil sumps and collecting pits for a maximum of 3 transformers, each transformer with less than 1,000 l of liquid	No oil sumps and collecting pits needed under certain circumstances (the complete text of DIN VDE 0101 before 2000, section 5.4.2.5 C must be observed)
Transformers with silicone oil or synth. diester oil**	K	As for coolant designation O		
Cast-resin dry-type transformers	A	No measures required		
* or fire point of the cooling and insulation liquid ≤ 300 °C ** or fire point of the cooling and insulation liquid > 300 °C				

Tab. 4/5: **Protective measures for water protection according to DIN VDE 0101 before 2000**

Designation of cooling agent	General	Outdoor installations
O	a Rooms: fire resistant F90A, separated b Doors: fire-retardant T30 c Low flammability required for external doors d Oil sumps and collecting pits are arranged to stop a fire spreading; except for installations in closed electrical operating areas with a maximum of 3 transformers, each transformer with less than 1,000 l of liquid e Fast acting protective devices	a Adequate clearances or b Fire resistant partitions
K	As for coolant designation O; a, b and c can be omitted when e is present	No measures required
A	As for coolant designation K; but without d	No measures required

Tab. 4/6: **Protective measures for fire protection and functional endurance according to DIN VDE 0101 before 2000**

Installation site requirements

Cast-resin transformers place the lowest demands on the installation site. This results from the regulations for ground water protection, fire protection and functional endurance in VDE 0101, IEC 60364-7-718 (VDE 0100-718) (see Tab. 4/5 and Tab. 4/6) and the EltBauVO [23].

How many transformers are required?

Depending on the application, the use of several transformers operated in parallel may be useful. GEAFOL transformers require almost no maintenance. For this reason, a back-up transformer for maintenance work need not be considered.

Caution!
Make sure that the two transformers to be operated in parallel have the same technical characteristics (including their rated short-circuit voltages).

4

The following is specified as reference value for the dimensioning of two transformers operated in parallel:

Rated power of each transformer =
1/2 x (power demand / 0.8)

Additional transformer ventilation for more power

The output of GEAFOL transformers up to 2,500 kVA, in degree of protection IP00, can be increased to 130 % or 150 % when cross-flow fans are installed. Efficient blowing can, for example, raise the continuous output of a 1,000 kVA transformer to 1,300 kVA or 1,500 kVA. However, the short-circuit losses are also twice or 2.3 times the value of the power loss for 100 % nominal load. Additional ventilation is a proven means for covering peak loads as well as compensating a transformer failure when transformers are operated in parallel.

No-load losses – reduced losses

In accordance with the "Guideline for Sustainable Building" from the former German Ministry of Transport, Building and Housing (presently: Ministry for Transport, Building and Urban Development) and with regard to the energy performance certificate for buildings based on the energy-saving regulations (EnEV 2009 [25]), transformers with reduced losses should generally be used. The economic efficiency of such a transformer can be verified through a loss evaluation. Your Siemens TIP contact can assist you in drawing up such an evaluation.

Conditions for installation – room layout

GEAFOL cast-resin dry-type transformers can be installed in the same room as medium- and low-voltage switchgear without any extra precautions. For plants which come within the scope of EltBauVO, the electric utilities room must be enclosed by fireproof walls and doors (walls of fire resistance rating F90A, doors in F30A).

Temperature of the cooling air

In accordance with the relevant standards, transformers are dimensioned for the following cooling air values:
- Maximum 40 °C
- Daily mean 30 °C
- Annual mean 20 °C

Normal service life consumption is achieved during normal operation. Particularly the mean annual temperature and the load are decisive for the service life consumption. Different ambient temperatures change the load capability of the system (see Tab. 4/7).

Special conditions for installation

Extreme local conditions must be taken into account when planning the system:

- The paint finish and prevailing temperatures are relevant for use in tropical climates.
- For use in altitudes of more than 1,000 m above sea level a special configuration with regard to heating and insulation level is required (see IEC 60076-11; VDE 0532-76-11).
- With increased mechanical demands being made – use in a ship, excavator, earthquake region, etc. – additional constructive measures may be required, e.g. supporting the upper yokes.

4.2.2 Oil-immersed distribution transformers

Distribution transformers with oil as a cooling and insulating liquid are either hermetically sealed or have an expansion tank. In TUNORMA distribution transformers (Fig. 4/6), the oil level in the tank and in the top-mounted bushing insulators is kept constant by means of an oil expansion tank, which is mounted at the highest point of the transformer. Changes in the oil level caused by varying thermal conditions only affect the oil expansion tank. The hermetically sealed system of the TUMETIC distribution transformers (Fig. 4/7) prevents the ingress of oxygen, nitrogen or moisture into the coolant. This improves the ageing properties of the oil to such an extent that the transformers remain maintenance-free throughout their entire service life. TUMETIC transformers generally have a lower height than comparable TUNORMA transformers.

A distinction is also made between the cooling and the insulating liquid:

- Mineral oil that meets the requirements of the international regulations for insulating oil (IEC 60296) – for distribution transformers without any special requirements
- Silicone oil that is self-extinguishing when a fire occurs. Due to its high fire point of over 300 °C, it is classified as a Category K liquid according to EN 61100 (VDE 0389-2).
- Diester oil, which does not pollute water and is bio-degradable. Diester oil also has a fire point of over 300 °C, a high level of safety against fires and is also classified as K-liquid according to EN 61100 (VDE 0389-2).

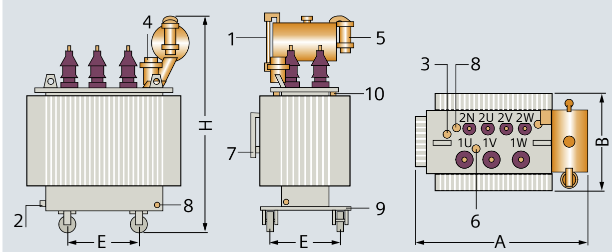
The design of the transformers depends on the requirements. For example, double-tank versions are available for special requirements in protected water catchment areas and versions with ultra-high interference reduction for use in EMC-sensitive areas.

Ambient temperature (annual mean)	Load capability
-20 °C	124 %
-10 °C	118 %
0 °C	112 %
+10 °C	106 %
+20 °C	100 %
+30 °C	93 %

Tab. 4/7: **System load capability depending on the ambient temperature**

With expansion tank

A = length; B = width; H = height
E = roller-to-roller center spacing



1 Oil level indicator
2 Oil drain
3 Thermometer well
4 Buchholz relays (on request)
5 Desiccant breather (on request)
6 Adjuster for off-circuit tap changer
7 Rating plate (moveable)
8 Earth connections
9 Pulling lug, Ø 30 mm
10 Lashing lug

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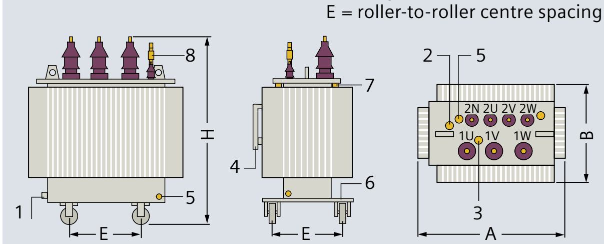
Fig. 4/6: **Oil-immersed distribution transformer with expansion tank**

Hermetically sealed tank

A = length;
B = width;
H = height
E = roller-to-roller centre spacing



1 Oil drain
2 Thermometer well
3 Adjuster for off-circuit tap changer
4 Rating plate (moveable)
5 Earth connections
6 Pulling lug, Ø 30 mm
7 Lashing lug
8 Filler tube

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Fig. 4/7: **Oil-immersed distribution transformer with hermetically sealed tank**

4.3 Standby Power Generating Set

A standby power generating set (for emergency standby power systems ESPS) is used to supply power when the public supply fails and may be required for several reasons:

- To fulfil statutory regulations for installations for gatherings of people, hospitals, or similar buildings
- To fulfil official or statutory regulations for the operation of high-rise buildings, offices, workplaces, large garages or similar buildings
- To ensure operation of safety-relevant systems such as sprinkler systems, smoke evacuation systems, control and monitoring systems or similar systems
- To ensure operation of IT systems
- To safeguard production processes in industry
- To cover peak loads or to complement the power supply from the normal grid

4.3.1 Dimensioning of the generator units

The DIN 6280 and ISO 6280 standard series are instrumental for the dimensioning and manufacturing of standby generator units. The design class of the generator unit results from the load demands. The following factors are some of the important factors for the power rating of the generator units:

- Sum of the connected loads = load capacity
- Operating behaviour of the consumers (e.g. switched-mode power supply units, frequency converters and static UPS units with high power distortions)
- Simultaneity factor g = 1
- Turn-on behaviour of the consumers
- Dynamic response and load connection response of the generator unit
- Ambient conditions at the installation site of the generator unit
- Reserves for expansions
- Short-circuit behaviour

4.3.2 Integration into the power system concept

The following selection criteria for the standby generating set must be considered due to the consumer-dependent parameters of the SPS such as power requirements, power distribution concept, simultaneity factor and reserves for extensions:

- Supply on the medium-voltage or low-voltage level
- Distribution of the SPS load over several standby power generating sets connected in parallel or supply via one large standby generating set
- Central installation or distribution of the individual power supplies close to the SPS consumers

The differences in cabling the safety power supply, the susceptibility of the control system, the outlay for switching and protection measures as well as the supply of the consumers "privileged" to receive emergency power during maintenance and repairs must be taken into account in the selection and design of a standby power generating set.

Some of the decisive criteria for making a choice between the medium-voltage and the low-voltage level are briefly described as seen from the medium-voltage viewpoint.

Medium voltage has the following advantages:

- Larger loads can be transmitted easier over longer distances
- Better power quality in extensive networks (voltage drop)
- Lower busbar currents at the low-voltage side allow for more cost-effective low-voltage switchgear.
- The required short-circuit current is attained much easier in the TN-S system for the "Protection through tripping" measure.

Medium voltage has the following disadvantages:

- Cost effectiveness should be checked when the power requirement is less than approximately 400 kVA.
- Greater expenses are required for the protection concept in large networks.
- (Additional) transformers with the associated switchgear and the appropriate protection are also required in the network for the safety power supply.
- A higher skill level is required for personnel operating the switchgear.

Generally a medium-voltage supply is only economical when higher power quantities must be transmitted over large distances.

4.3.3 System behaviour and planning framework

Turn-on and operating behaviour of consumers

The start-up and turn-on behaviour of electric motors, transformers, large lighting systems with incandescent or similar lamps has a major effect on the generator unit output. Especially when there is a large proportion of critical consumers in relation to the generator unit output, an individual test must be performed. The possibility of staggering the connection of loads or load groups significantly reduces the required generator unit output. If turbocharger motors are used, the load must be connected in steps.

All the available possibilities of reducing the start-up loads of installed consumers should be fully exploited. The operation of some consumer types can also have a major effect on the generator unit output and generator design. A special test must be performed when supplying consumers with power electronic components (frequency converters, power converters, UPS).

Dynamic response

The dynamic response of the generator unit at full load connection and for the load changes to be expected must be adapted to the permissible values of the consumers. The design class of the generator unit in accordance with ISO 8528 is determined by the consumer type or the relevant regulations. Fulfilling the required values can result in an oversizing of the engine, generator or both components. As a rule, modern diesel engines with turbochargers and possibly charge air cooling are usually not suitable for load connections greater than approx. 60 % in one load impulse. If no particular consumer-related requirements are placed on the generator unit, the load connection must be performed in several steps.

Short-circuit behaviour

If no particular measures are taken, the unit generators supply a three-pole sustained short-circuit current of approx. 3 to 3.5 × I_n at the generator terminals. If the generators supply larger networks, a higher short-circuit current may be necessary to maintain the disconnection condition. In such cases, it is necessary to oversize the generator or alternatively, to use a release with an earth fault protection function.

Environmental conditions

The reference conditions for diesel motors must be taken into account here. ISO 3046-1 (DIN 6271-3) specifies an ambient or air-intake temperature of 27 °C, a maximum installation altitude of 1,000 m above sea level and a relative humidity of 60 %. If less favourable conditions are present at the installation site of the generator unit, the diesel engine must be oversized or the engine-specific derating factors must be taken into consideration.

Room layout and system components

When planning the generator unit room, the local building regulations must be taken into account. The planning of the generator unit room can also have a significant influence on the acquisition costs of a standby power supply system. The installation room should be selected according to the following criteria:

- Short cable routes to the supply point (low-voltage main distribution board)
- The room should be located as far away as possible from residential rooms, offices, etc. (offending noise)
- Problem-free intake and exhaust of the required air flow rates
- Arrangement of the air inlets/outlets taking into account the main wind direction
- Problem-free routing of the required exhaust pipe
- Easy access for moving in the components

The generator unit room must be selected so that is it large enough to easily accommodate all the system components (also see Fig. 4/8). Depending on the installation size, there should be 1 to 2 m of access space around the generator unit. The generator unit room should always have a temperature of at least +10 °C in order to prevent condensation and corrosion forming and to reduce the engine preheating.

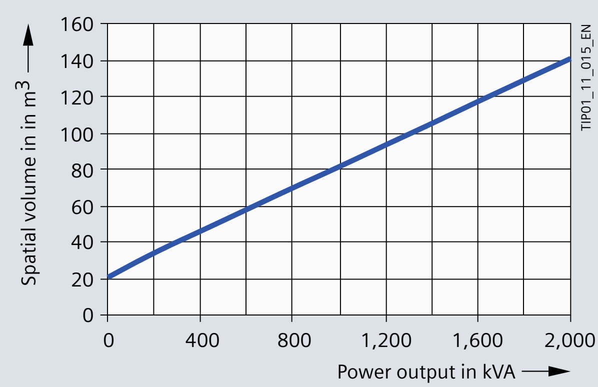

Fig. 4/8: **Space requirements of a complete standby power generating set including soundproofing**

4

4.4 UPS System

The use of a UPS system is for the protection of sensitive consumers in the normal power supply system (NPS) and to ensure their continual operation during power failures (see Fig. 3/14). The proper integration of the UPS system into the power supply concept is of vital importance for the availability of the entire power supply system. The following general aspects concerning UPS should be considered in the planning:

- Selectivity for the switching and protective function in conjunction with the UPS system
- Disconnection conditions (personal protection in accordance with IEC 60364-4-41 (VDE 0100-410)) in conjunction with the UPS system
- Factoring in the short-circuit energy I^2t as well as the short-circuit current I_k" for the static bypass
- Protection of the UPS main distribution (possible spof) at UPS output; in particular in case of UPS being connected in parallel

Basically, we distinguish between dynamic and static UPS systems. Do note that the system is also a static UPS system if a flywheel is used to supply critical loads via the electronic inverter in case of voltage problems.

