> *Decision is a risk rooted in the courage of being free.*
> *— Paul Tillich*

> *Lectures:*
>
> - *Smart Grids: Fundamentals and Technologies in Electric Power Systems of the future | SpringerLink*

1. Vision and Strategy for the Electricity Networks of the Future

1.1 Drivers of Smart Grids

> *n this area in the 21st century. The main challenges that need to be solved in the European Union are [1]: • the decreasing availability*
> *show annotation*

- the decreasing availability of fossil and nuclear primary energy sources (PES) and,
- accordingly, their rapidly increasing prices,
- the 70% dependency of Central Europe on imported PES,
- the increasing impact of greenhouse emissions on the environment.

> *he known locations are similar. The main difference in the figures consists in the differenti-ation between the known reserves and the expected increase of resources which could be exploited by non-traditional technologies (e.g. hydraulic fracturing of rock for gas exploitation). However, both references unde*
> *show annotation*

> *ased energy needs of the future.* *Consequently, the European Union has set ambitious objectives for the year 2020 to:* *• lower energy consumption by 20*
> [show annotation]()

- lower energy consumption by 20% by enhanced efficiency of energy use,
- reduce CO2 emissions by 20% and,
- ensure that 20% of the primary energy is generated by renewable energy resources (RES).

> *bio fuel and hydro power.* *Consequently, electric energy has to carry the main part of the renewable energy production by having an annual share of >30% in 2020. All of the member states of the European Union have set their individual targets in support of the common strategy for 2020.* *In 2006, the European Commission*
> [show annotation]()

> *yment document [8] as follows:* *A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electric-ity supplies.* *A Smart Grid employs innovat*
> [show annotation]()

> *nd secure electric-ity supplies.* *A Smart Grid employs innovative products and services together with intelli-gent monitoring, control, communication and self-healing technologies to:* *• enable the network to integrat*
> [show annotation]()

- enable the network to integrate users with new requirements;
- better facilitate the connection and operation of generators of all sizes and technologies;
- enhance the efficiency in grid operations;
- allow electricity consumers to play a part in optimizing the operation of the system;

- provide consumers with more information and choice in the way they secure their electricity supplies;
- improve the market functioning and consumer services;
- significantly reduce the environmental impact of the total electricity supply system;
- deliver enhanced levels of reliability, quality and security of supply

> *quality and security of supply. Consequently, a Smart Grid supports the introduction of new applications with far-reaching impacts: providing the capabilities for safe and controllable inte-gration of more renewable, especially volatile energy sources (depending on the weather conditions) as well of new categories of network users like electric vehicles and heat pumps into the network; delivering power more securely, cost efficiently and reliabl*
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> *ities after faults and finally, enabling con-sumers to be better informed about their electricity demand and to actively partici-pate in the electricity market by Demand Side Response on dynamic tariffs .This vision will lead to new pr*
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1.2 The Core Elements of the European Smart Grid Vision

- Distributed energy resources (DER)
- Renewable energy sources (RES)

> *the European Smart Grid Vision The electricity supply of the future will be shared by central power stations and distributed energy resources (DER) . Both concepts may contain rene*
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> *ectricity Networks of the Future Ultimately, the Smart Grids will combine existing technologies—improved and updated—with innovative solutions . The future grids will be based*
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> *ds" and "Virtual Power Plants". Centralized generation will still play an important role, but many more actors will be involved in the generation, transmission, distribution and operation of the system, including the end consumers .Based on these considerations,*
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Based on these considerations, the core elements of the vision are defined in as follows:

1. Create a *toolbox of proven technical solutions* that can be deployed rapidly and cost-effectively, enabling existing grids to accept power injections from distributed energy resources without contravening critical operational limits (such as voltage control, switching equipment capability and power flow capacity);
2. Establish *interfacing capabilities* that will allow new designs of grid equipment and new automation/control arrangements to be successfully interfaced with existing, traditional grid equipment;
3. Ensure *harmonization of regulatory and commercial frameworks* in Europe to facilitate cross-border trading of both power and grid services (such as reserve power, for instance Nordic hydropower), ensuring that they will accommodate a wide range of operating situations;
4. Establish shared technical standards and protocols that will *ensure open access*, enabling the deployment of equipment from any chosen manufacturer without fear of lock-into proprietary specifications. This applies to grid equipment, metering systems and control/automation architectures;
5. Develop *information, computing and telecommunication* systems that enable businesses to utilize innovative service arrangements to improve their efficiency and enhance their services to consumers.

> *nd of interaction possible. Advanced Information and Communication Technologies (ICT) will be the key for: • advanced distribution automati*
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- advanced distribution automation to enhance the quality of supply,
- a coordinated energy management covering generation, storage and demand in the framework of virtual power plants (VPP),
- provision of new metering services to the consumers including motivation methods for efficient use of electricity
  - by dynamic tariffs,
  - by the real-time communication of information to the end consumers,
  - to visualize the current tariffs, their demand and the related costs.

2. Smart Generation: Resources and potentials

2.1 New Trends and Requirements for Electricity Generation

- Primary energy sources (PES):

> *ments for Electricity Generation Electricity generation is the process of electric energy production and requires the use of primary energy sources (PES). PES is defined as an energy form that is available in nature and that has not yet been used in any conversion or transforma-tion process. The world's annual electricity g*
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> *fuels or by nuclear fission. Nowadays, renewable energy sources (RES) such as geo-thermal power and con-centrated solar thermal power (CSP) are also applied for the electricity generation via heat. Furthermore, the renewable el*
> show annotation

> *ectricity generation via heat. Furthermore, the renewable electricity generation is increasingly using the direct conversion of mechanical rotation into electricity by using the kinetic energy of wind, waves and flowing water. Additionally, chemical proce*
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By 2015, the worldwide contributions of various PESs applied for electricity generation were:

- 65.3% fossil PES (39.2% coal, 22.8% natural gas, 3.3% oil)
- 23.8% RES (15.9% hydroelectric, 6.8% other RES),
- 8.1% nuclear power.

> *and trees is not possible. The effect of excessive amounts of CO_2 in the atmosphere is the increase of the overall temperature of the planet (global warming) with the consequence of a growing risk for extreme weather catastrophes (floods, hurricanes, heat waves and droughts) .The reduction of the CO_2 e*
> *show annotation*

> *b ~20c ~44Bio fuelb ~0.2 37–6021 Increasing the efficiency of electricity generation by more than 60% may be achieved by three means: • Technological improvement,• Co*
> *show annotation*

Increasing the efficiency of electricity generation by more than 60%:

- Technological improvement
- 联合循环 Combined cycle (CC)—using the gas flow after combustion in gas turbines and the generated heat for steam production,
- 热电联产Cogeneration of heat and power (CHP)

2.2 Volatile Renewable Energy Sources: Wind and Sun

2.2.1 Wind Power Plant

> *and Sun2.2.1 Wind Power Plants In general, wind power plants include many different concepts with regard to their construction, type of generator, type of network interconnection, type of control system as well as type of*

> operation. *Currently, most wind turbin*
> show annotation

> *ions reach altitudes over 200 m.* *The first modern wind turbines that were applied for electric power generation were operated at a constant angular speed independent of the wind speed, and their generators were directly coupled with the network.* *The generators used in thes*
> show annotation

> *ration: Resources and Potentials* *The mechanical power of such turbines can be controlled by the following three aerodynamic principles* *:1. stall control,2. active- s*
> show annotation

- stall control 失速控制
- active-stall control 主动失速控制
- pitch control 节距控制

> *e with synchronous generators.27* *The adequate control system consists of the following main parts:* *• pitch controller,• controller*
> show annotation

- pitch controller,
- controller of network-side converter,
- controller of rotor-side converter including the MPPT controller (maximum power point tracking 最大功率点跟踪控制器)

> *d reached 590 GW in 2018.* *China became the world market leader regarding the installed wind power capacity followed by the USA and Germany* *. A different picture emerge*
> show annotation

2.2.2 Utilization of Solar Power for Electricity Generation

- Photovoltaic technology (PV)
- Concentrated solar power (CSP)

> *Power for Electricity Generation* *Solar power is increasingly being used for electricity generation by converting the sunlight into electricity, either directly using the photovoltaic technology (PV), or indirectly using the principle of concentrated solar power (CSP).* *Plant examples of both technolog*
> [*show annotation*]

> *hnologies are shown in Fig. 2.9.* *PV converts the photon energy of the solar radiation into electric energy using the photovoltaic effect. The conversion takes place within solar or photovoltaic cells, which are based on semiconductor technologies* *. Materials presently used for p*
> [*show annotation*]

> *about 90% of the world's market.* *The photovoltaic cells are connected and assembled to build a photo-voltaic (or solar) panel. Each panel is rated by its DC output power under standard test conditions, and typically ranges from 100 to 320 W.* *The effi-ciency of a PV p*
> [*show annotation*]