4.4.1 Dynamic UPS systems

The two main components of a dynamic UPS system are the electric motor and the generator, which are synchronized as a machine unit. In accordance with DIN 6280-12, critical consumers are supplied by the generator. The different systems considered as dynamic UPS systems are described in this standard. Fig. 4/9 shows a schematic classification acc. to DIN 6280-12.

4

The machine unit principally has a low kinetic energy for bridging voltage failures in the millisecond range. Normally this range is extended to a defined time by the use of flywheels as energy storage and/or battery systems. The bridging time then amounts to seconds or minutes. To cater for bridging times in the hour range, a diesel engine can additionally be coupled. To cover the period until the diesel engine has started up, intermediate storage systems (flywheel, battery) maintain the power supply for the generator (see Fig. 4/10).

The operating modes of dynamic UPS systems in accordance with DIN 6280-12 permit further distinctions to be made:

- Active readiness mode (quick-starting – short break: 2 to 500 ms)
- Continuous mode (electrically isolated load supply via UPS: immediate readiness – no break)
- Active following mode (uninterruptible transfers between load supply from the normal network and load supply from the following UPS: immediate readiness – no break)

Please note that this classification does not correlate with the classification of static UPS systems (see Fig. 4/11). Even in the continuous mode, the dynamic UPS may be frequency-dependent if the line voltage is not transformed into a so-to-speak independent supply voltage for the motor using a converter.

An active readiness mode is not feasible for the ICT components in the data centre, since manufacturers established the ITIC curve from [15] as outlined in chapter 3, in which the permissible voltage conditions (see Abb. 3/2) for the power supply of ICT components are described. Whilst this curve was introduced for single-phase 120-volt equipment using a 60-hertz AC frequency, it is also used for many other product series in a similar form today.

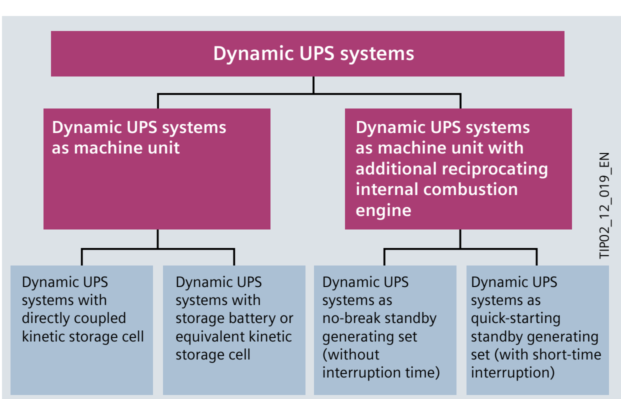

Fig. 4/9: **Overview of suitable dynamic UPS systems**

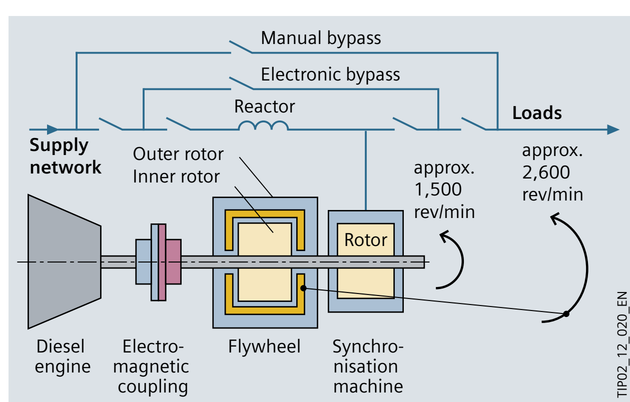

Fig. 4/10: **Schematic view of a dynamic UPS system using a combination of diesel engine, flywheel and generator power**

4.4.2 Static UPS systems

To influence the supply voltage, power electronic components such as diodes, thyristors, and transistors are in static UPS systems. Dependent on the influence exercised, IEC 62040-3 (VDE 0558-530) classifies static UPS systems according to the quality of the UPS output voltage and the behaviour in case of line faults (see Tab. 4/8).

The simplified circuit diagrams in Fig. 4/11 demonstrate that the UPS double-converter technology (VFI system)[1] provides a supply quality for the power consumers which is independent of the feed-in system. With the VI-UPS, the voltage is set independent of the UPS input voltage, whereas the frequency at the UPS output is linked to that at the UPS input. In an "off-line circuit" (VFD), both the voltage and frequency at the UPS output depend on the conditions at the input. Do note for all UPS types in your planning that repercussions from the UPS input will affect the quality of electric power distribution upstream of the UPS.

Since a spatial separation of ICT components from power supply components is desired in the data centre, larger, better performing UPS units with a 3-phase connection and double-converter system (on-line UPS system) are usually used. The systems comprising UPS and battery should be accommodated in separate operating rooms for reasons that include EMC, noise, maintenance, fire protection and much more.

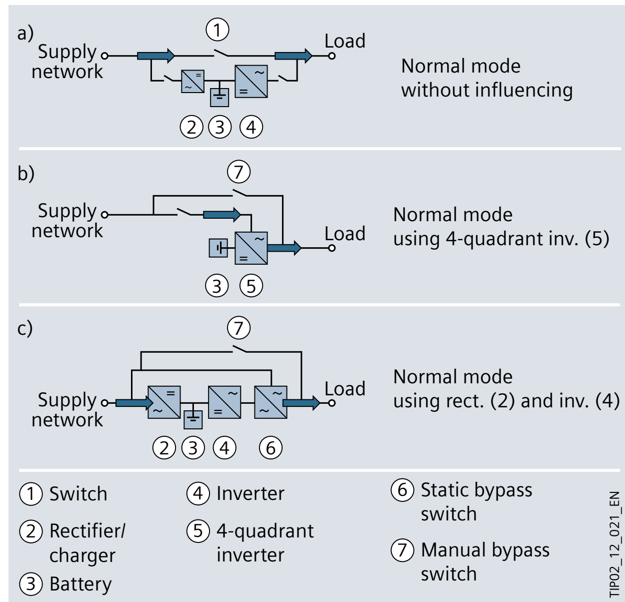

Fig. 4/11: **UPS systems with energy flow during normal operation: a) Off-line UPS system, b) Line-interactive UPS system c) On-line UPS system**

1 voltage and frequency independent

Line faults	Time	For example	EN 62040-2	UPS solution	Supplier solution
1. Power failures	> 10 ms				–
2. Voltage fluctuations	< 16 ms		**VFD** Voltage + Frequency Dependent	**Classification 3** Passive standby mode (off-line)	–
3. Voltage peaks	4 to 16 ms				–
4. Undervoltages	continuous		**VI** Voltage Independent	**Classification 2** Line-interactive mode	–
5. Overvoltages	continuous				–
6. Surge	< 4 ms				–
7. Lightning strikes	sporadic				Lightning and overvoltage protection (IEC 60364-5-53)
8. Voltage distortion (burst)	Periodic		**VFI** Voltage + Frequency Dependent	**Classification 1** Double-conversion mode (on-line)	–
9. Voltage harmonics	continuous				–
10. Frequency variations	sporadic				–

Tab. 4/8: **Types of line faults and matching UPS solutions based on IEC 62040-3 (VDE 0558-530) [12]**

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To increase their performance and improve availability, parallel-connected UPS systems may be used. Do note that with an increasing number of components, the servicing outlay will also increase and that the higher system complexity may cause new kinds of faults. For reasons of usage efficiency, the load-dependent UPS efficiency rate should also be considered in the redundancy concept. Therefore, a (2+1) redundancy may create a somewhat higher availability, leaner maintenance costs and lower losses in operation, than for instance, a (6+1) redundancy.

A current trend which may be important for the planning of reliable power supply in the data centre is the extendibility and redesign capability achieved from modular UPS systems. A modular UPS system allows the integration of extension modules into an existing system when performance demands are rising. To this end, a possible final brown field scenario should already be on hand when operation starts. It is often argued that extension modules can help reduce initial investment costs. Moreover, easy extendibility and fast swapping of modules can reduce the UPS failure period in case of a fault – thus increasing availability as against a conventional UPS solution.

Both aspects, advantages in cost and availability, are critically reviewed in a "white paper" by Emerson Network Power [26]. This paper compares a 40-kW UPS with a modular UPS system (10-kW power modules, built into a UPS structure suitable for 40 kW).

Availability

Owing to the higher number of components in a modular solution, their failure rate is significantly higher. But since it can be assumed that the UPS service team will be called in case of a simultaneous fault in both UPS systems and that a service program with spare parts provision was selected, there is practically no difference in the time expense for troubleshooting. The following availability figures are given in the "white paper" [25]:

- Modern simple UPS system, (1+1)-redundant availability = 0.99999998
- Modern simple UPS system, not redundant availability = 0.99996510
- Modular UPS system, (4+1)-redundant availability = 0.99999320

Cost

As far as costs are concerned, the "white paper" arrives at different findings dependent on the extension scenarios for a smaller data centre. For a redundant UPS system with an unfavourable power grading (50 kW UPS units) the monetary advantages of a modular solution can be calculated. Vice versa, the simple UPS solution is more cost-effective if the performance requirement is better met by the UPS (40 kW). In both cases the cost difference is around 10%.

All in all, the number of UPS units should not be too high, and should be reasonably spread out. Important aspects of UPS usage, which unfortunately cannot easily be taken into account in availability assessments are product quality and services which affect both the mean time between failures (MTBF) and the mean downtime (MDT). But for MDT, it is not only the downtime of the UPS which needs to be considered but also the actual time, until the whole system is fully operable again. This may result in much longer periods of full operational failure in the face of complex linkings between hardware and software and far-reaching virtualisation systems than the mere time for troubleshooting a UPS defect.

4.5 Low-voltage Switchboards

When planning a low-voltage switchboard, the prerequisites for its efficient dimensioning are knowledge of the local conditions, the switching duty and the demands on availability. To prevent downtimes, replaceability and reliability of supply are the most essential criteria for power distribution in the data centre. A vital basis here is deploying withdrawable-unit systems both in circuit-breaker-protected and in fuse-protected systems.

The prevention of personal injury and damage to equipment must, however, be the first priority in all cases. When selecting the right switchgear, it must be ensured that a type-tested switchgear assembly (design verification according to IEC 61439-1/-2 (VDE 0660-600-1/-2) with extended testing of behaviour in the event of an internal arcing fault (IEC/TR 61641, VDE 0660-500, Addendum 2) is deployed. The selection of the switching and protective devices must always be made under consideration of the regulations that have to be observed with regard to the requirements for the entire supply system (full selectivity, partial selectivity).

Recommendation:
Interfacing a low-voltage switchboard with busbar insulation to the feed-in system using busbar systems with standard connector components both minimizes the occurrence of faults and their effect.

When low-voltage switchgear is fitted, the minimum clearances between switchgear cabinet and obstacle as specified by the manufacturer must be observed (Fig. 4/12). The minimum dimensions for operating and servicing corridors according to IEC 60364-7-729 (VDE 0100-729) must be taken into account when planning the space required (Fig. 4/13 and Fig. 4/14).