> *advantages of the PV technology.* *Obviously, the economic efficiency of PV power plants is higher in countries with more intensive and continuous sun radiation.* *The main disadvantage of the PV*
> [*show annotation*]

- Main disadvantages of the PV technology

> *ve and continuous sun radiation.* *The main disadvantage of the PV technology is the unavailability in darkness. The application of CSP systems may overcome this disadvantage and provide an around the clock electricity generation by using thermal storage capabilities* *.CSP systems use lenses or*
> [*show annotation*]
>
> *全天候发电*

> *ng thermal storage capabilities.* *CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The*

> *focused solar energy is directed to heat up a working fluid inside absorber tubes or other containers. The concentrated heat is then used as a heat source for a conventional power plant.* *A wide range of concen-trating t*
> *show annotation*

> *es the electricity generator.* *The upwind generator technology is based on the chimney principle. An area of ground is covered by a glass plane. The air under this cover is heated up by solar radiation and as a result of the air expansion the air flows through turbines into the chimney tower that is allocated in the center of the covered area. This principle is simple, but it provides a very low efficiency of about 1%. A rated power of some 100 MW would require an altitude of 1000 m and an area of 12 km2 [7]* *.Considering the worldwide po*
> *show annotation*
>
> *Simple but low efficiency*

2.3 Cogeneration of Heat and Power Applying Renewable Energy Sources

- Cogeneration of heat and power (CHP)

> *pplying Renewable Energy Sources* *A significant growth in the shares of cogeneration of heat and power (CHP) is one of the objectives of the European Union (see Sect. 1.1, SET Plan Table 1.1) to increase the energy efficiency* *.Some countries introduced su*
> *show annotation*

> *oduction use the CHP technology.* *The use of RES in CHP has two positive effects, namely an increase up to 85% in the overall (electrical and thermal) energy efficiency and a reduction of the CO_2 emissions.* *The following RES—CHP technologi*
> *show annotation*

The following RES—CHP technologies are currently being applied:

- Thermal steam power plants based on bio mass combustion,
- Gas turbines fired by bio gas,
- Gas engine driven by bio gas,
- Combined Cycle Gas Turbine (CCGT) using bio gas,
- Geothermal plants with steam turbines,
- Fuel cells

> *lants is presented in Fig. 2.16. The CHP plants may be optimized for heat or electricity production. The operation with an optimized heat production offers the higher efficiency with a minimum of energy losses. However, the electricity market offers a higher optimization potential according to the economic benefits. The thermal storage unit i*
> *show annotation*
>
> *optimized heat production; higher efficiency; minimize energy losses; higher optimization potential; economic benefits*

> *ig. 2.16 is optional. However, the inclusion of thermal storage capabilities allows for a more flexible and economic optimum operation of the electricity generation depending on the related market prices. Thermal storage helps to increase the economic benefits .Table 2.6 CHP technologies ba*
> *show annotation*
>
> *more flexible optimum operation;*

2.3.1Bio Fuel Power Plants

- Advantages

> *ials2.3.1 Bio Fuel Power Plants The use of bio fuel provides two major advantages in the sense of the Smart Grid concept :1. Biological materials con*
> *show annotation*

1. Biological materials contain energy that is derived directly from chlorophyll (叶绿素) *photosynthesis* (光合作用).
2. Bio fuel is the only renewable energy source that does not depend on the weather and that guarantees a continuous energy generation.

> *s too much CO2 to be reabsorbed.* *Consequently, the bio fuel is being used to replace energy derived from fossil fuels, and thereby reduce emissions of greenhouse gases.* *2. Bio fuel is the only r*
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- 可以直接燃烧 (combustion) 固体生物质 (solid biomass)，如木屑、灰尘、树皮等

> *er generation from wind and sun.* *Heat and power generation in CHPs can be made by direct combustion of solid biomass such as wood chips, dust, bark and shavings. Another practical solution is the gasification of such biomass material. Both conversion paths are the most important for biomass based cogeneration.* *Figure 2.17 presents a bio*
> show annotation

> *ed bio gas into the gas network.* *The sources of biomass are quite different and have to be converted in relation to their present form. Sources of biomass can be wastes or residues from biologi-cal or industrial processes* *. Table 2.7 shows a selection of*
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> *stalled capacity of about 27 GW.* *China will become the most important growth market for biomass power plants in the next ten years. With an increase of around 750 MW per year, China will become the national market with the highest sales in the world* *[25].A further benefit of b*
> show annotation

> *highest sales in the world [25].* *A further benefit of bio gas power plants is that they are able to generate electricity in a combined cycle and, in this way, to increase the plant's electricity efficiency.* *In electricity generation the co*
> show annotation

- Combined ctcke gas turbine (CCGT, 联合循环燃气轮机)

> *plant, as depicted in Fig. 2.18. This is called a Combined Cycle Gas Turbine (CCGT) plant, and can achieve an electric efficiency of around 60%, in contrast to a single cycle steam power plant which is limited to efficiencies of around 35–42% . Many new gas power plants*
> *show annotation*

2.3.2 Geothermal Power Plants

> *t.2.3.2 Geothermal Power Plants Geothermal power plants generate electricity from geothermal energy. Geothermal energy refers to heat within the earth and originates from the residual heat from the formation of the earth and the radioactive decay of isotopes inside the planet, which act as natural nuclear power. Geothermal electricity generation requires transferring the naturally occurring high temperature from deep underground to the surface by fluid circulation .Geothermal electric plants h*
> *show annotation*

2.3.2 Fuel Cells

> *and Potentials2.3.3 Fuel Cells A fuel cell is a device that converts the chemical energy from a fuel into electric-ity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are also applicable .The fuel cell is an efficient e*
> *show annotation*

> *e methanol are also applicable. The fuel cell is an efficient energy conversion system that converts the chemical energy of the fuel directly into electricity. With this principle, only one energy conversion step required: chemical energy into electrical energy .Comparing this single conver*
> *show annotation*

> *the CHP technology is achieved. There are many types of fuel cells, but they all consist of two electrodes (anode–cathode) and an electrolyte that allows charges to move between the two electrodes of the fuel cell .The fuel cell principle is pres*
> [show annotation]

> *gh the membrane chan-nels). The hydrogen proton migrates through the channel structure of the mem-brane on the other side to the cathode and the electron moves through an external electrical conductor from the anode to the cathode .The directed external movement*
> [show annotation]

> *from the anode to the cathode.The directed external movement of the electron creates electric energy. However, the electron flow through the conductor creates a direct current (DC). The DC power has to be converted into AC power for the electric network access. Once reaching the cathode throug*
> [show annotation]

> *for the electric network access. Once reaching the cathode through the membrane channels, the protons recom-bine with the electrons which reached the cathode via the conductor. Both react with the oxygen to create water H2O. There are six different type*
> [show annotation]

- PEM: Proton-Exchange Membrane: 质子-外热膜
- LT PEMFC: Low temperature PEM fuel cell
- HT PEMFC: high temperature PEM fuel cell

> *the different electrolytes. The benefits of the HT PEMFC compared to the LT PEMFC are the better tolerance to impurities in the gases and the fact that humidification of the reaction gases is not necessary. The main disad-vantage of HT PEMFC is primarily due to the higher system complexity. However, the water management of*
> [show annotation]

> *to the higher system complexity. However, the water management of both LT and HT PEM FCs is crucial to the cell performance: too much water will flood the membrane, too little will dry it; in both cases, power output will drop. Stable PEMFC operation therefore requires a humidification module as an additional system component to solve these issues. Furthermore, the application of*
> [show annotation]

- DMFCs: Direct-methanol fuel cells 甲醇燃料电池

> *a PEMFC are shown in Fig. 2.21. Direct-methanol fuel cells (DMFCs) are a subcategory of the PEMFC and use methanol as fuel. Their main advantage lies in the ease of transport of methanol, the high energy- density and the liquid stability under all environmental conditions .Heat exchanger / FC CoolingFuel*
> [show annotation]

- PAFC Phosphoric acids fuel cells 磷酸燃料电池

> *more important than efficiency. Phosphoric acid fuel cells (PAFC) use phosphoric acid as an electrolyte. They were the first fuel cells to be commercialized. Improved stability in performance and low costs have made the PAFC a good candidate for early stationary applica-tions between 100 and 400 kW . Disadvantages include rather l*
> [show annotation]

> *a-tions between 100 and 400 kW. Disadvantages include rather low energy —density, the low energy efficiency of 37–42% and the aggressive electrolyte. The medium temperature fuel cell*
> [show annotation]

- MCFC: Medium temperature fuel cell 中温燃料电池

> *and the aggressive electrolyte. The medium temperature fuel cell MCFC operates in the range of 600–700 °C and has a molten-carbonate electrolyte . Since they are operated at ver*

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>
> *Since they are operated at very high temperatures, non-precious metals can be applied as the catalyst, in this way reducing the costs.*

- SOFC: High temperature fuel cell 高温燃料电池

> *iciencies can be as high as 85%. The high temperature fuel cell SOFC (800–1000 °C) is characterized by a high tolerance against impurities in the gases and has a high efficiency. Due to the extremely high temperature, however, only selected materials fulfill the corre-sponding requirements .Because of their low weight, as*
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- Usage of fuel cells

> *the corre-sponding requirements. Because of their low weight, as compared to batteries, and their efficient energy supply, fuel cells are used in the aerospace industry and for submarines as auxiliary power units .Fuel cell systems can be applie*
> show annotation

> *arines as auxiliary power units. Fuel cell systems can be applied in the stationary sector to supply domestic or industrial systems, as well as in mobile applications for use in vehicles, elevators and motorcycles .Due to very fast response*
> show annotation

> *range of a few kW to several MW. Fuel cells have been introduced for cogeneration of heat and power in a num-ber of projects . Figure 2.21 presents such*
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- Limits of fuel cells

> *the heating of a swimming hall.* *However, for the most part, fuel cell systems are not yet economically competitive for the large scale electricity generation in power systems. Only through further cost reductions and long-term stability of the fuel cells, will this technology become usa-ble for the establishment of power plants with significant power capacities. Scientists and experts are intensely working to improve the fuel cell technologies worldwide* *.2.4 Electric Energy Storage Sy*
> show annotation
>
> *Not economically competitive for the large scale electricity generation; further cost reductions and long-term stability; intensely working*

2.4 Electric Energy Storage Systems

2.4.1 Introduction and Categories of Electricity Storage

- EESS: 电能储能系统

> *ategories of Electricity Storage* *Electric Energy Storage Systems (EESS) are usually classified by two criteria: the rated power and time of discharge which corresponds with the energy stor-age capacity.* *According to these criteria thr*
> show annotation

> *the energy stor-age capacity.* *According to these criteria three use cases of EESS may be defined: Power Quality, Power Bridging and Energy Management.* *2.4 Electric Energy Storage Syst*
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> *ration: Resources and Potentials* *Ensuring Power Quality often requires providing supporting energy to avoid voltage sags, flicker or supply interruptions. The requested power is needed for short time intervals (in the range of seconds and minutes) and may be rated from a few kW (kilowatt) to a few MW (megawatt).* *Typical EESS for this use case*
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Typical EESS for this use case may be based on the technologies of:

- High power fly wheels
- superconducting magnetic energy storage
- high power super capacitors,
- several types of batteries.

> *rs,• several types of batteries.* ***Power Bridging is mostly used to provide an uninterrupted supply if the main power fails.*** *For example, this use case is a*
> *show annotation*

> *and tele-communication centers.* ***In principle, the DC power supply of the control and pro-tection facilities in substations belongs to the power bridging concept.*** *This use case may be also*
> *show annotation*

Typical EESS technologies for Power Bridging are:

- high energy super capacitors,
- several types of batteries

> *rs,• several types of batteries.* ***Energy Management is mainly used for power balancing, peak shaving, and for energy storage during low price periods and injecting energy during high price periods.*** *This use case will play a*
> *show annotation*

> *during high price periods.* ***This use case will play a significantly growing role in the Smart Grid environment for covering of energy deficits in general and for storing excesses of renewable power.*** *Both the discharge and the char*
> *show annotation*

The EESS technologies suitable for energy management tasks include:

- Pumped-storage hydro-electric power plants (PSHPP), 抽水蓄能水电站
- compressed air energy storage (CAES), 压缩空气储能器
- high energy batteries of various technologies,

- indirect principles like
  - “power to gas” and
  - a combination of thermal storage/electric heating to ensure a more flexible contribution of CHP plants for energy management

> *HP plants for energy management. Because of the growth of more fluctuating power consumption and the increasing installed capacity of volatile renewable energy technologies with weather depend-ent generation, the need for the use case “Energy Management” is stronger than ever . Further considerations in this*
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2.4.2 Long-Term Bulk Energy Storage Plants

- PAHPP: Pumped-storage hydroelectric power pants 抽水蓄能水电发电厂

> *orage Hydroelectric Power Plants Pumped-storage hydroelectric power plants (PSHPP) provide the largest-capacity form of electric energy storage. They consist of upper and lower reservoirs, the connecting tube system, the power plant chamber and the substation as depicted in Fig. 2.21.The m*
> show annotation

> *ation as depicted in Fig. 2.21.T The main parameters defining the generation power capability of the plant are the inner diameter D (cross section) of the connecting tubes and the difference of the heights ΔH between the upper reservoir and the allocation of the turbine–pump aggregate. The discharge time and the stor*
> show annotation

> *per water reservoir (Fig. 2.22). The optimum operation mode of PSHPP simply consists of using the best tur-bine time and pump time depending on the demand and market prices to shift as much water as possible between the upper and the lower water reservoirs. This means the pumped-stora*
> show annotation

> *ates in a circulation mode.* *PSHPPs are currently used to store the electric energy during times of weak load and low energy prices by filling up the upper water reservoir and then generate the electric energy during peak load and high price times by using the potential and kinetic energy of the water flowing down through the tubes into the lower reservoir* *.Figure 2.23 presents the 80 MW*
> show annotation

> *ration: Resources and Potentials* *The energy efficiency of the PSHPPs varies in practice between 70 and 80% depending on the age, the technology and the geographical conditions.* *Excellent pumped-storage hydr*
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- CAES: Compressed Air Energy Storage 压缩空气储能器

> *2 Compressed Air Energy Storage* *Compressed Air Energy Storage (CAES) is a further way to store bulk energy generated at one time for use at another time* *.Due to the large volume of*
> show annotation

> *ne time for use at another time.* *Due to the large volume of air to be compressed, CAES systems often use existing large underground caverns. The main types of caverns suitable for CAES are salt cavern* *s.A large quantity of energy can*
> show annotation

> *heat. Expansion requires heat).* *The efficiency of the storage improves signifi-cantly if the heat generated during compression can be stored and then used for the expansion process* *.There are several ways in*
> show annotation

> *used for the expansion process.* *There are several ways in which a CAES system can manage the heat, for example the adiabatic or the isothermal principles* *.Adiabatic storage retains the h*
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> *绝热原理和等温原理*

> *using a salt dome (1978) [33]. It is based on a combination of a gas turbine and a compressed air combustion engine. During low-price weak load p*
> *show annotation*

原理：It is based on a combination of a gas turbine (燃气涡轮机) and a compressed air combustion engine (压缩空气内燃机).

- During *low-price* weak load periods, the motor consumes power to compress and store the air in the underground salt caverns.
- During *peak load* periods, the process is reversed and the compressed air is returned to the surface. The air is used twice:
  - *burn the gas fuel* in the combustion chamber of the gas turbine
  - provide *supplement rotation power* for the compressed air combustion engine

> *ressed air combustion engine. This combination allows a significant enhancement of the efficiency of the overall plant. In a pure gas turbine a significant energy contribution is required for com-pressing the combustion air. In the CAES power station, howe*
> *show annotation*

- Stationary Electric Batteries 蓄电池

> *3 Stationary Electric Batteries An electric battery is a device consisting of electrochemical cells that are able to convert chemical energy into electric energy (discharge) and vice versa (charge) . Analogous to the fuel cel*
> *show annotation*

> *ion–oxidation) and zinc–bromine. There are a number of technical parameters besides the capital and operational expenses that influence the economic efficiency of the battery applications .This concerns, among others,*
> *show annotation*

> *ncy of the battery applications.* *This concerns, among others, such parameters as the life time of the battery system, the cycle durability, the charging–discharging efficiency, the self- dis-charge and the energy density* *.Table 2.10 presents an overv*
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> *or the various technologies.49* *The traditionally used battery system in the past was the lead-acid battery that is mainly applied,* *for example, in the auxiliary D*
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> *ubstations (see also Sect. 3.1).* *Its basic design incorporates two lead electrodes immersed in a sulfuric acid. During the charge and discharge phases, hydrogen ions (H+) travel in the acid solution between the two electrodes and electrons travel in the external circuit.* *Lead-acid batteries have th*
> show annotation

> *ronmental issues regarding lead.* *The analysis of the technical and economic parameters demonstrates that the NaS, Redox flow and Li-ion batteries are more suitable for energy management applications* *.The sodium–sulfur battery is*
> show annotation

- The redox flow battery 氧化还原电池

  > *e systems as shown in Fig. 2.25.* *The redox flow battery can offer almost unlimited capacity by using larger and larger storage tanks, it can be left completely discharged for long periods with no damage and it can be recharged simply by replacing the electrolyte if no power source is available to charge it.* *Flow batteries are normally des*
  > show annotation

> *10 MWh) stationary applications. The lithium-ion battery family is based on the principle that the lithium ions move between the anode and cathode of the cell to carry the charges. The cath-odes are composed*
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- The cathodes are composed of metal oxide containing lithium particles,
- the anodes are made of layered graphite (石墨) carbon.
- 充电阶段：阴极的锂原子成为离子，并穿过电解质分离器到达碳阳极。到达阳极后，锂离子与电子结合以锂原子的形式沉积在碳层之间。
- 放电阶段：相反的过程会发生：锂原子失去电子到阳极，并以离子的形式返回阴极。
  During the charging phase, lithium atoms at the cathode become ions and traverse the electrolyte separator to the carbon anode. Upon reaching the anode, the lithium ions combine with electrons and are deposited between the carbon layers as lithium atoms. During the discharge phase, the reverse process occurs: The lithium atoms lose electrons to the anode and travel back as ions to the cathode.