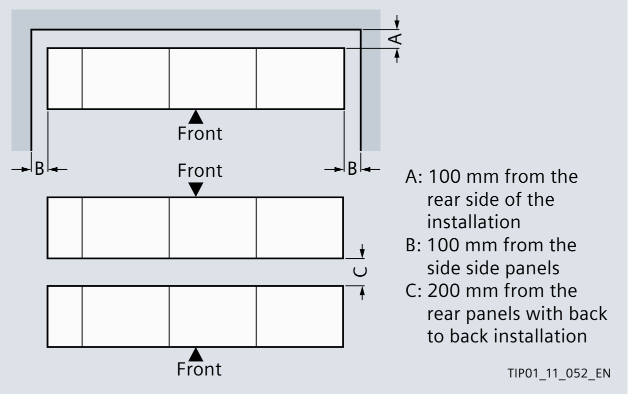

Fig. 4/12: **Clearances of low-voltage switchgear to obstacles**

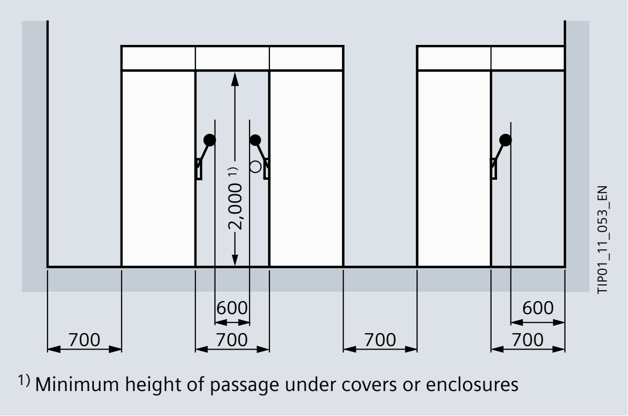

Fig. 4/13: **Reduced corridor widths at opened doors**

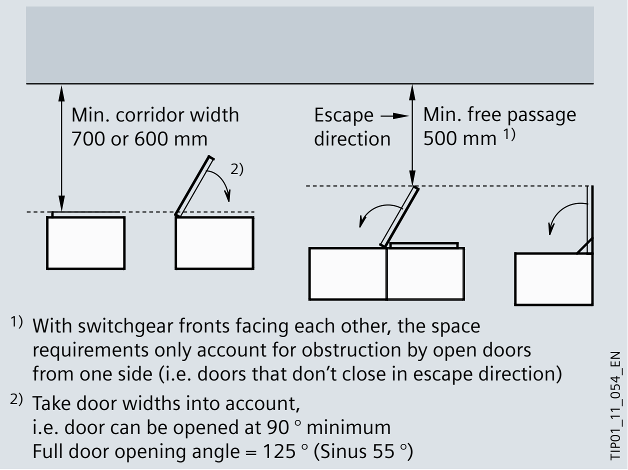

Fig. 4/14: **Minimum corridor width for switchgear fronts**

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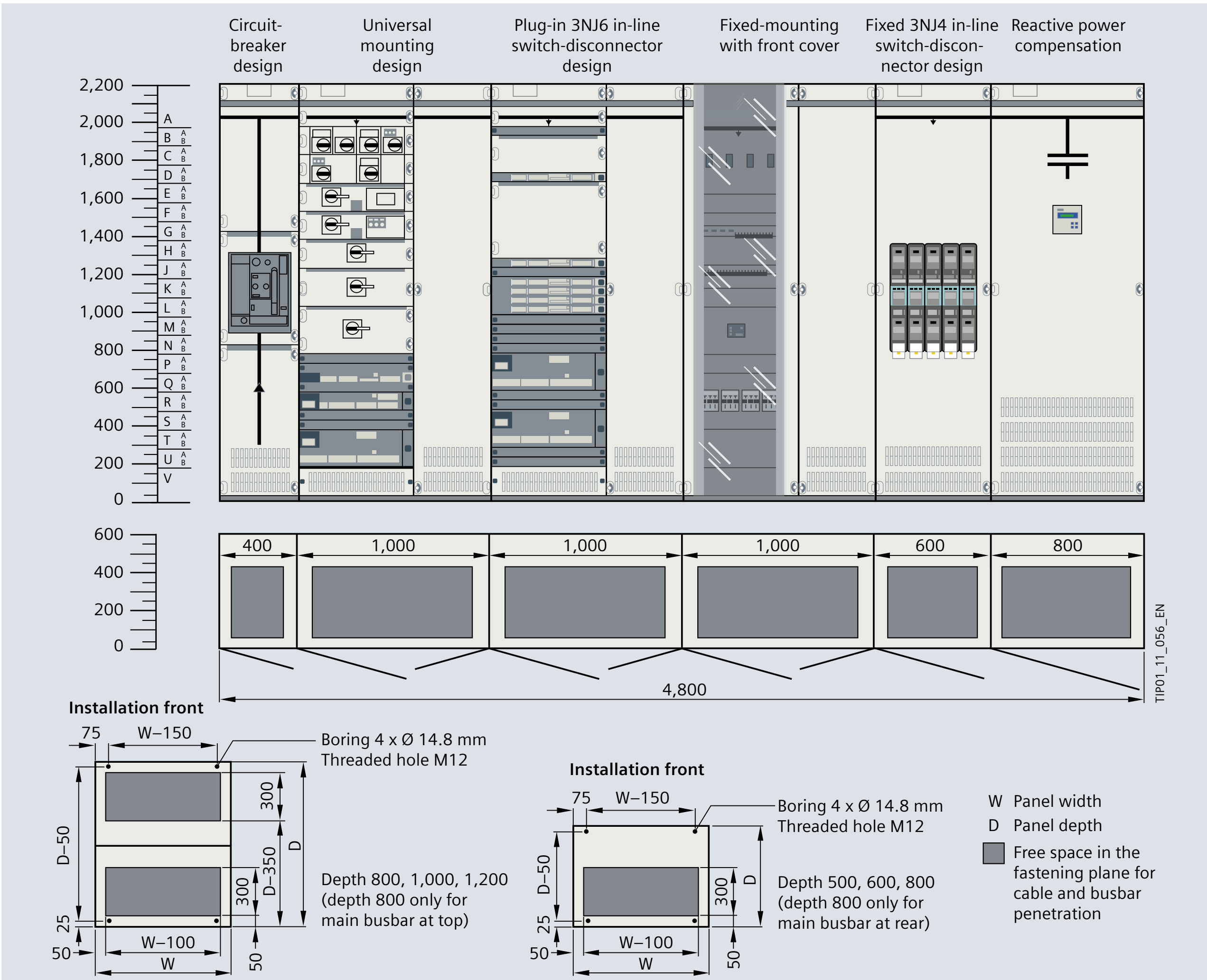

Fig. 4/15: **Low-voltage switchboard – for example SIVACON S8: Busbar position at the rear 2,200 × 4,800 × 600 (H × W × D in mm)**

Panel type	Circuit-breaker design	Universal mounting design	3NJ6 in-line switch-disconnector design	Fixed-mounted design	3NJ4 in-line switch-disconnector design	Reactive power compensation
Mounting and design	Fixed-mounted withdrawable-unit design	Fixed mounting Plug-in design Withdrawable-unit design	Plug-in design	Fixed-mounted design with front covers	Fixed mounting	Fixed mounting
Function	Incoming feeder Outgoing feeder Coupling	Cable outlets Motor feeders	Cable outlets	Cable outlets	Cable outlets	Central compensation of the reactive power
Current I_n	Max. 6,300 A	Max. 630 A or 250 kW	Max. 630 A	Max. 630 A	Max. 630 A	Max. 600 kvar
Connection	Front and rear side	Front and rear side	Front side	Front side	Front side	Front side
Panel width [mm]	400/600/800/ 1,000/1,400	600/1,000/1,200	1,000/1,200	1,000/1,200	600/800	800
Internal separation	1, 2b, 3a, 4b	2b, 4a, 3b, 4b	1, 3b, 4b	1, 2b, 4a, 3b, 4b	1, 2b	1, 2b
Busbars	Rear/top	Rear/top	Rear/top	Rear/top	Rear	Rear/top/ without

Tab. 4/9: **Various mounting designs according to panel types**

4.5.1 Double-front installations

In the double-front installation, the panels are positioned in a row next to and behind one another. The main feature of a double-front installation is the extremely economic design since the branch circuits on both operating panels are supplied by one main busbar system only. The “double-front unit” structure is required for the assignment of certain modules. A double-front unit (Fig. 4/16) consists of a minimum of two and a maximum of four panels. The width of the double-front unit is determined by the widest panel (1) within the double-front unit. This panel can be placed on the front or rear side of the double-front unit. Up to three panels (2), (3), (4) can be placed on the opposite side. The sum of the panel widths (2) to (4) must be equal to the width of the widest panel (1). The panel combination within the double-front unit is possible for all technical installations with the following exceptions.

Exceptions:

The following panels determine the width of the double-front unit and may only be combined with an empty panel:
• Bus sectionalizer unit
• 5,000 A incoming/outgoing feeder
• 6,300 A incoming/outgoing feeder

Fig. 4/15 and Tab. 4/9 exemplify the dimensions and different panel types of the SIVACON S8 low-voltage switchboard.

Double-front installations – top view

Double-front installations only with main busbar system at the rear

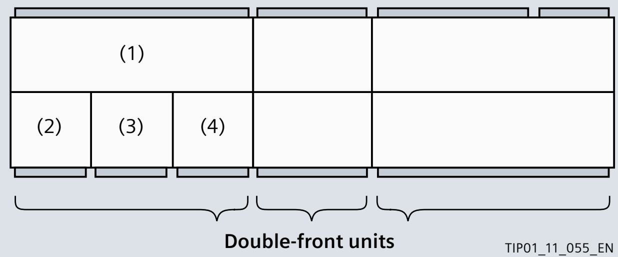

Fig. 4/16: **Panel arrangement for double-front installations**

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4.6 Sub-distribution Systems

The bedrock distribution concepts based on regional and application-specific parameters play an essential part in the implementation of different solutions for electric power distribution in data centres. The term ”power distribution unit” (PDU) generally used here refers to the following items of equipment:

- Distribution cabinets (distribution boards equipped with or without power management)
- Busbar trunking systems
- "Power bars” (fused, or non-fused, switching function, or respectively measuring and managing functionality)
- 19-inch distribution racks for server cabinets (special format for ”power bars", e.g. equipped with miniature circuit-breakers, manual bypass switches, fixed wiring)

4.6.1 Distribution boards

Though distribution boards can principally be designed as flush-mounted, surface-mounted and floor-mounted boards, planning with floor-mounted cabinets is more useful in data centres due to a higher degree of flexibility (see Fig. 4/17). Sub-distribution boards are often installed in confined spaces, recesses or narrow corridors. This often results in a high device packing density.

In order to prevent device failures or even fire caused by excess temperatures, special attention must be paid to the permissible power loss in relation to the distribution board size, its degree of protection and the ambient temperature.

Fig. 4/17: **ALPHA 630 floor-mounted distribution board**

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Connection compartments

After the installation of the switchgear and distribution boards, the internal or external connection compartment available for outgoing cables and wires is decisive for the rational sequence of the connection work. A particularly small extent of encapsulation at first appears to be very economical because of the low purchase price. However, due to the confined space, the installation expenses can be so high when connecting cables and wires the first time and later that the cost-effectiveness is lost. For cables with a large cross section, make sure that there is enough space to spread the wires and for routing the cable.

Solutions providing measuring instruments for every branch circuit to the server cabinets allow for a user-specific power management and cause-based allocation of costs and invoicing, for example for webspace providers.

4.6.2 Busbar trunking systems

Considering the complexity of modern building projects, transparency and flexibility of power distribution and power transmission are indispensable requirements. In the data centre, a continuous power supply is indispensable for server and network operation. At the same time, the scope for retrofitting and changeover without interrupting normal operations is a decisive economic advantage. Siemens busbar trunking systems are ”design-verified low-voltage switchgear and controlgear assemblies” for which the required testing has successfully been performed in accordance with IEC 61439-1/-6, (VDE 0660-600-1/-6). In view of the straightforward planning, quick installation and a high level of flexibility and reliability, they satisfy the requirements of a cost-effective power distribution system (Fig. 4/18).

The main advantages of busbar trunking systems are:

- Straightforward network configuration
- Low space requirements
- Easy retrofitting in case of on-the-spot changes of locations and connected loads of equipment
- High short-circuit strength and low fire load
- Increased planning security

If busbar trunking systems are used in the data centre, these advantages show up in comparison to a cable solution. It is quite easy to imagine that this brings about cost benefits of up to 30 %, considerable time saving given installation in a comparable magnitude as well as a high degree of flexibility for connecting racks during normal operation (Fig. 4/19).

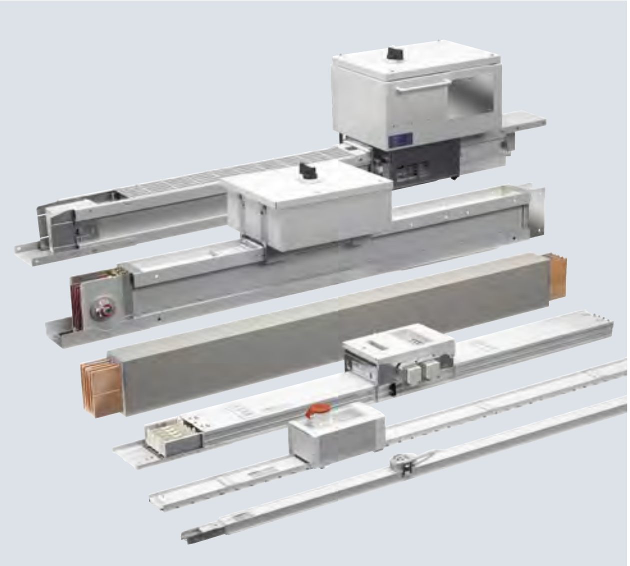

Fig. 4/18: **Busbar trunking system**

Power transmission

Busbar without tap-off points are used for power transmission. They are available in standard lengths and custom lengths. Besides the standard lengths, the customer can also choose a specific length from various length ranges to suit individual constructive requirements.

Upwards of a rated current of approximately 1,600 A, busbars have a significant advantage over cables and wires in the material and installation prices as well as in the costs for additional material, such as cable terminations or for wall bushings. Both these costs and the time benefits during installation increase with the rising rated current.

Variable power distribution

This means that with the busbar trunking system, electricity cannot just be tapped from a permanently fixed point as with a cable installation. Tapping points can be varied and changed as desired within the entire power distribution system. In order to tap electricity, you just have connect a tap box to the busbar system at the tapping point. This way a variable distribution system is created for linear and/or area-wide, distributed power supply. Tap-off points are

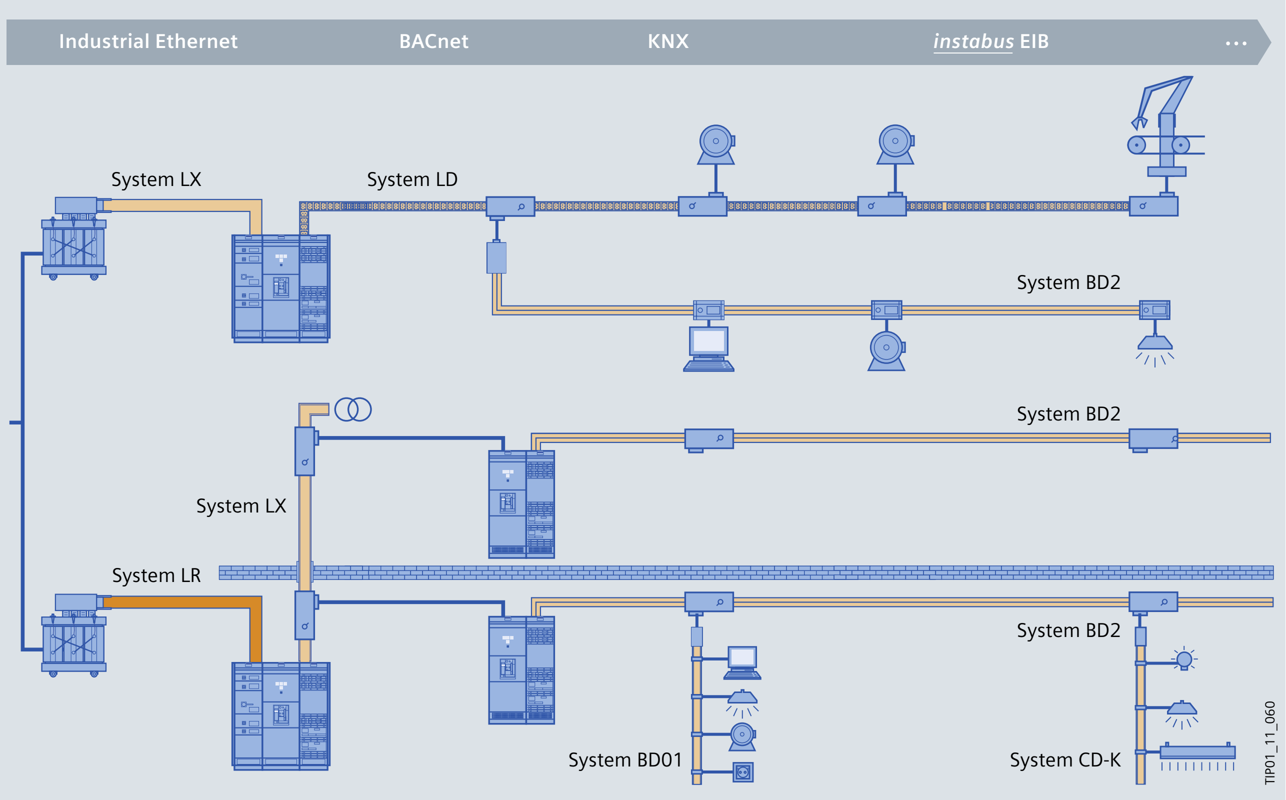

Fig. 4/19: **Busbar trunking systems for different requirements and loads**

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provided on either or just one side on the straight tap boxes. For each busbar trunking system, a wide range of tap boxes is available for the connection of equipment and electricity supply. Communication and measuring options are also feasible.