> *vel back as ions to the cathode. Li-ion batteries are characterized by light weight, high energy density, high efficiency and low self-discharge rates. To provide more power, connecting many small batteries in a parallel circuit is more efficient .Li-ion batteries are current*
> show annotation

> *r plants (see also Sect. 9.3.1). However, lithium-ion batteries can be dangerous under some conditions since they contain a flammable electrolyte and are also kept pressurized. This requires high quality standards for these batteries consisting of many supplement safety features .The application of stationar*
> show annotation

> *many supplement safety features. The application of stationary batteries for energy management applications throughout the world is still limited due to economic reasons. The most battery storage systems are generally still*

> *expensive . However, it is expected that s*
> [show annotation]

- "Power to Gas" by Electrolysis and Methanation
  When the contribution of volatile RES becomes higher than 20% of the total consumption, the external storage will become important.

> *rage will become important. If the surplus of electricity may be used to produce hydrogen and other fuel gases, then it can be utilized fully whenever there is a demand. The production of fuel gases will be an instrument to utilize the excesses of available energy .The hydrogen and other gases pr*
> [show annotation]

> *excesses of available energy. The hydrogen and other gases produced by electrolysis or methanation can be used as a fuel for powering combustion engines or for fuel cells . In this sense, hydrogen i*
> [show annotation]

> *fuel in electricity generation. However, the energy balance of the hydrogen production is negative, i.e. the energy input for the electrolysis is higher than the energy that can be generated afterwards. But, as a storage medium, h*
> [show annotation]

- Electrolysis 点解

> *ontaneous chemical reaction. The key process of electrolysis is the interchange of atoms and ions by the removal or addition of electrons from the external circuit. The desired products of electrol*
> [show annotation]

> *are demon-strated in Fig. 2.27. The power to gas process for this concept is performed in a two- step approach . In the first step hydrogen*
> [show annotation]

1. Hydrogen is produced in the electrolysis process
2. A part of hydrogen will be used for methanation

3. Methane can be used to supply various gas consumers and as a fuel for electricity generation

> *special supply projects [40]:53 For example, the small Norwegian island municipality Utsira is supplied by an energy system including wind power plants and a storage system consisting of an electrolysis unit, a compressed air storage system, a fuel cell and a hydrogen turbine. A similar pilot project using wi*
> *show annotation*

- Electric Energy Management by Thermal Storage

> *gy Management by Thermal Storage Thermal storage consists of the temporary production and storage of heat for a later use. The expenses for thermal storage*
> *show annotation*

> *ge of heat for a later use. The expenses for thermal storage are lower than for electricity storage. Wherever volatile renewable*
> *show annotation*

> *urces and Potentialspenetration, thermal storage becomes one option to contribute for energy manage-ment and provide reliable energy supplies. Therefore, thermal storage w*
> *show annotation*

> *de reliable energy supplies. Therefore, thermal storage will play a growing role in the electric energy management in different ways .For example, CSP plants use the*
> *show annotation*

> *oling in cold storage chambers. This principle can also be used to compensate an excess of electric energy and to save energy for cooling in periods of weak renewable electricity generation .Thermal storage is also use*
> *show annotation*

> *ase heat over a number of hours. A combination of thermal storage, electric heating and solar heat generation is used also for municipal district heating systems. The basic heat load is gen*
> show annotation

> *sion (see Sect. 1.1, Table 1.1). For efficiency reasons, the CHP plants are mainly scheduled in accordance with the heat demand, which depends on the weather conditions and is significantly reduced in the summer time when only the provision of hot water and industrial heat is required. A typical heat demand schedule*
> show annotation

> *5 6 7 8 9 1 0 1 1 1 2MonthP th55 The introduction of thermal storage units into the CHP systems will allow a much more flexible scheduling of the CHP with a focus on the electricity market. Furthermore, the combination*
> show annotation

> *ocus on the electricity market. Furthermore, the combination of electric heating and thermal storage may play a significant role in the energy management of the future. The related scheme exten-sion of*
> show annotation

The extension of CHP plant provides the following opportunities:

- The CHP plant produces electric power that is market driven in high price/high demand periods and is independent of the thermal power schedule. The excess of thermal energy will be stored.
- In low price/low demand periods the electricity generation of the CHP plant is shut down and the heat demand is covered by the thermal storage.
- Excesses of renewable electricity production may be compensated by electric heating

2.5 Enhanced Flexibility Requirements for Controllable Power Plants

> *ts for Controllable Power Plants* *The compensation management of the fluctuations of volatile renewable electricity generation requires the coordinated operation of all definitely controllable sources of power generation and demand: power plants, storage plants and demand side management DSM.* *TurbineCondenserCooling towerGen*
> *show annotation*

> *ants require between 1 and 3 h.* *A short start-up duration is one of the requested features to meet the fluctuation challenges.* *The flexible controllability*
> *show annotation*

> *eet the fluctuation challenges.T* *he flexible controllability of the power plant includes further parameters like the power gradient, the flexibility interval and the minimum power generation requested for a stable operation* *.These parameters are presented*
> *show annotation*

> *daily generation schedules.* *However, the flexi-ble reaction to fluctuations caused by RES requires the fast availability of certain volumes of control power from power plants operated at the minimum generation level.* *However, operation at reduced p*
> *show annotation*

> *efficiency of the power plants.* *Consequently, the flexibility of the remaining thermoelectric power generation requires* *:• high power control gradients*
> *show annotation*

- high power control gradients without reduction of the plant life time,
- the availability of high power gradients within the whole flexibility interval,
- the achievement of a minimum generation level of 20%,
- maintaining high efficiency even under reduced generation conditions.

> *assets and their interaction.* *Another economic challenge concerns the motivation for investment to con-struct and operate new power plants. This challenge will change the pricing con-ditions and will require the trade of*

> *"power gradient products".* *In this case, the power st*
> [show annotation]

> *uested duration of availability.* *To conclude the considerations in both Chaps. 1 and 2 it can be stated:* *The Smart Grid concept requires*
> [show annotation]

- The Smart Grid concept requires a significant enhancement of *flexibility* regarding the electricity generation processes and the power system operations. Furthermore, it is necessary that the generation process becomes "Smart".
- Both the Smart Grid and Smart Generation processes will ensure the *sustainable and environmentally friendly electric power supply* of the future. They will also lead to enormous technical developments in both fields and, in principle, a system strategy for "Smart Electric Power Systems" is required.

3. Modern Technologies and the Smart Grid

3.1 Substations: The Network Nodes

> *Substations: The Network Nodes* *Electric power flows through several substations at different voltage levels on its way between the bulk power stations and the end consumers.* *The networks at the transmis*
> [show annotation]

> *n lines have the same voltage.* *However, typically, the substations transform voltage from high to low and/or vice versa* *. Substations may perform any of*
> [show annotation]

Substations may perform any of several other important functions like:

- voltage control,
- reactive power control or power factor correction,

- power flow control by phase shifting transformers or power electronic plants,
- UHV, EHV or HV DC/AC conversion to connect High Voltage DC (HVDC) lines,
- connection of two un-synchronous power systems by UHV/EHV/HV DC coupling

> *hnologies and the Smart Grid ... A small "switching substation" may contain little more than one busbar plus some feeders. Large transmission substations,*
> *show annotation*

3.1.1 Schemes and Components of Transmission Substations

Substations 变电站

> *ion to perform maintenance work. Each network element (line, transformer, coupling, voltage transformer) con-nected to the busbars builds a switch bay. The switch bays are equipped with several primary devices (dimensioned for the primary voltages and currents) and secondary devices for control, measurement and protection. The overview of the primary*
> *show annotation*

Table 3.1 Devices applied in the switch bays

Device	Symbols	Function
Circuit breaker (CB)	OFF ON	Can interrupt short-circuit currents e.g. "I_{sc}" = 70 kA, V_r = 380 kV
Isolator or Disconnector Ground switch	Open Closed	Visible disconnection, saves CB's Cannot switch currents Connects phases to ground Cannot switch under voltage
Surge arrestor		Limits atmospheric or switching over-voltages
Current transformer		Transforms high currents to 1/5 A
Voltage transformer		Transforms EHV/UHV/HV/MV to 100/110 V