4.6.3 “Power bar” and 19-inch withdrawable PDU

Power bars and PDUs in 19-inch format can be used for the supply of ICT components. The “power bars” can be fastened at many places in the rack using screwed joints. The space at the side of the 19-inch withdrawable unit space can also be utilized here.

The 19-inch withdrawable PDUs are fastened between the slide-in spars. This means they take up the space of servers and ICT equipment in the rack.

Both rack distribution outfits allow connections inside the rack to be made and released quickly and safely using capacity-true plug connectors. Other possible additional features of these PDUs that can be obtained are:
- Disconnector and protection of the plug connectors
- Measuring options for active and apparent power
- Network interfacing for data transmission

Sensors monitoring the ambient rack conditions, such as temperature and air humidity, and the option of remote switching the current terminals enable operator control features of these rack-oriented PDUs to be expanded.

4.7 Low-voltage Protective and Switching Devices

The safety of man and machine becomes ever more important as processes become increasingly more complex. The protective and switching devices made by Siemens help create optimal prerequisites for full plant protection and thus for safe and reliable operation in a modern power distribution system. Data centres place the strictest requirements on electric power supply. The call for more efficiency is accompanied by a demand for optimal safety and fewer downtimes. This means that only optimally matched components and products from a single supplier complying with a guaranteed uniform quality standard based on national and international standards and regulations can ensure an adequately high degree of safety. They bring about trouble-free operation over many years on a commercial basis thanks to the high degree of reliability and availability of the individual components and hence of the whole system.

Siemens meets the data centre requirements with a wide range of protective and switching devices. High quality and technological benefits coming from these power distribution components result in savings of electricity and maintenance costs.

4.7.1 Air circuit-breakers

3WL air circuit-breakers (Fig. 4/20) are used as feed-in, distribution, tie and feeder breakers in electrical installations. They serve to switch and protect generators, transformers, busbars, cables, distribution boards, motors and capacitors. Advantages of 3WL:
- Easy planning, mounting and retrofitting thanks to a modular design in just three sizes, few components and a uniform set of accessories
- Integrated communication concept for PROFIBUS and Modbus
- Four short-circuit switching capacity classes for all applications
- Excellent reliability and service life
- Effective diagnostics management; measured values provide the basis for efficient load management for creating power demand profiles and cost allocation to cost centres

4.7.2 Moulded-case circuit-breakers

3VL moulded-case circuit-breakers (Fig. 4/21) are used as incoming/outgoing feeders in low-voltage switchboards. In addition, they are used as switching and protective devices for motors, transformers and capacitors and as line units with the capability to stop and disconnect in combination with lockable rotary operating mechanisms and terminal covers. Advantages of 3VL:

- Easy planning, mounting and retrofitting thanks to modular design, few components and a uniform set of accessories
- Fully communication-capable via PROFIBUS DP and Modbus
- Broad product range from 16 A to 1,600 A
- Three switching capacity classes
- Low-price solution that satisfies all customer requirements
- Customer-specific solutions available ex works

Fig. 4/20: **3WL air circuit-breakers**

4.7.3 Switch-disconnectors with fuses

The pluggable 3NJ62 switch-disconnectors with fuses are fitted wherever as many cable paths as possible need to be accommodated in the most confined of spaces for power distribution in low-voltage switchboards (Fig. 4/22). Advantages of 3WL:

- Easy planning, mounting and retrofitting
- Type-tested in accordance with IEC 60947-3 (VDE 0660-107)
- Conversion, retrofitting and hot swapping without disconnecting the switchgear
- Developed for switchgear in plug-in design
- De-energized (off-circuit) fuse change
- No maintenance
- High level of personal protection
- Operating handle only lockable in OFF position
- Unambiguous switch position display

Fig. 4/21: **3VL moulded-case circuit-breakers**

4.7.4 Low-voltage circuit-protection systems

Siemens SENTRON low-voltage circuit-protection systems comprise fuse systems and protective switches that cut off the current in the event of a short circuit, and protect against hazardous shock currents in case of direct or indirect contact with live parts (Fig. 4/23).

Fig. 4/22: **3NJ62 switch-disconnectors with inserted fuses**

Fig. 4/23: **Switch strip with components from the SENTRON device range**

4.8 Power Management System

The focus of a power management system is on the demand for improved transparency of energy consumption and energy quality in data centres as well as on ensuring the availability of power distribution. Holistic transparency is the basis for optimizing energy costs and consumption. The information obtained through this transparency provides a realistic basis for cost centre allocations as well as for measures to improve the energy efficiency. In addition, it documents the savings achieved.

Functions of the power management system

- Analysis of the energy data / energy flows with specific load curve diagrams
- Visualisation of the interdependencies
- Detection of savings potentials, assessed minimum and maximum values
- Energy measurements for accounting purposes (internal cost centre allocation, external billing)
- Benchmarking, internal (rack-line / building part) or external (property/installations with comparable use based on obtained measured values)
- Visualisation of the power supply with switching states and energy flows
- Preparation of decisions, e.g. regarding power supply extensions
- Verifiable efficiency improvements
- Targeted troubleshooting from fast, detailed information about events and faults that occur in the power distribution system inside the server room / building
- Fault and event messages (e.g. switching sequences) are logged with a date and time stamp, so that downtimes can be documented and fault processes traced and analysed later using the data recorded
- Compliance with purchasing contracts via the selective control of consuming devices
- Automatic notification of the service personnel

Levels of the power management system

Power management is the special energy view on a data centre or a data centre property ranging from the energy import and distribution through to the power consumers themselves. It comprises the following levels:

- Energy value acquisition using SENTRON/PAC multi-function measuring instruments
- Processing of the measurement data
- Monitoring including visualisation, archiving, report and messaging

Data acquisition systems and measuring instruments can be directly connected to the server with the power management software, e. g. "powermanager" from Siemens, via Modbus TCP. The software then handles the actual recording, visualisation and logging of the acquired values.

A SIMATIC S7 Controller allows a comparable network for industrial bus systems such as PROFINET or PROFIBUS-DP to be built up. PROFIBUS expansion modules can be used for the direct integration of measuring instruments as well as for the 7KM PAC3200, for example. In both cases, a 7KM PAC4200 measuring instrument can serve as gateway to a subordinate Modbus RTU network linked either via Modbus TCP or via PROFIBUS-DP using PROFIBUS expansion modules (Fig. 4/24).

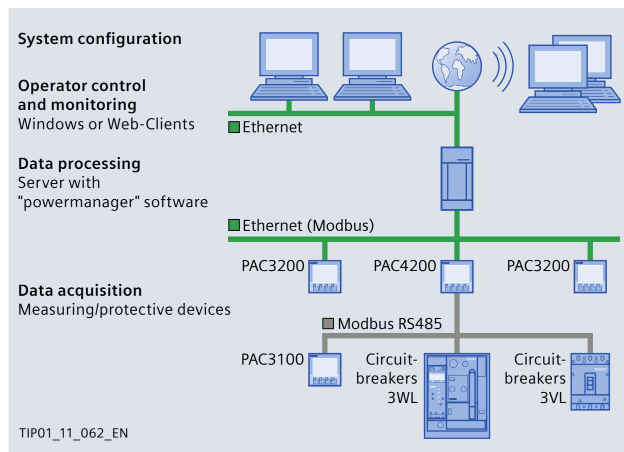

Fig. 4/24: **Structure of a power management system**

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Measurements

The basis of each power management system are the measured values and data from the field level in which the energy in consumed. To prepare the ground for ISO 50001 and for budgeting, those measuring instruments and evaluations tools must be considered that utilize the communication options of switching devices at the field level.

Measuring instruments (multi-function instruments, electricity meters, motor management) can produce calculated data (phase displacement, work, power) in addition to current and voltage readings (see Fig. 4/25).

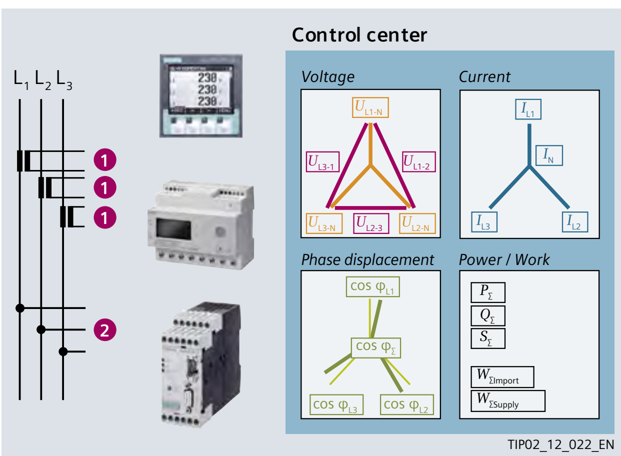

Fig. 4/25: **Measurement procedures**

❶ Current transformers convert/transform current measurements into standard values (1 A or 5 A), as the currents typically used in low-voltage distribution (up to 6,300 A) cannot be processed directly.

❷ The voltage tap directly records the voltages applied/ measured.

Multi-function measuring instruments

The 7KM PAC3200 multi-function instrument (Fig. 4/26) is a ready-to-fit instrument for power distribution systems and control cabinets. It acquires current, voltage, power factor as well as energy and power values precisely and reliably for branch circuits or individual consumers. In addition, it is equipped with an Ethernet interface as standard (with Modbus TCP) and optionally with PROFIBUS DP or Modbus RTU. The free of charge "powerconfig" software is available for configuration, which simplifies setting a number of measuring devices at a time.

- Basis for accurate cost allocation owing to high measurement precision
- Wide range of functions, therefore only one device version required for different measurement tasks
- Easy handling thanks to intuitive user prompting with multi-language plain-text displays
- Rapid mounting owing to latching bracket
- Mounting without tools also possible
- Easy integration into every power management system or automation system thanks to a variety of communication options
- Comprehensive recording of consumption via 10 energy meters

Fig. 4/26: **7KM PAC3200 multi-function measurement instrument**

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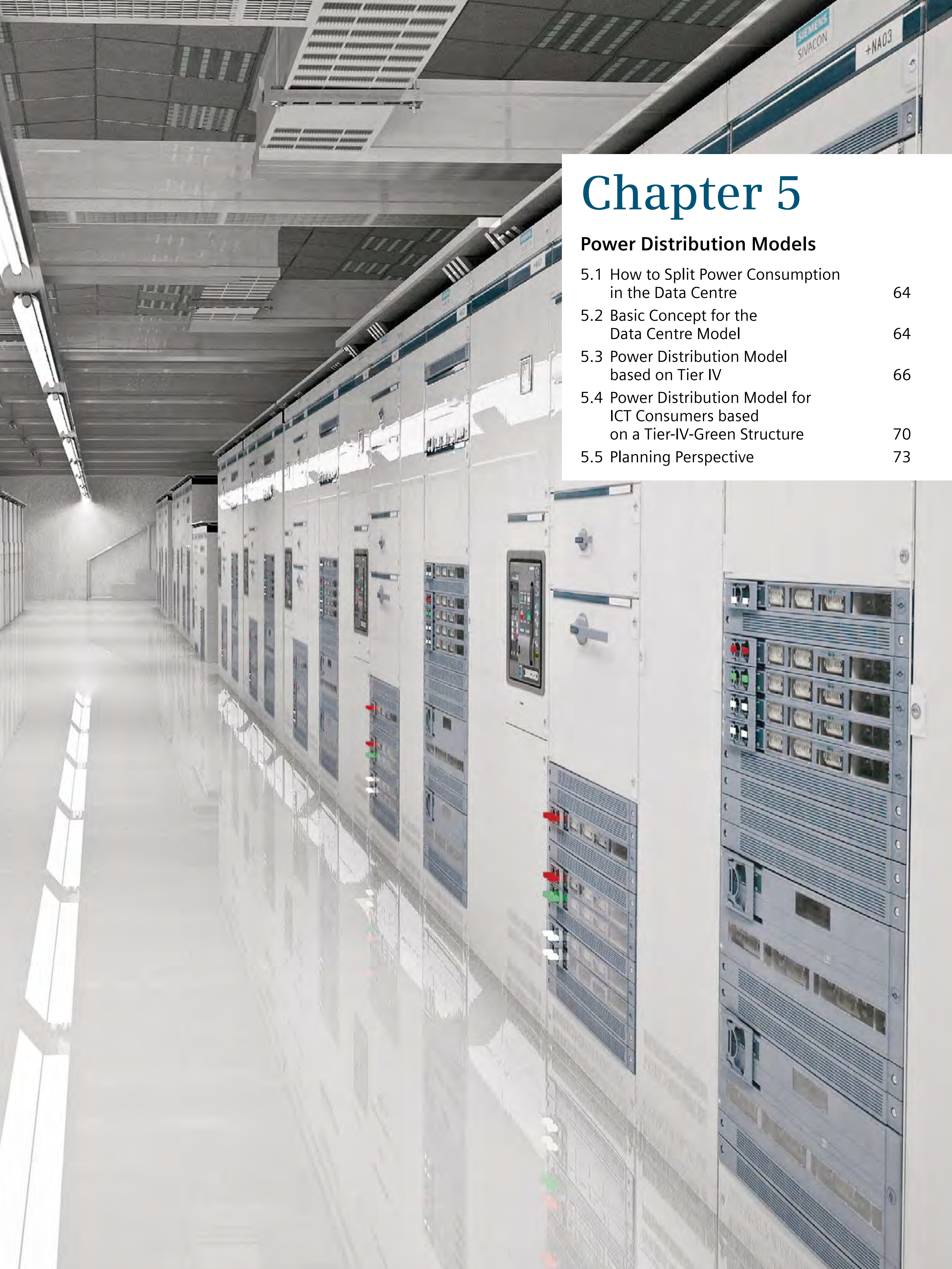

Chapter 5

Power Distribution Models

5 Power Distribution Models

The components of electric power distribution will be discussed below under the aspect of Totally Integrated Power and combined as an example of a system solution. Totally Integrated Power offers everything that can be expected from a future-oriented power distribution system: openness, integration, efficient engineering tools, manifold options for communication and a substantial improvement in efficiency. Data centre users benefit from high-level electricity supply in both quality and quantity at favourable conditions.