- 断路器 CB
- 隔离器或隔离开关
  接地开关
- 浪涌避雷器
- 电流变压器
- 电压变压器

> *dary voltages of 100 V AC. The voltage measurements are used for: • Monitoring and recording of th*
> *show annotation*

- Monitoring and recording of the voltages,
- Protection devices like distance, voltage or frequency protection,
- Synchronism-check before connecting a feeder to the busbar,
- Voltage control

> *known as secondary technology. The transformers, the switch devices and the busbars are dimensioned for the high primary voltages and currents, and they belong to the primary technology category .The surge arrestors are connect*
> *show annotation*

3.1.2 Innovative Air Insulated Switchgear Technology

创新型空气绝缘开关设备技术

> *Insulated Switchgear Technology The most valuable device of the switchgear is the circuit breaker. The circuit breaker has to*
> *show annotation*

> *ar is the circuit breaker. The circuit breaker has to interrupt high short circuit currents which may reach values up to 80 kA in extra high voltage networks. The interruption of such high c*
> *show annotation*

> *断路器必须中断短路电流，可能达到高达 80 kA的超高压网络。*

- AIS: Air insulated switchgear technology

> *xiliary network in substations67 In the past various types of circuit breakers were installed in the substations such as the bulk oil tank circuit breaker, the minimum oil circuit breaker or the air blast circuit breaker. In the last few decades there ha*
> *show annotation*
>
> *散装油断路器、最小油路断路器、空气断路器*

> *the air blast circuit breaker. In the last few decades there has been a shift from AIS to using only gas insulated circuit breakers in the UHV, EHV and HV substations . They offer the most cost eff*
> *show annotation*
>
> *仅在特高压、超高压、高压变电站中使用气体绝缘断路器。*

> *substation. Source Siemens AG69 The isolators are motor driven and the opening or closing operations may require a few seconds .The consideration of latency is*
> *show annotation*

3.1.3 Gas Insulated Switchgear

> *s mentioned in Sect. 3.1.2, sulfur hexafluoride is a superior dielectric gas that is also used in gas insulated switchgears at moderate pressures for phase to phase and phase to ground insulation. The high voltage conductors*
> *show annotation*

The main drivers for using gas insulated switchgear are:

- Restricted space availability what is important in highly populated or mountainous areas,

- Expensive land acquisition or legal restrictions,
- Requirements for environmental compatibility or community acceptance,
- Aggressive environmental conditions, e.g. coastal sites or industrial sites,
- Heavy weather conditions, e.g. strong wind, snow and ice,
- Seismic (地震活动) activity with the need for high seismic stability through a low centre of gravity,
- Extension or refurbishment or upgrading of AIS under restricted space availability.

> *cheme is presented in Fig. 3.15. Besides the fundamental space reduction the compact GIS design provides the following additional benefits: • Short and economic planni*
> *show annotation*

Benefits of Gas insulated switchgear (GIS):

- Short and economic planning and delivery period possible through customer-tailored and pre-defined combinations of switchgear modules,
- Short and economic installation period possible through factory pre-assembled and pre-tested units,
- Restricted foundations, e.g. in mountainous or river areas realized with outdoor-GIS,
- High level of availability through encapsulation and modular, service friendly design,
- Minimal maintenance efforts realized through encapsulation of moving parts and less insulators,
- High degree of safety for operating personnel realized through earthed encapsulation,
- Long operating life: >50 years.

3.2 Control and Automation of Power Systems by Digital Technologies

3.2.1 The Hierarchy and the Data Processing of Power System Control and Automation

> *er System Control and Automation* *The power system control is performed in a four tiered bottom up hierarchy:* *• Process level, • Bay control le*
> *show annotation*

- Process level
- Bay control level
- Substation control level
- Network control level

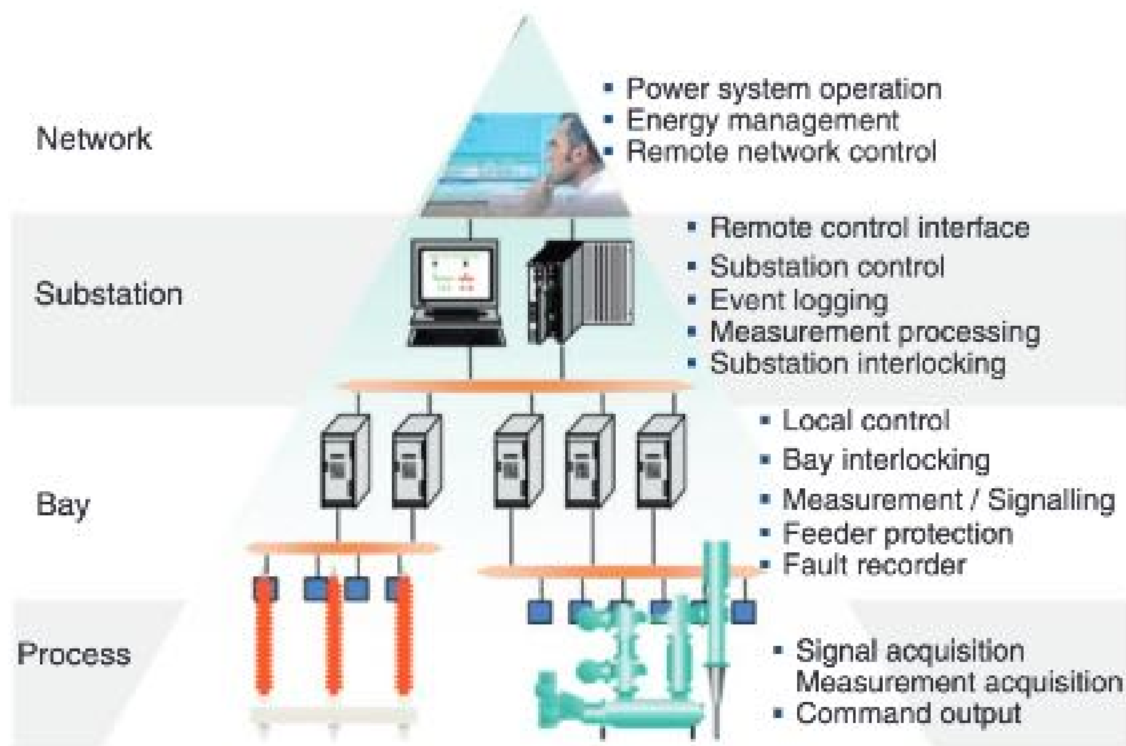

Fig. 3.16 Hierarchy of the power system control

At the process level:

- binary status signals indicate, for example, the positions of the switchgear or the transformer tap changer,
- analogue measurement data (voltage, current) are available at the interfaces of the instrument transformers,

- binary output commands are set for the control of switchgear, tap changers and various equipment for protection, automation or auxiliary needs,
- analogue target values may be set to change the behavior of regulation facilities (e.g. the target value for voltage can be set to the transformer voltage controller)

> *is still not broadly applied. The bay level is equipped with intelligent electronic devices (IEDs) which provide the interfaces for the process data acquisitions. The conventional way for t*
> *show annotation*

At the bay level the IEDs (Intelligent electronic devices 智能电子设备) perform two main tasks:

1. Bay control and processing of the basic data for the Substation Automation System (SAS), data exchange with the substation control level,
2. Protection of the bay related network assets against stress and damages caused by disturbances and/or critical state conditions (e.g. overloading, over voltages).