5.1 How to Split Power Consumption in the Data Centre

To obtain a rough data centre model for the development of a power distribution concept, the relations of the power requirements of the main components are firstly set up. A Power-Usage-Efficiency (PUE) value of 1.5 serves as a basic assumption. This means that two thirds of the electrical energy are used to supply servers and other ICT components, whereas the other third is employed to supply the data centre infrastructure.

$$\text{PUE} = \frac{\text{Total power consumption}}{\text{Power consumption of the ICT components}}$$

The split up of power consumption with regard to the essential server components and the power supply and air conditioning infrastructure components is entered into this formula. Specialist publications often distinguish between averaged values derived from measurement data (annual mean, monthly mean, week and day values) and theoretically established values from the summation of characteristic data for the power demand of equipment and components. These inconsistent PUE assessments always call for a definition of the framework parameters.

Furthermore, the requirements placed on availability and performance of the individual components must also be considered. The more compact servers are designed, the more problematic becomes the issue of heat dissipation in order to avoid an overheating of ICT components. On top of that, guidelines like ASHRAE [27] declare wider temperature ranges as admissible for data centre operation. Since these guidelines mostly consider temperature means, it must be kept in mind that a slight increase of the mean temperature in the room may well result in a significant temperature rise on the chip. A short power failure may at the same time result in a malfunction of the cooling system for one or two minutes and only a slow rise again of the cooling power. All in all, the permissible operating temperatures on the individual chips may be exceeded under certain circumstances. As such, the power supply for cooling should be implemented as a VFI-classified UPS system (see section 4.4.2).

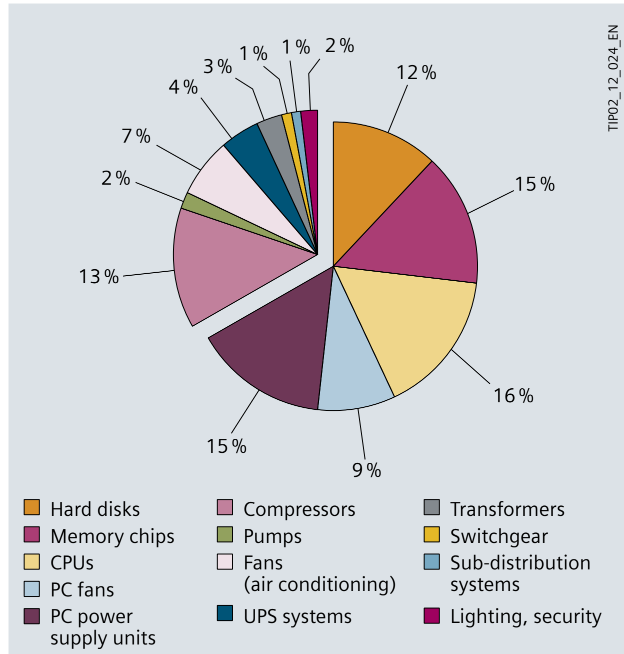

Fig. 5/1: **Power distribution of a data centre as percentage with a PUE value of ca. 1.5 (ratio of 2:1 for ICT power demand and infrastructure power demand)**

5.2 Basic Concept for the Data Centre Model

The number of racks is often drawn upon as the basis for the data centre size. To determine the power demand of the data centre, other basic model data to be defined are the size of the available space for ICT components (see [5]) and the power demand per rack. Current publications specify widely varying values from 1.5 to over 40 kW as power demand per rack.

An important criterion for planning electric power distribution is the degree of availability which is required and the corresponding redundancy concept or a specification of the Tier topology for electric power supply and cooling based on the data centre model of the Uptime Institute [20].

With regard to the fictitious data centre models described here, the following assumptions apply to the ICT area, the power demand and availability requirements:
• 4 computer rooms
• 40 racks (42 height units) in 4 rows per room
• 15 kW power demand per rack, split between blade servers and slimline servers as well as network switches

- The space requirements for the computer rooms are calculated from an average power per unit area of approximately 2 kW / m². This is because a factor of 5 to 10 must be provided for the cold and hot aisles as well as distribution boards and air conditioning facilities in relation to a footprint of 1 m² per rack
- The area surface ratio of the total data centre to computer room area must factor in size relationship and availability requirements. For an initial estimate, a tier-dependent factor on the basis of the Tier classification of the Uptime-Institute may be assumed as space requirements for the infrastructure:
  - Tier II (n+1) relative to Tier I (n)
    Factor 1.2 (for n = 5) to factor 2 (for n = 1)
  - Tier III (n+1) relative to Tier II (n+1)
    Factor 1.25
  - Tier IV (n+n) relative to Tier I (n)
    Factor 2
  - Tier IV ((n+1)+(n+1)) relative to Tier I (n)
    Factor 2.4 (for n = 5) to 4 (for n = 1)

Starting from a typical relation for the space requirements of 2:1 for computer rooms to infrastructure area with an (n+1) redundancy, the space requirement value doubles for the intended Tier IV structure with (n+1)+(n+1). As a result, the infrastructure takes up the same space as the "white space".

For the ICT components, this means a total power demand of 2,400 kW and, assuming a PUE value of 1.5, a power demand for the data centre of 3,600 kW. Each of the four computer rooms is chosen in the 300 m² size, so that a total area of about 2,400 m² will have to be provided for a data centre designed for Tier IV with (n+1)+(n+1). Fig. 5/2 shows the schematic plan view for a ground-level data centre.

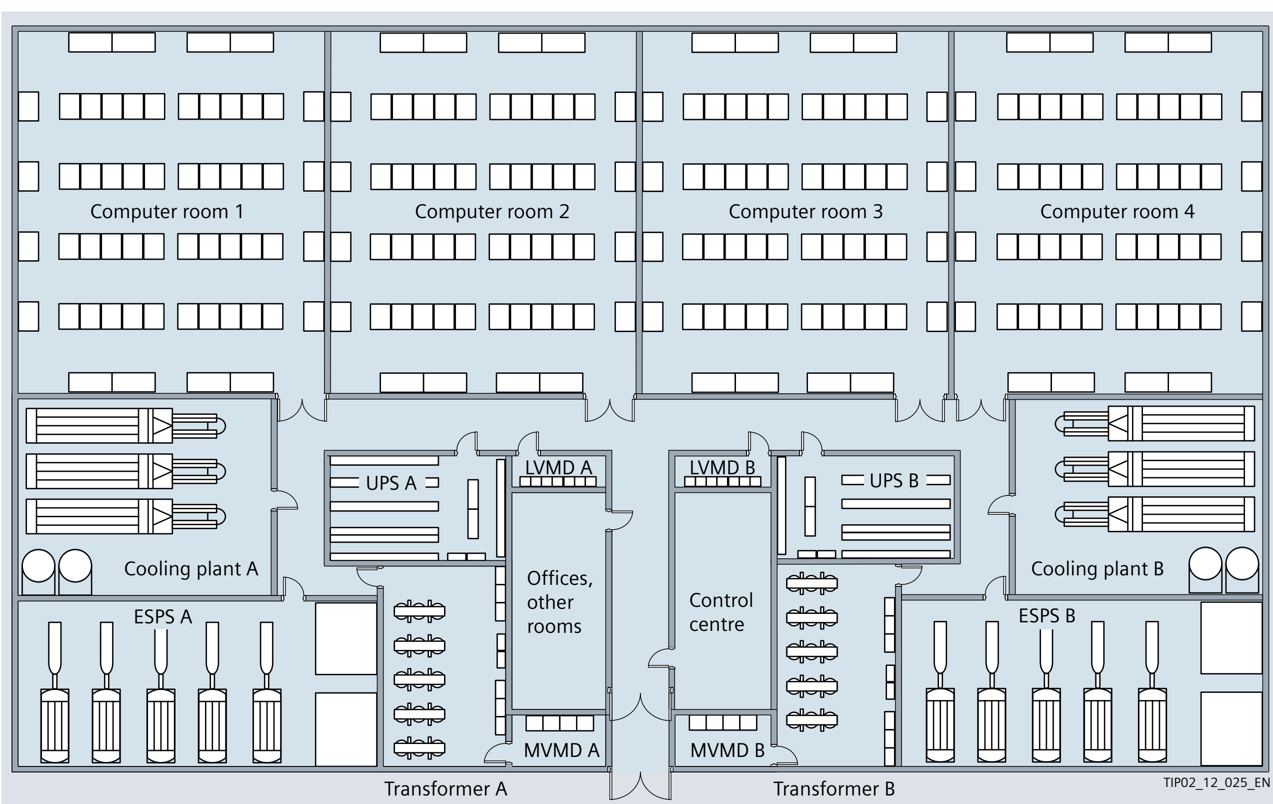

Fig. 5/2: **Schematic plan view of the data centre model**

5

5.3 Power Distribution Model based on Tier IV

The Tier IV structure gives rise to a subdivision of the two supply busbars which, in turn, supply the computer rooms and the technical installations in the building (TIB). Fig. 5/3 illustrates the supply structure. It can be assumed here that the computers in the control centre are only supplied from one power supply unit. But usually, it is the safety-relevant parts of the control centre, the fire monitoring equipment and other safety equipment which are redundantly designed. They should be connected through two supply paths, if possible. Tab. 5/1 lists the main components for the electric power supply infrastructure in this model.

For the calculations on IT A and B busbars of relevance for data centre operation, it suffices to perform this calculation for one busbar only, e.g. for busbar A. The SIMARIS design

2	Medium-voltage switchgear
10	GEAFOL cast-resin transformers (1,250 kVA)
10	ESPS with diesel generator (1,200 kW)
6	Static UPS systems (1,200 kVA) with battery for the computer rooms
4	Static UPS systems (200 kVA) with battery for critical infrastructure
2	Low-voltage switchgear for the computer rooms
2	Low-voltage switchgear for critical infrastructure
2	Low-voltage switchgear for normal power supply (NPS)
2	Low-voltage switchgear for safety power supply (SPS)
2	Busbar trunking systems between UPS and computer rooms
32	Busbar trunking systems for power connection of racks

Tab. 5/1: **Itemization of the data centre model acc. to main components**

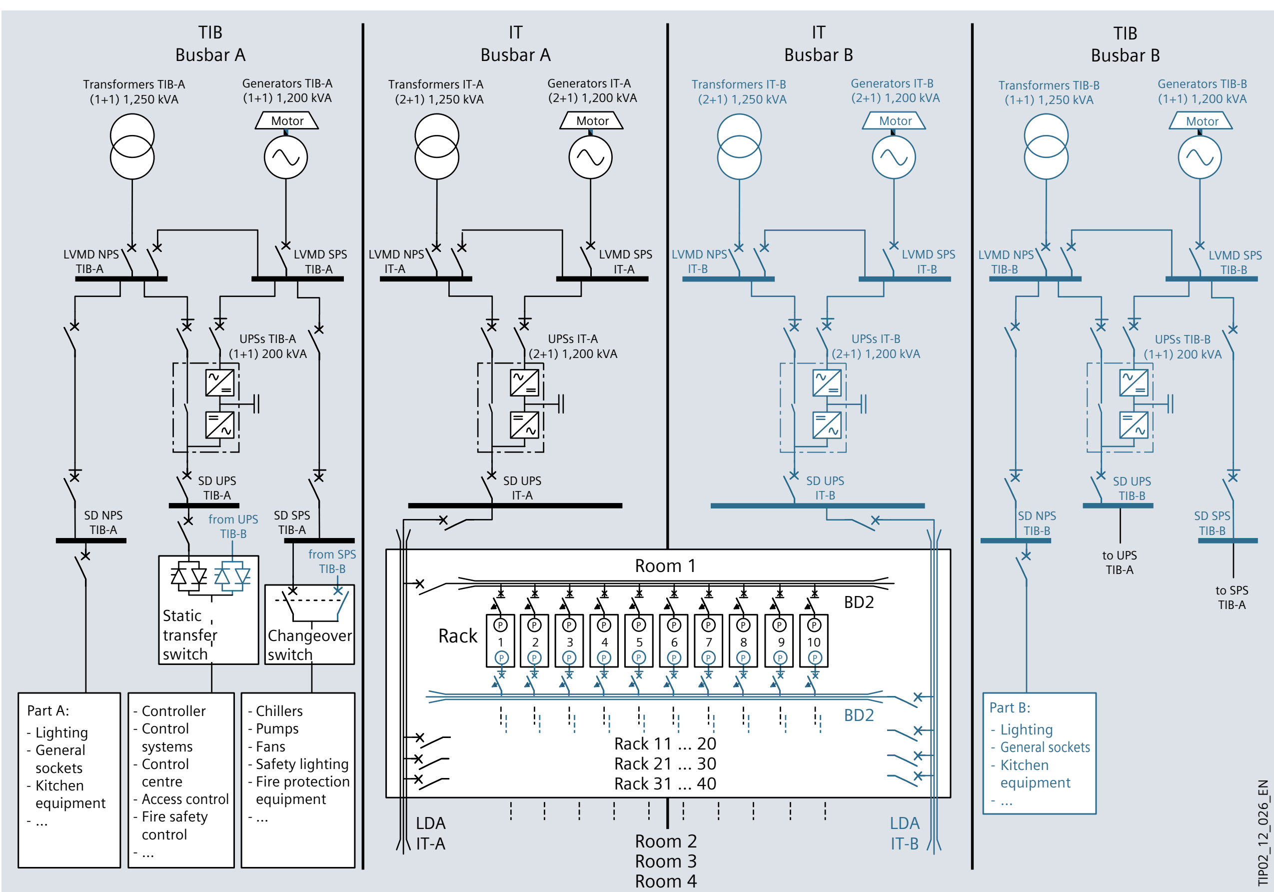

Fig. 5/3: **Pattern of the electric power supply structure for a Tier-IV data centre and (n+1)+(n+1) system redundancy** planning tool maps one of the two IT busbars and analyses it. The four busbar lines which represent one row of racks each in the room and the rack connections within the busbar lines will have different circuit-breakers and fuse switch disconnectors to reveal behavioural aspects. The rack connections are mapped in SIMARIS design and can be loaded in a variety of ways. In SIMARIS design, the 8DJH medium-voltage switchgear feeds the cable to the GEAFOL transformers for the IT busbar under consideration. Fig. 5/4 shows the single-line diagram for a configuration example. The diagram considers the critical case of the ICT components being power-supplied from one IT busbar only. In normal operation, the load is split between the redundant power supply units.

The "professional" version of the SIMARIS tool makes it possible to transfer results attained in SIMARIS design directly to SIMARIS project and exploit them. This helps to plan switchgear cabinets from end-to-end and rearrange them as desired. The results in form of diagrams, front views, descriptions and technical specifications can be exported and further utilized in the planning process.

Typically, the project documentation comes up with both general and product-specific data. The drawings can be output as a PDF file or CAD file for further utilization. For further use, e.g. in planning documents, various views and single-line diagrams can be selected. The technical specifications in RTF or GAEB 90 format furnish the planner with an accurate and detailed specification of the products used.

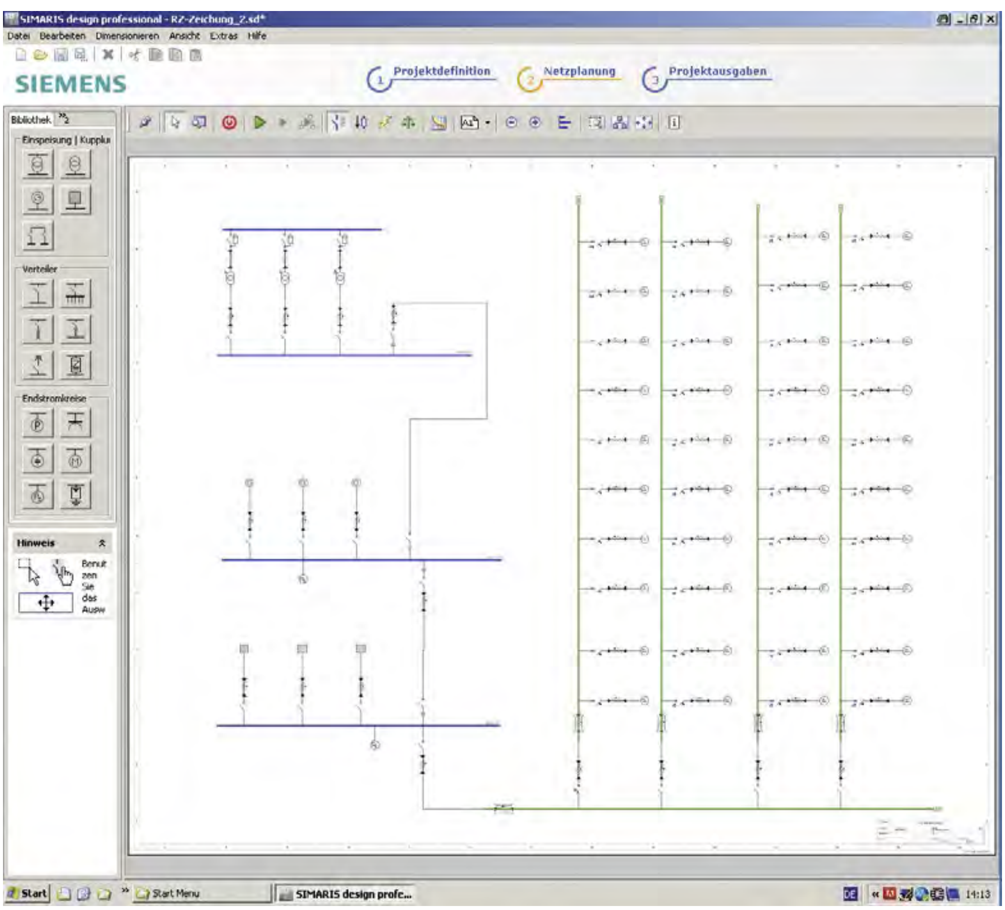

Fig. 5/4: **Power system planning for a data centre concept in SIMARIS design**

Tab. 5/2 shows the network parameters and Tab. 5/3 to Tab. 5/7 contain some important technical data about the main components of this example from the project documentation for one of the four ICT rooms.

General	
Standards	IEC
Altitude of installation	< 1,000 m
Medium voltage	
Nominal voltage	10.0 kV
Ambient temperature	40.0 °C
Max./Min. Short-circuit power	100.0 / 50.0 MVA
Neutral-point connection	Low-resistant
Conductor temperature MV cable	
At $I_{k\ max}$ When disconnecting At voltage drop	20.0 °C 80.0 °C 55.0 °C
Low voltage	
Nominal voltage	400.0 V
Power supply system/ connection to earth	TN-S
Line frequency	50.0 Hz
Permissible touch voltage	50 V
Ambient equipment temperature	45.0 °C
Voltage factor c_{max}	1.1
Voltage factor c_{max}	0.95
Conductor temperature of LV cable	
At $I_{k\ max}$ When disconnecting At voltage drop	20.0 °C 80.0 °C 55.0 °C

Tab. 5/2: **Power system parameters for electric power supply of the ICT components of an IT busbar in the data centre for the project example**

GEAFOL transformers

Apparent power	1,250 kVA
Rated voltage HV [1)]	10 kV
Tapping range:	± 2 × 2.5 %
Rated voltage LV [2)]	0.4 kV
Vector group	Dyn5
Short-circuit voltage	6 %
losses	reduced
No-load loss P_0	2.4 kW
Short-circuit loss $P_{k\ 120}$	11 kW
Loss at rated transformer power	9.6 kW
Sound power level	75 dB
Fan added	No
Outer dimensions Length Width Height	 1,720 mm 990 mm 1,605 mm
Total weight	2,600 kg
Position of HV and LV terminals	at the top
Order number	4GB61 44-3DY00-1AA0-ZV...

[1)] HV: High-voltage side [2)] LV: Low-voltage side

Tab. 5/3: **Technical data of GEAFOL transformers for electric power supply of an IT busbar in the data centre for the project example**

MVMD 1.1

Switchgear type	8DJH
Rated voltage	12 kV
Operating voltage	10 kV
Rated frequency	50 Hz
Rated short-time current	16/1 kAs-1
Rated operating current	630 A
Accidental arc qualification	Yes
Pressure absorber	No
Capac. voltage testing system	HR
Communication	No
Total weight	2,010 kg
Outer dimensions Total width Height Depth	 3,250 mm 2,000 mm 775 mm

Tab. 5/4: **Technical data of a medium-voltage main distribution system (MVMD) for electric power supply of an IT busbar in the data centre for the project example**

5

LVMD 1.1A

Distribution system	SIVACON S8
Switchgear type	Single front
Operating voltage U_e	400 V AC
Ambient temperature	35 °C
Degree of protection	IP40
Air vents	Yes
Busbar system	L1-L3, PE, N
Main busbar position	rear, top
Protection against accidental arcing	Busbar insulation
Rated current $I_{e\ oben}$	1,824 A
Short-time current $I_{cw\ top}$	65 kAs^{-1}
Cross section $L_{1...3\ top}$	1 × 4 × 20 × 10
Total weight	1,336 kg
Outer dimensions Height Width Installation depth	 2,200 mm 2,400 mm 600 mm
Max. power loss to be dissipated P_v Power loss 80 % Power loss 100 %	 2,960 W 4,560 W

Tab. 5/5: **Technical data of the low-voltage main distribution (LVMD) system for electric power supply of an IT busbar in the data centre for the project example**

LVTS 1.1C4

Busbar trunking system	LDA
Rated current	1,100 A
Rated operating voltage	1,000 V
Rated frequency	50...60 Hz
Degree of protection	IP34
Busbar configuration	L3 – N – PE
System configuration	TN-S
Mounting type	horizontal on edge
Fire load busbar trunking units	4.00 kWhm^{-1}
Total weight	933 kg
Total length	50 m
Outer busbar trunking unit dimensions Width Height	 180 mm 180 mm

Tab. 5/6: **Technical data of the busbar trunking system LDA (low-voltage trunking system LVTS) for electric power supply of an IT busbar in the data centre for the project example**

LVTS 1.1C.4.1.1.1

Busbar trunking system	BD2
Rated current	160 A
Rated operating voltage	690 V
Rated frequency	50...60 Hz
Degree of protection	IP52, IP54, IP55
Busbar configuration	L_3 – $N_{0.5}$ – PE(N)
Power supply system/connection to earth	TN-S
Mounting type	horizontal on edge
Fire load busbar trunking units	1.00 kWhm^{-1}
Total weight	191 kg
Total length	30 m
Outer busbar trunking unit dimensions Width Height	 167 mm 68 mm

Tab. 5/7: **Technical data of the busbar trunking system BD2 (low-voltage trunking system LVTS) for electric power supply of an IT busbar in the data centre for the project example**

5

5.4 Power Distribution Model for ICT Consumers based on a Tier-IV-Green Structure

The substantial outlay needed to implement a Tier IV structure with (n+1)+(n+1) redundancy becomes obvious when you compare, for instance, the ICT load with the installed UPS capacity which is required to supply this load via busbars A and B. To assure a maximum power demand of 2,400 kW, UPS systems with a total capacity of 7,200 kVA are used (Tab. 5/1). Hence, the UPS systems on one IT busbar are only 33 % utilized even under full utilisation of the data centre capacities. This is because ICT components can be presumed which tolerate load splitting. Each of the two existing power supply units can immediately take over total supply in case of a fault of the other unit. Of course, you can also use smaller units in the Tier IV model presented in the previous section. As a result, the utilisation of the individual systems is raised.

The first measure for a more efficient configuration of power supply is to transfer the concept of the "swing" generator acc. Fig. 5/3 to the transformers. Since a start-up

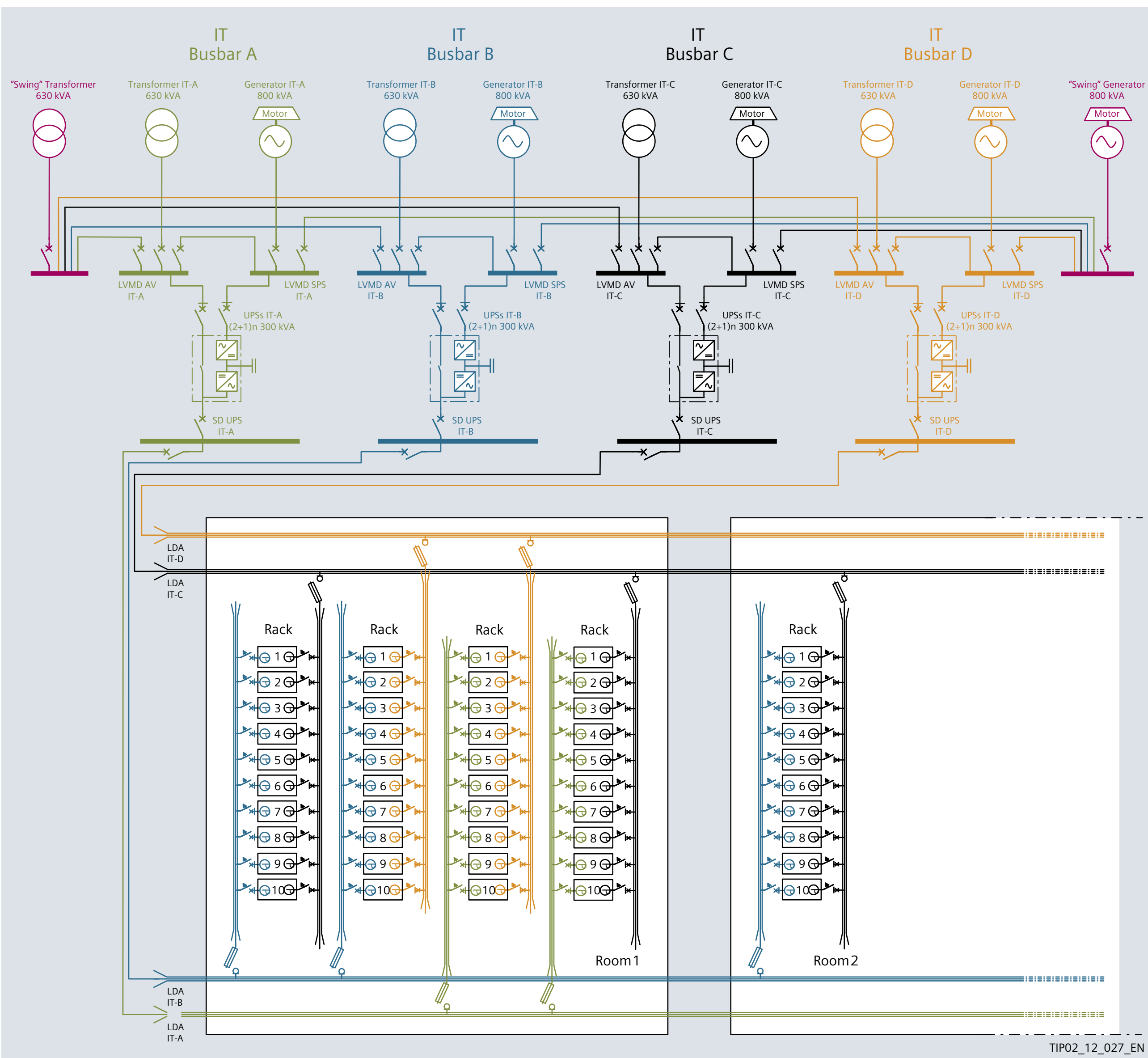

Fig. 5/5: **Pattern of the power supply structure for the computer rooms in a Tier-IV-Green data centre** of the generators is permitted for those consumers backed by UPS systems as well as the SPS consumers, a joint redundancy with a separate supply path is sufficient. The same applies for connecting the "swing" transformer into supply.