> *ntly higher sampling resolution. At the bay level the IEDs perform two main tasks: 1. Bay control and processi*
> *show annotation*

The process data can be

- visualized in the device screens on local request and
- used in a programmable logic to start special automation programs,
- communicated to the upper level of the substation control

> *if the feeder is under voltage. Appropriate command and impact signals for the process can be performed in the following ways: • generated by automation a*
> *show annotation*

可用如下方式执行适当的命令和冲击信号：

- generated by automation algorithms (e.g. voltage control, switch sequences, protection trips),
- initiated by the operator locally using the control facilities of the bay devices,
- received from the substation control level via communication- either initiated by personnel at the substation control level or transferred from the network control level to the substation control level and forwarded from here to the process

Station control level

> *d from here to the process. The substation control level provides an interactive work place for the operator with control and visualization elements. Here the scheme of the whole su*
> *show annotation*

> *s that there is no current flow. The substation control level provides communication interfaces to the network control center and, if requested, to further network service providers like the asset and maintenance management, network planning or protection supervision. Not all available data is communicated between all of the levels instead the information exchange has to be engineered .The network control center*
> *show annotation*

Network control center

> *exchange has to be engineered.T he network control center observes and controls all substations of the net-work. Furthermore, the power in-feed of the connected power stations and the power exchange with the neighboring power stations are managed on this level. 75The transmission system oper*
> *show annotation*

> *e managed on this level. 75 The transmission system operators (TSO) build the "control area" in the territory of their network, control the reserve power availability and ensure in this way the frequency stability . The network*

> *control centers pr*
> show annotation

3.2.2 Protection and Control in Substations

> *rogressive industrial countries. The substation control technology was stable and remained unchanged for about 100 years from the beginning of the electricity supply until the 1990s. A broad wall of the substat*
> show annotation

> *sub-station automation systems. The protection technology has also changed within the last few decades—from the electromechanical relay schemes completed on panels to analogue pro-tection cubicles to digital protection devices as shown in Fig. 3.18. At*
> show annotation

> *t stage of development are the intelligent electronic devices "IED", which are char-acterized by the ability to combine a wide variety of functions in a configurable way and thus also integrate protection, automation and bay control tasks in one device .The protection cannot avoid dis*
> show annotation

The protection cannot avoid disturbances but minimize the consequences through:

- rapid, secure and selective disconnection of the faulty equipment,
- automatic reclosing for supply recovering in case of transient failures,
- logging and recording the disturbance and supporting a fast network recovery

3.2.3 Control Center Technologies

> *(see also Sect. 1.2, Fig. 1.7) The transmission system operation at the highest level performs two basic functions :• Energy Management System (EMS*
> show annotation

- Energy Management System (EMS) and
- Network Supervision, Control and Data Acquisition (SCADA).

> *2.3 Control Center Technologies* *The power system control is structured in the hierarchical levels transmis-sion, sub-transmission (or regional distribution) and local distribution* *(see also Sect. 1.2, Fig. 1.*
> *show annotation*

> *ol and Data Acquisition (SCADA).* *The control center of transmission systems is often called "dispatching center" in the context with the combination of both functions* *.Most countries in Europe op*
> *show annotation*

> *hnologies and the Smart Grid ...* *The technology of the dispatching centers is mainly based on components which are commercially available on the markets for computer and communica-tion technologies.* *The specific of the vendor*
> *show annotation*

> *if the dispatching center fails.* *The SCADA functions in the dispatching center cover all connected users of the network and are, in principle, similar to the substation SCADA. The complete map-ping of the physical network infrastructure within the dispatching system is stand-ard.* *Sophisticated representations a*
> *show annotation*

- The Energy Management System (EMS)

> *are coordinated by the NA block.* *The Energy Management System (EMS) is operated in closed cooperation with the day-ahead and intra-day energy spot markets. Based on the load and renewable energy forecasts each time interval has to be covered by the most economic mix of energy sources available.* *The EMS also includes the*
> *show annotation*

> *hnologies and the Smart Grid ... Expert systems build a separate functional block and support the operators in finding the best solutions to manage congestions and to avoid critical network conditions .Besides the communication wi*
> *show annotation*

Besides the communication with the remote control console for emergency operations further gateways are supported:

- Communication with other dispatching centers,
- Bridges to other enterprise services like
    - network planning,
    - asset management,
    - maintenance management,
    - financial control,
    - energy trading,
    - training simulator for education

3.3 Transmission Technologies

3.3.1 overview

> *sion Technologies3.3.1 Overview The transmission and sub-transmission technologies are classified according to the mechanical construction principle as • Overhead lines,• Underground o*
> *show annotation*

Classes:

- Overhead lines
- Underground or submarine lines which can perform as
    - Cable lines
    - Gas insulated lines (GIL)

related to the voltage level as:

- HV Lines (>60–<220 kV)
- EHV Lines (extra-high voltage ≥220–<800 kV)
- UHV Lines (ultra-high voltage ≥800–1200 kV)

according to the physical transmission principle as:

- AC Lines or
- DC Lines.

> *hnologies and the Smart Grid ... The AC transfer capacity is limited by two parameters: • maximum transmission distance,*
> *show annotation*

AC transfer capacity lis limited by:

- maximum transmission distance,
- maximum transmission power.

> *0° the static stability is lost. Furthermore, in the case of faults the voltages decline and the transfer capacity is reduced accordingly. The subsequent power swing can b*
> *show annotation*

> *.1% for 1200 MVA power transfer. The related temperature increase of the conductors also limits the power transfer capacity .In this way, the power transfer*
> *show annotation*

3.3.2 AC-Transmission

> *t Grid ...3.3.2 AC-Transmission AC overhead transmission lines are constructed with steel towers, porcelain, sil-icone or glass insulators, ground and phase conductors consisting of a steel core providing the mechanical stability and aluminium housing providing a low electric resistance . The typically used ratio of th*
> *show annotation*

> *mposite insulators. Source IEC99* ***The bundling of conductors starts with the EHV level and has two functions:*** *1. Increase of the equivale*
> show annotation

1. Increase of the equivalent diameter of the conductor surface to decrease the electric field strength “E” at the conductor surface. In the result the energy losses caused by the corona effects (ionization of the air environment) may be reduced.
2. Growth of the conductor cross section and reduction of the electric resistance: In the result the energy losses caused by the current flow may be reduced.

> *lower the values of R and X are.* ***The capacitance is influenced by the diameter of the bundled conductors (increase) and the distances between the phases and to the ground (decrease). Therefore, a trend dependency of the voltage level is not clearly visible.*** *Accordingly, the Smart Grid requ*
> show annotation

3.3.3 DC-Transmission

> *nsulators.3.3.3 DC-Transmission* ***The conversion of AC to DC power and vice versa requires an active and fast con-trol of the valves in the converter stations*** *.Two converter valve technologie*
> show annotation

Two converter valve technologies are currently available:

- Current source converters (CSC) or line commutated converters (LCC) applying light triggered thyristors (LTT).
- Voltage source converters (VSC) applying insulated gate bipolar transistors (IGBT).

> *e with a power transfer of 5 GW.* ***The development of HV-DC circuit-breakers has become a high priority in recent years. Basically, DC circuit breakers may***

> *be realized by • pyrotechnic type interruption,*
> [show annotation]

DC circuit breakers:

- pyrotechnic type interruption,
- traditional AC circuit breakers modified for DC,
- electronic current control by semiconductors,
- a combination of such solutions.

3.3.4 Flexible AC Transmission Using Active and Reactive Power Control

> *ctive and Reactive Power Control The power system of the future must be flexible, secure, cost effective and envi-ronmentally compatible. The combination of these tasks can be tackled with the help of intelligent solutions . Flexible AC Transmission Syste*
> [show annotation]

- FACTS: Flexible AC Transmission System

> *help of intelligent solutions. Flexible AC Transmission Systems (FACTS) will play an increasingly important role in the future development of power systems. FACTS consists essentially of th*
> [show annotation]

The impact of FACTS on the power transfer is achieved by:

1. Parallel compensation: control of the voltages on one or both sides of the transmission line. Higher voltages cause a higher power transfer.
2. Series compensation: reduction of the line reactance through serially connected capacitors.
3. Load flow control: influence of the voltage angle difference between the line ends.

3.4 Present Challenges for Transmission Grids

3.4.1 The Impact of Fluctuating Wind and Solar Power Generation

> *Wind and Solar Power Generation The installed power of wind parks and photovoltaic plants will grow dramatically and, depending on the development concepts for the energy mix, it may exceed the peak power demand in a control area. The power generation from wind and sun varies significantly and influences the loading of the network assets (see Sect. 2.5). The volatility*
>
> show annotation

> *hnologies and the Smart Grid ... The photovoltaic plants deliver power during the daylight only, and during the day each cloud can lead to intermittency. Typical power generation statis*
>
> show annotation

3.4.2 The Dislocation of Generation and Load Centers

> *outes for a total of 3400 km.115 The innovations are focussed on the introduction of an EHV DC overlay network .The described enhancement of*
>
> show annotation

> *hnologies and the Smart Grid ... During strong wind periods the AC network is heavily loaded and high losses of reactive power may lead to voltage reductions accompanied by the dan-ger of voltage collapses. Alternately, during weak wind periods the AC network is weakly loaded and an excess of reactive power may cause over-voltages. In Fig. 3.60 these conditions*
>
> show annotation

4. Design of distribution networks and the impact of new network users

4.1 Categories of Distribution Networks

> *d category definitions is given.* *The distribution networks are designed to distribute the electric energy to the consumers in a maximum economic and reliable way.* *Consequently, the practice o*
> *show annotation*

> *at of the transmission systems.T* *herefore, in this chapter the considerations are mainly focussed on the prac-tice of the local distribution networks at the medium and low voltage levels.* *(sub-transmission is considere*
> *show annotation*

4.2 Primary and Secondary MV Distribution

> *ry and Secondary MV Distribution* *The MV distribution network begins at the transformer in-feed from the over-laying network (mainly 110 kV), whereby the transformer is connected to the medium voltage busbar* *.In about 80% of the 110 k*
> *show annotation*

> *ary and sec-ondary distribution.* *The primary distribution equipment has to be dimensioned for load currents up to 4000 A and for short circuit currents up to 72 kA.* *The feeders connected to t*
> *show annotation*

> *uit currents up to 72 kA.* *The feeders connected to the busbar of the substation are equipped with circuit breakers and protection schemes* *. The primary distribution switc*
> *show annotation*

> *tchgear for the consumer supply.* *The secondary distribution network leads downstream outside the substation to the supply areas. Each feeder builds a chain connecting the subsequent MV/LV transformer terminals.* *These terminals are based on the*
> *show annotation*

> *some examples of such terminals.* *Distribution terminals are used for a wide spread extension of the MV net-work with parallel feeders.* *The supplement outgoing fee*
> *show annotation*

4.3 Network Categories for MV and LV

> *Network Categories for MV and LV* *In accordance with this principle various network structures are applied such as* *• Meshed operated network,• Open*
> *show annotation*

In accordance with this principle various network structures are applied such as

- Meshed operated network,
- Open loop network,
- Open loop back-up feeder network,
- Opposite station network

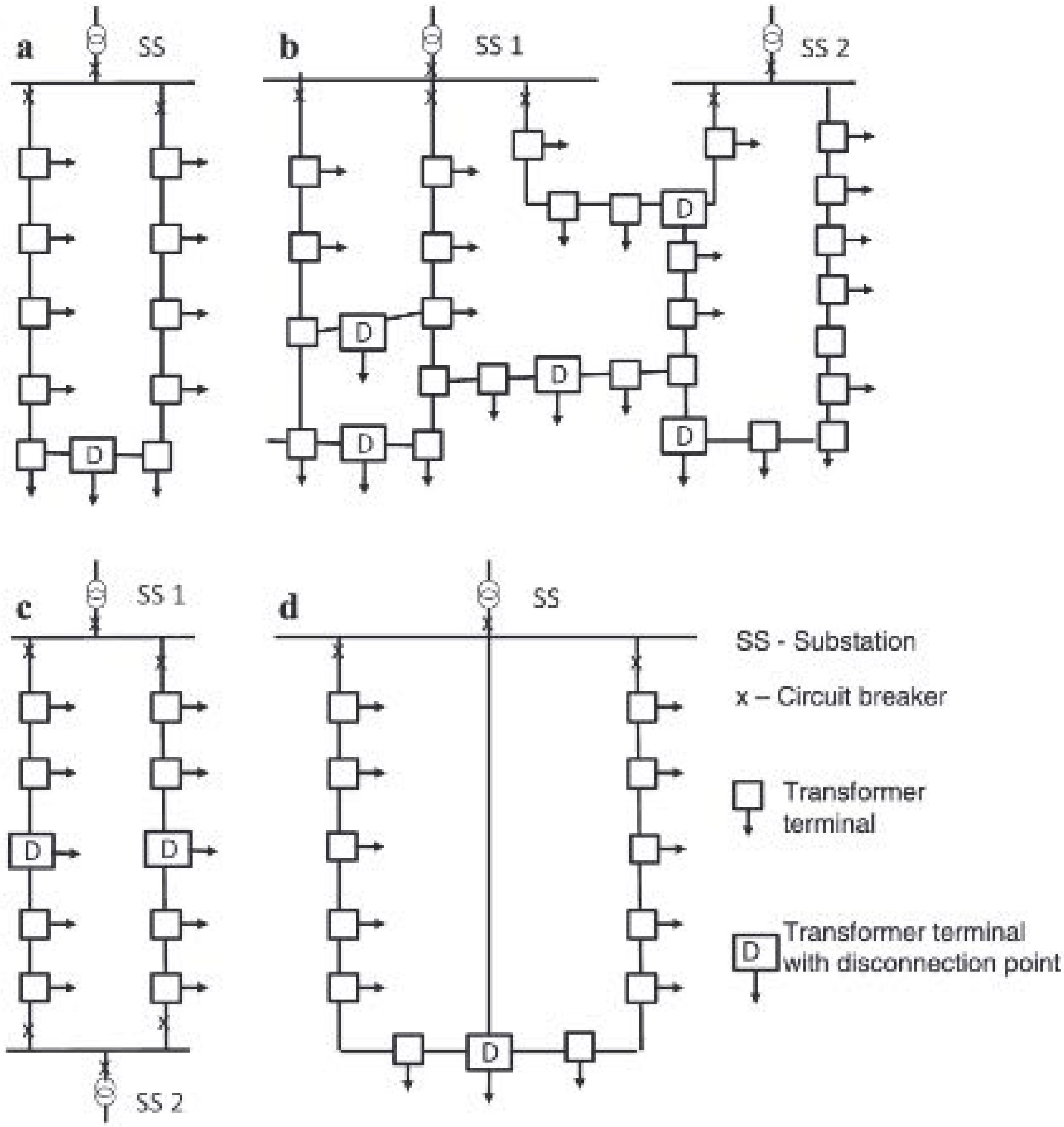

Fig. 4.12 Various MV network schemes using the connectable feeder end principle. **a** open loop, **b** meshed operated, **c** opposite substation in-feed, **d** back-up feeder

4.4 Neutral Grounding Concepts

> .4.4 Neutral Grounding Concepts *The method of neutral grounding does not influence the behaviour of a network under normal operating conditions.* However, in the case of the mos
> show annotation

> er normal operating conditions. *However, in the case of the most frequent fail-ure, namely the phase to earth fault, the duration of the disturbance, the number of the affected consumers, the work load for the operators, the*

> voltage and current stresses for the network assets and the extent of the damage into a double earth fault depend on the method of neutral grounding [4].The application of the diff
> show annotation

> 334.4 Neutral Grounding Concepts The selection of the most efficient neutral grounding method depends on the type of lines (overhead or cable), the line to ground capacitance, the size of the network and the fault currents .In the past, most networks
> show annotation

Types:

1. Resonant Grounding
2. Isolated Neutral
3. Solid and low impedance (current limiting) neutral grounding
4. Combined methods

4.5 Protection for Distribution Networks

4.5.1 MV Networks

> ution Networks4.5.1 MV Networks In MV networks the digital protection relays have been introduced in the majority of substations and distribution terminals of central Europe. It is common now to apply combined devices covering several protection and control functions . Such devices have been avail
> show annotation

> control devices is presented. The combined devices are designed with a basic core serving the common system functions like the memory management, the permanent check of the analogue and binary input signals, the display and setting functions, etc. The protection and control tasks
> show annotation

> *orks are presented in Table 4.3.* *The overcurrent protection provides three various elements for the three phase currents and the ground current.* *The high current element I≫ and*
> [show annotation]()

> *ple of "reverse interlocking".* *The reverse interlocking principle is based on the following: If the fault is located behind the feeder protection in the network direction* *(case 2 in Fig. 4.30) the picku*
> [show annotation]()
>
> *反向连锁原则*

- 定向电流保护

> *r control and supervision tasks.* *The directional overcurrent protection is applied in networks where the pro-tection coordination depends on both the magnitude of the short circuit current and the direction of the power flow to the fault location* *. This type of protection is req*
> [show annotation]()

- 电压保护

> *e phase voltages for processing.* *The voltage protection has the task to protect electrical equipment against under- and over-voltages.* *Both operational states are*
> [show annotation]()

- 负序保护

> *a possible loss of stability.* *The negative sequence protection detects unbalanced loads in the network.* *The application of unbalanced*
> [show annotation]()

- 频率保护

> *ign of Distribution Networks ...* *The frequency protection detects abnormally high and low frequencies in the network or in electric machines.* *If the*

> *frequency lies outsid*
> show annotation

- 热过载保护

> *generator from the network (f>). The thermal overload protection is designed to prevent thermal overloads and subsequent damaging of the protected assets. The protection function rep*
> show annotation

- 电机保护

> *nsformers, motors or generators. The motor protection contains a set of functions like the motor starting protec-tion, a restart inhibit and a load jam protection. The starting protection protect*
> show annotation

- 接地故障保护

> *during a sudden rotor blocking. The ground fault protection has to be designed in accordance with the neutral grounding method applied in the network. Depending on the method th*
> show annotation

> *ct high impedance ground faults. The typical characteristic of intermittent ground faults is that they disappear autonomously only to strike again after some time. This mainly can happen in cables due to aged insulation or in cable joints caused by water ingress .The ground fault pulses can*
> show annotation

> *l damage to the equipment. Therefore, the intermittent ground fault protection operates in the following way: The intermittent ground fault impulses are detected and their duration is recorded and accumulated. If the sum reaches a settable v*
> show annotation