When splitting loads to four IT busbars A to D, much smaller components can be used (Fig. 5/5). The Tier-IV-Green in the example requires five transformers of a 630 kVA rating and twelve UPS systems each with a nominal power rating of 300 kVA. The summated UPS total power of 3,600 kVA is equivalent to 1.5 times the maximally required ICT consumer power and amounts to just half the UPS power for the Tier-IV concept in the previous section.

The comparison of Tier-IV-Green with the typical Tier-IV solution is particularly suited for some operation-relevant components like the transformer and the UPS. Even in the planning phase, an estimation can provide some ideas on efficiency under normal operating conditions.

Since power failure plays a subordinate part for day-to-day routine, an efficiency evaluation of transformers and UPS systems under normal operating conditions will suffice. In a scenario featuring a continuous load of 75 % utilisation of electric power supply to ICT components, Tab. 5/8 summarizes some data on equipment and plant sizes for the different Tier concepts of the IT busbars. A 75 % utilisation is realistic, given that servers – even under idling conditions – can have a consumption share of 50 % and more, referred to the nominal power demand under full utilisation [28]. Five loss-reduced transformers with a 630 kVA power rating and a total of twelve UPS systems each with 300 kVA apparent output power are used in order to enable the consumers to be split into four subgroups for the four different supply paths (Fig. 5/5).

In order to demonstrate the effect of a more intense modularisation for the (n+1)+(n+1) structure of the Tier IV model, a variant with n = 6 and corresponding 400-kVA UPS systems and transformers is specified in addition to the variant described in Chapter 5.4. No separate diagram is shown for this variant, only the values are listed in Tab. 5/8.

A theoretical efficiency curve is used to determine operational losses of the UPS systems in all the variants (see Fig. 5/6). Just as above, an active redundancy is assumed here for the power supply units for the servers and other ICT components, meaning the load is split. No-load losses must be factored in for the "swing" transformer in the Tier-IV-Green concept.

The operational losses of generators do not need to be considered, since their period of use in case of fault and during regular tests ought to be short compared to the continuous operation of the data centre. Therefore an investment into many small units would not be worthwhile for the generators, except in instances where the operator wants to use the generators to balance peak loads. This requires project-specific energy management, necessitating automation of the generator operating mode. If you want to integrate the storage batteries of the UPS systems into this kind of concept, you should keep in mind that additional charging and discharging cycles rapidly age the storage batteries. Furthermore, there would have to be the scope for the generators to be connected after a specified time to supply the UPS input and reload the storage batteries.

Continuous utilisation throughout the whole year is idealized for data centre operation and related energy losses in Tab. 5/8 Loss-reduced variants with 6 % short-circuit voltage

	Tier IV (n+1) + (n+1)	Tier IV (n+1) + (n+1)	Tier-IV-Green
Redundancy	n = 2	n = 6	m = 3, n = 2
Rated power of transformers	6 × 1,250 kVA	14 × 400 kVA	5 × 630 kVA
Transformer type	GEAFOL 10/0.4 kV, 6 %, red. losses	GEAFOL 10/0.4 kV, 6 %, red. losses	GEAFOL 10/0.4 kV, 6 %, red. losses
Power splitting	6 × 300 kW	14 × 128.6 kW	4 × 450 kW + 1 × no load
Total annual transformer losses	127,900 kWh	160,200 kWh	182,200 kWh
UPS systems	6 × 1,200 kVA	14 × 400 kVA	12 × 300 kVA
Power splitting	6 × 300 kW	14 × 128.6 kW	12 × 150 kW
UPS efficiency (acc. to Fig. 5/6)	94.4 % (25 % utilisation)	95.2 % (32 % utilisation)	95.7 % (50 % utilisation)
Total annual UPS losses	884,750 kWh	757,000 kWh	678,000 kWh
Losses (Transf. – UPS)	1,012,650 kWh	917,200 kWh	860,200 kWh

Tab. 5/8: **Estimate of power losses of different redundancy structures when operating transformers and UPS systems (1,800 kW power demand – around the clock – corresponding to 75 % utilisation of power supply for the IT busbars in the above described model)**

5

u_{zr} are chosen for the GEAFOL transformers. The transformer losses are calculated in keeping with the data given in [30]. No-load losses are factored in the calculation for the "swing" transformer.

The cost of investment for the Tier-IV-Green solution will be significantly lower than for the two Tier IV solutions. A rough estimate shows that the Tier-IV-Green solution only amounts to about two thirds of the investment to be raised as against the more cost-effective Tier IV variant. Although the UPS costs make the lion's share in that investment as a single cost item, a comparison of the transformer investment costs even shows a 40 % plus benefit for the Tier-IV-Green solution.

When considering the operational losses of the transformers, the first impression is one of Tier-IV-Green seeming more inefficient. Crucial is here the operating point of the transformers in relation to the rated power. Fig. 5/7 compares the power losses of some selected GEAFOL transformers and demonstrates that from the viewpoint of operational efficiency, a transformer with a higher rated power should be chosen for the Tier-IV-Green solution. The load curves are to be considered for the assessment of total costs. To find the total cost optimum, efficiency calculations should be performed which take into account the investment and operating costs.

Just looking at the power losses of a 630-kVA transformer and a 1,250-kVA transformer in Fig. 5/7 makes it clear that approximately 30 % savings could be feasible if larger transformers were used. A simple calculation for data centre operation using five 1,250-kVA transformers instead of the 630-kVA variants in the Tier-IV-Green system brings about a reduction of the total annual power losses to approximately 128,800 kWh – given a 450 kW power demand for the four transformers plus the no-load losses for the "swing" transformer. Thanks to such high saving effects, the additional investment into larger and more efficient transformers will often pay for itself within the first two or three operating years.

In view of the still relatively high power demand of servers, memory disks and other ICT components, a minimum power demand of the ICT components of about 50 % and more is realistic. The vertical dashed line on the left in Fig. 5/7 at 300 kW marks this value for our example with a maximum power value of 600 kW power per server room. The second vertical dashed line at 450 kW corresponds to an assumed utilisation of 75 %. Fig. 5/7 shows that the higher the utilisation of the data centre is assumed to be, the more beneficial in terms of operating losses it becomes to use larger transformers .

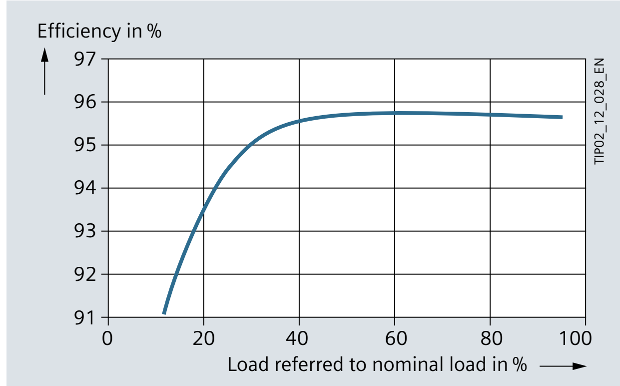

Fig. 5/6: **Example for the load dependency of the UPS efficiency acc. to [29]**

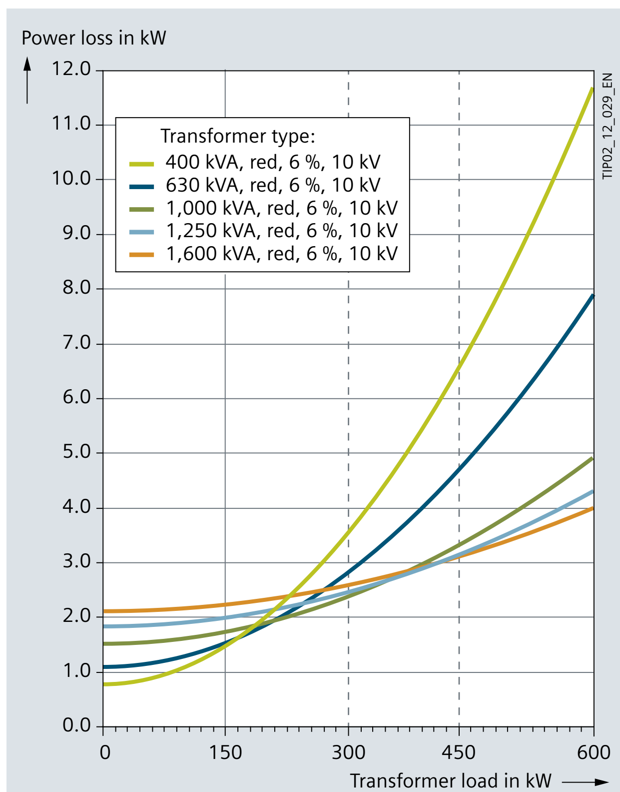

Fig. 5/7: **Power loss comparison of different GEAFOL transformers as a function of the load connected**

Attention!
All efficiency assessments are essentially dependent on the power distribution concept and the framework parameters of utilisation. Added to this are variabilities of contract terms with regard to power purchase, environmental aspects and financing options. You may contact your Siemens TIP expert for detailed evaluations of any specific requirements.

5

The optimisation of electric power distribution for the technical installations in buildings often yields fewer savings only compared to the previously described efficiency evaluations for electric power supply of the ICT components. If a "swing" generator and "swing" transformer is used for that, too, their number is then reduced to three each. The reduction of the necessary cooling power in the data centre through cutting losses in the electric power distribution system is, however, low, considering that about one fifth of 10 % of the total power consumption – i.e. 2 % of that no longer needs to be cooled. Therefore, the UPS systems for the technical building installations remain unchanged and as do the corresponding power variables of generators and transformers.

The rooms for generators, transformers and UPS systems in Fig. 5/2 take up about one half of the space required for the data centre infrastructure. By way of optimisation, these space requirements can be reduced by about 25 %, as shown in Fig. 5/8.

5.5 Planning Perspective

The above sizing of the infrastructure in the data centre model is adapted to the prevailing circumstances. Owing to the ever decreasing size of components coupled with increasing ICT performance, two development scenarios can be imagined. On the one hand, increasing chip performance (see Fig. 5/9) might result in lower electricity consumption of the ICT components and hence to an oversizing of the infrastructure. But on the other hand, the increasing compactness of the ICT component might also lead to a more intensified usage of the available space. Linked to this are a growing electricity demand and a higher thermal density in the ICT rooms.

Since the demand for IT power seems to grow incessantly due to the Internet, data traffic and telecommunication, it might well be expected that data centre operators want to utilize the existing space for a most comprehensive range of IT services. Thus, the area-related electricity demand will grow and so will the cooling demand due to the greater amount of heat being dissipated. Increasing compactness results in the generation of waste heat concentrated in a small space. This heat concentration may easily result in

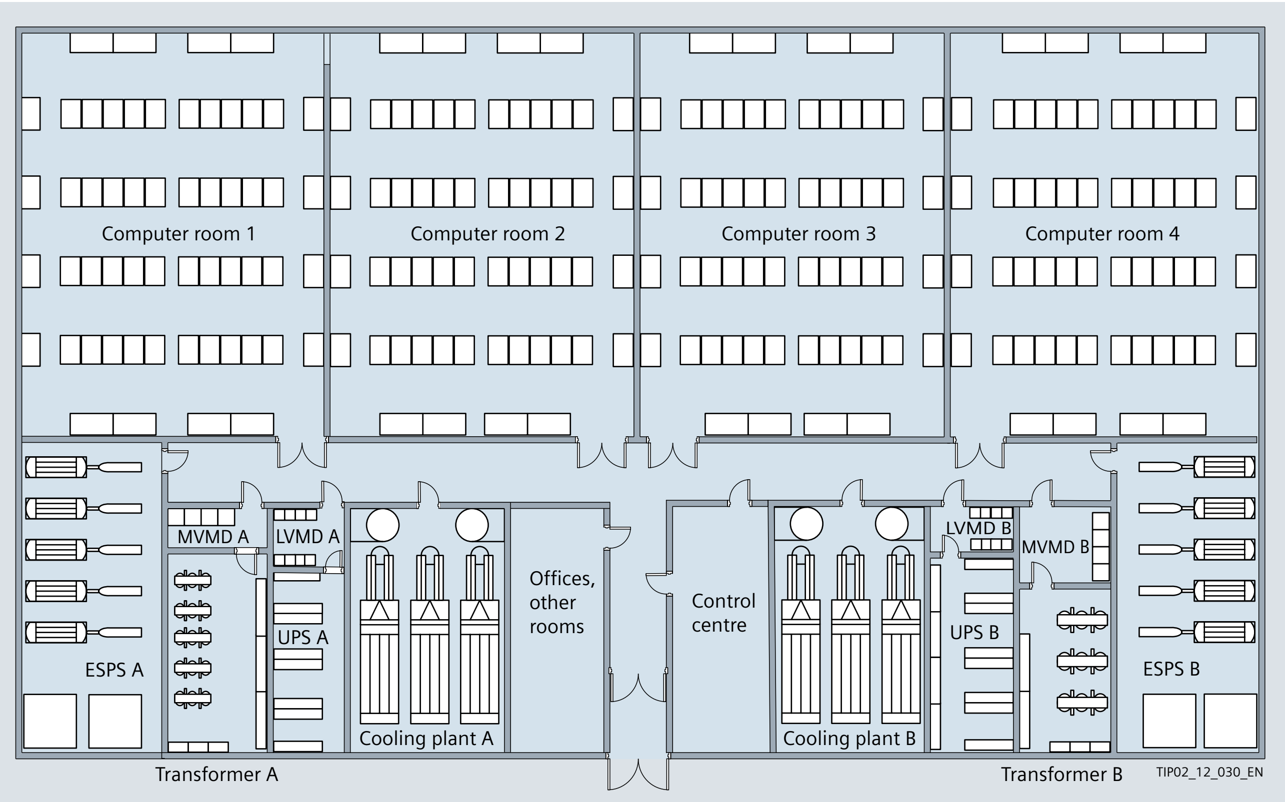

Fig. 5/8: **Room layout for a data centre model acc. to the Tier-IV-Green concept** overheating of the chips and IT components should the coolers not work satisfactorily.

For planning, this creates the problem of differing development cycles. While the technical development of servers and routers almost cries out for a replacement of technically outdated equipment after 4 to 5 years, the electric power distribution components are designed for a service life of 20 to 40 years. And for reasons of profitability, the data centre operators don't want to be forced to replace them much earlier. Therefore, planning must involve that appropriate service and spare parts management services be ensured from the supplier.

The continuing increase in energetic power density of IT hardware in conjunction with a disproportionately rising technical performance capability can result in a reduction of the space needed for the IT hardware. This brings about an ever increasing demand of electric power on the one hand and an ever more concentrated waste heat on the other. As this could affect power supply of the coolers required here, fans and pumps may possibly have to be supplied from UPS units. Insufficient cooling caused by a power outage of 10 to 20 seconds can, even at this stage, give rise to damage owing to overheating. This means that a long-term-based infrastructure concept for a data centre should always correlate with the ICT hardware plans.

An alternative for defusing the issue could lie in modular data centre concepts as they are offered by Siemens. In this context, modularity is not merely limited to single parts, but just as with a construction kit, sub-modules and complete modules may be used to build or expand a data centre. This is to be considered in the planning of electric power distribution. The essential prerequisite for the use of modular data centre concepts is the compatibility of the different development stages, such as can be offered by responsibility-conscious suppliers for appropriate periods of usage.

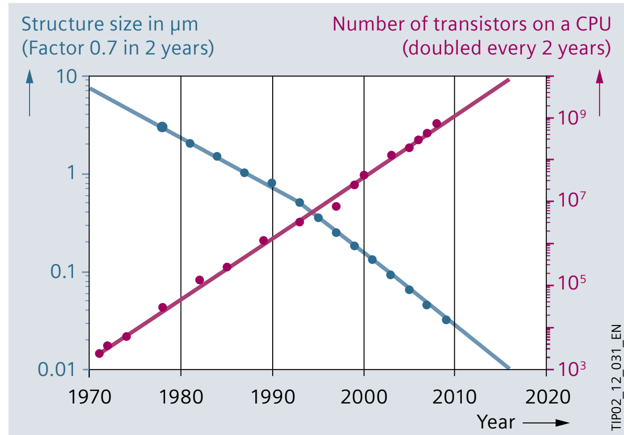

Fig. 5/9: **Development of the size of transistors and the number of transistors per CPU [31]**

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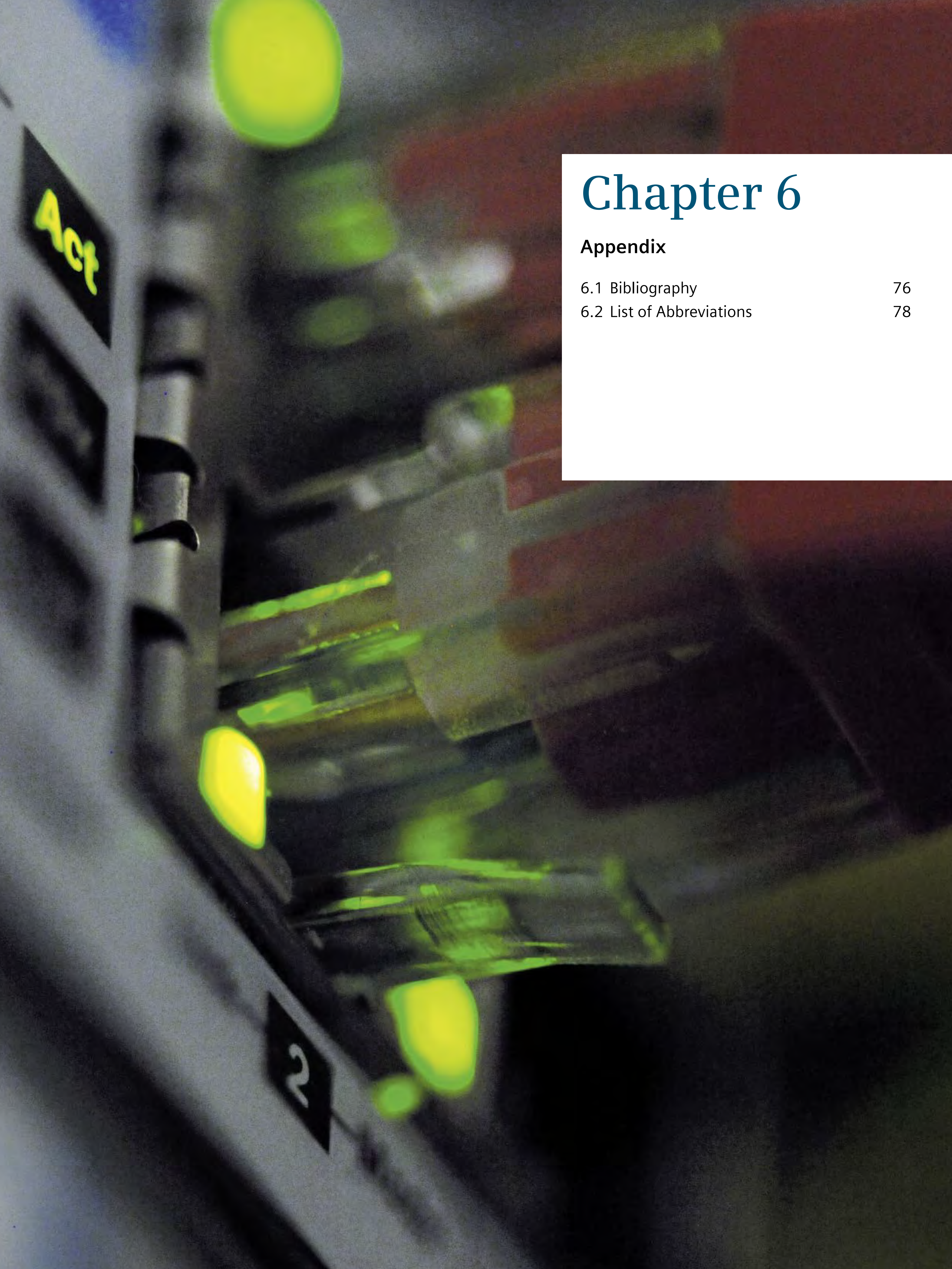

Chapter 6

Appendix

6 Appendix

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6.2 List of Abbreviations

A

AC	Alternating current
AEC	Availability Environment Classification
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AVC	Availability class

B

BITKOM	Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e.V. (German Federal Association of Information Business and Telecommunication and New Media, registered association)
BSI	Bundesamt für Sicherheit in der Informationstechnik (German Federal Office for Information Security)

C

CEP	Central earthing point
CPU	Central processing unit

D

DaC	Data Centre
DC	Direct current
DIN	Deutsches Institut für Normung (German Standardisation Institute)
DP	Data processing
DSO	Distribution system operator

E

EltBauVO	Verordnung über den Bau von Betriebsräumen fur elektrische Anlagen (German Ordinance on the construction of electrical operating areas)
EN	European standard
EnEV	Energieeinsparverordnung (Energy Saving Ordinance; Germany)
ESPS	Emergency standby power supply

G

GAEB	Gemeinsamer Ausschuss Elektronik im Bauwesen (Joint Committee for Electronics in the Building Trade in Germany)

H

HRG	Harvard Research Group
HV	High-voltage side (primary voltage)
HV HRC fuse	High-voltage high-rupturing capacity fuse

I

ICT	Information and communication technology
IEC	International Engineering Consortium
IP	Ingress protection
ISO	International Organization for Standardization
IT	Information technology
ITIC	Information Technology Industry Council

L

LBNL	Lawrence Berkeley National Laboratories
LV	Low voltage
LVMD	Low-voltage main distribution

M

MDT	Mean downtime
MTBF	Mean time between failure
MTTR	Mean time to repair
MV	Medium voltage
MVMD	Medium-voltage main distribution

N

NPS	Normal power supply

O

OLE	Object linking and embedding
OPC	OLE for process control

P

PC	Personal computer
PDU	Power distribution unit
PE	Protective earth conductor
PEN	Combined protective and neutral conductor
PUE	Power Usage Efficiency (Relation between the total power demand and the power demand of ICT components in the data centre)

R

RCD	Residual current protective device
RTF	Rich text format
RTU	Remote terminal unit

S

spof	Single point of failure
SPS	Safety power supply

T

TCP	Transmission control protocol (data transmission)
TIB	Technical installations in buildings
TV	Television

U

UPS	Uninterruptible power supply

V

VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik (German Association for Electrical, Electronic and Information Technologies)
VFD	Voltage and frequency dependent
VFI	Voltage and frequency independent
VI	Voltage independent

Z

ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie (German Electrical and Electronic Manufactures’ Association)

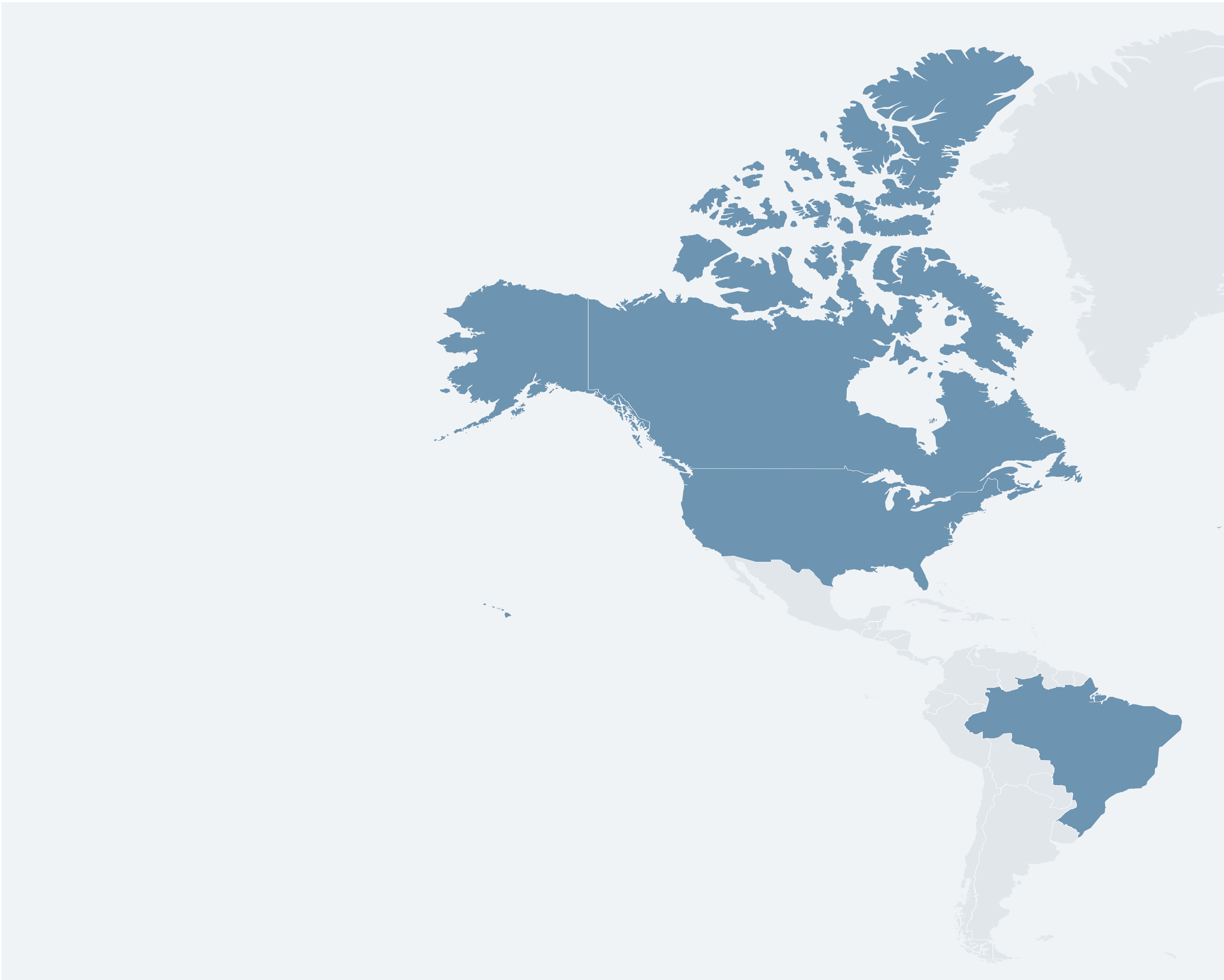

Fig. 6/1: **World-wide support for the planning of power distribution solutions by Siemens TIP**

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