- 断路器故障保护

> *rning about a developing danger.* *The breaker failure protection monitors the proper tripping of the relevant circuit breaker.* *If after a settable time de*
> *show annotation*

- 自动重合闸

> *is not required for MV networks.* *The automatic reclosing function is mainly used in networks with overhead lines.* *Here the experience shows t*
> *show annotation*

- 同步功能

> *ill re-trip the circuit breaker.* *The synchronization function provides the synchronization check before con-necting 2 sections of a network, for example a feeder and a busbar.* *The synchro-nization check eval*
> *show annotation*

- 故障定位器

> *the stability of the network.* *The fault locator is a supplement to the protection functions and calculates the distance to the fault.* *This supports the fast eliminat*
> *show annotation*

> *can be configured individually.* *Advanced protection devices also provide fault or disturbance records,* *mean-ing the registration and p*
> *show annotation*

> *nication links is also foreseen.* *Additionally, disturbance reports may present the sequence of pickup, trip and reset events in the form of an event log* *.150 4 Design of Distribution Ne*
> *show annotation*

4.6 Distribution Network Operation

4.6.1 Ensuring Power Quality

> *ion4.6.1 Ensuring Power Quality* *The distribution network operators are obliged by law to ensure a reliable, con-sumer friendly, ecologic and economically efficient electric power supply to the society with the highest possible level of power quality* *.The definition of the power qua*
> [show annotation]

The definition of the *power quality* is based on the three pillars:

- reliability of supply,
- voltage quality and
- service quality

> *ge quality and• service quality.* *The reliability of supply is verified by statistical analyses of such indices as the frequency of supply interruptions, the average time of supply interruptions or the energy not delivered on time.* *The application of probabilisti*
> [show annotation]

> *principles applied by the DNOs.* *The voltage quality is affected by the technical parameters of the network (like short circuit power or network impedance), the characteristics of the network assets and, especially, by the technical processes and parameters of the network users* *.The majority of the applied*
> [show annotation]

> *k voltage at the access points.* *The demand processes of the network users may impact the voltage quality on all voltage lev-els.* *The damping of the voltage*
> [show annotation]

> *uality on all voltage lev-els.* *The damping of the voltage quality disturbances depends on the technical parameters of the network and its assets: The lower the impedance, the higher the damping* *.SAIDI, [min/a]600500400300200*
> [show annotation]

> *6 Distribution Network Operation Fast voltage sags and flicker can be compensated by applying dynamic voltage restorers which perform an extremely fast in-feed of reactive power to stabilize the voltage. The establishment of such devic*
> *show annotation*

> *or the allocation of industries. The service quality expresses the quality of the relationship between the elec-tric power supply companies and the consumers. As a result of the unbundling o*
> *show annotation*

4.6.2 Process Management

> *g DNO.4.6.2 Process Management The Distribution Control Centre (DCC) performs the core of the process man-agement in distribution . Advanced DCCs present on scree*
> *show annotation*

> *s man-agement in distribution. Advanced DCCs present on screen the network topology, measurements, meter values, event messages in schemes, diagrams, profiles, tables and reports . The control is possible by usi*
> *show annotation*

he management of the electricity distribution is focused on two basic systems:

- SCADA—supervisory control and data acquisition,
- GDOF—general decision and optimization functions.

The SCADA system performs the functions:

- Alarms in case of critical loading, disturbances of the voltage quality and faults,
- Acquisition and processing of measurements and meter values,
- Switch commands and further control (e.g. transformer tap changing),
- Monitoring of the network topology,

- Evaluation and archiving of the results of the performed application functions.

The GDOF system is more concentrated on the power balancing functions which have a strong impact on the network operations:

- Load and local generation prediction,
- Load control,
- Optimization of the purchase and import of electric energy,
- Condition simulations.

> *energy,• Condition simulations. The network operator is able to estimate the current network situation by an appropriate visualization on the screens. The following functions are perf*
> *show annotation*

The following functions are performed in this way:

- Network supervision,
- Switching and control procedures,
- Starting of actions to eliminate faults and disturbances.

4.7 New Trends in Distribution Systems

4.7.1 Distributed Generation and New Types of Load

分布式发电和新型负载

> *Generation and New Types of Load The new challenges for distribution network operation are caused by global tar-gets to reduce the CO_2 emissions, to increase the share of renewable energy in the energy balance and to increase the energy efficiency (see also Sects. 1.1 and 1.3).I*
> *show annotation*

- DER: distributed energy resources 分布式能源

> *able generation (see Sect. 7.1).* *A significant part of the renewable energy will feed into the distribution net-works from a large amount of small sized distributed energy resources (DER).* *As a consequence of these tren*
> *show annotation*

> *ign of Distribution Networks ...* *The connection of DER in the LV and MV networks, however, may cause bi-di-rectional load flows between the LV, MV and HV networks.* *If the load is lower than the g*
> *show annotation*

> *een the LV, MV and HV networks.* *If the load is lower than the generation, bottom–up (reverse) power flows will occur. And, because the meteor-ological conditions which directly affect generation levels are volatile, the load—gen-eration balance can change multiple times during the day. Consequently, the power flow becomes volatile and changes its direction multiple times during the day as well.* *Furthermore, the energy effic*
> *show annotation*

> *for the majority of LV networks.* *The achievement of the energy efficiency targets will also be supported by a paradigm change regarding the heating systems for households, small enterprises and public buildings.* *Program have been started*
> *show annotation*

4.7.2 Impact on Power Quality

> *s.4.7.2 Impact on Power Quality* *Due to the significant shares of DER, especially volatile energy sources and the appearance of new loads like e-mobiles, extreme situations may occur which may cause short-term over-stressing of the network assets and of devices on the consumer side* *.MV: 20, 20, 30 kVLVFig. 4.38*
> *show annotation*

> *y occur in the supply direction.* *Great challenges are seen in the reverse interferences of the new network users regarding the voltage quality:* *• Over-*

> *voltages through the conn*
> show annotation

Great challenges are seen in the reverse interferences of the new network users regarding the voltage quality:

- Over-voltages through the connection of generators,
- Under-voltages through powerful simultaneous loads,
- Flicker (闪烁，飘忽不定) by wind power and photovoltaic plants,
- Harmonic distortions generated by the power electronic converters of wind power and photovoltaic plants and by the charging units for e-mobiles.

> *the influences mentioned above. In conclusion, the considerations regarding the impact of new users of distri-bution networks clearly demonstrates that distribution network operations will becomes more complex and will need more intelligent coordination, control and supervision in the sense of Smart Grids .References1. B. M. Buchholz.*
> show annotation

5 Smart Operation and Observability at the Transmission Level

> *operation failures is rising. The application of advanced power automation technology helps to increase the system observability, to provide guidance for the dispatchers and to automatically perform the proper countermeasures in emergency situations. In this context, the term "*
> show annotation

- Congestion management 堵塞管理

> *oad flows through the net-work. Congestions may occur within a short time as a result of unforeseen outages of power stations or network assets or due to significant deviations from the regis-tered schedules that are larger than expected. Chapter 5Smart Operation and Obs*
> show annotation

> *由于电站或网络资产的意外中断，或由于与电力站点的严重偏差大于预期，可能在中段时间内堵塞。*

5.1 The Root Causes of Large Blackouts and the Lessons Learned

> *d the Voltage Collapse Phenomena Power system operation includes the harmonious co-ordination of many processes in a large cybernetic system composed of millions of components of equipment. The main challenges are: 1. Balanced interplay of tr*
> *show annotation*

Challenges of Power system operation:

1. Balanced interplay of transmission capabilities, electricity demand and power generation,
2. Coordinated protection, control and communication functions supporting a flexible, real-time adaptation of the system conditions to actual situations.

> *nmark, Italy, Athens and Moscow. Voltage collapse can occur if the reactive power demand of the loads rises sig-nificantly due to voltage reduction in the grid. This mainly applies to motor-driven loads. The additional reactive pow*
> *show annotation*

> *s learned from this event are:• SCADA systems and communication links have to be secure under all circum-stances and have to be engineered so that they are uninterruptable, • Appropriate guidance for dispa*
> *show annotation*

The lessons learned from this event are:

- SCADA systems and communication links have to be secure under all circumstances and have to be engineered so that they are uninterruptable,

- Appropriate guidance for dispatchers accompanied by automatic network congestion management have to be performed if the transmission network is weakened for hours at a time,
- The protection parameters should be adapted to the network conditions

> *the affected substa-tions. The time synchronization via satellite of all intelligent electronic devices (IEDs) for protection and control in the power system is now a strong request .5.1.3 Large Supply Interruptio*
> show annotation

> *clusion it should be stated:• Each operation requires a network security calculation in advance of taking action ,• Operations that bring the sys*
> show annotation

In conclusion it should be stated:

- Each operation requires a network security calculation in advance of taking action,
- Operations that bring the system into a N-1 unsecure situation should be strictly avoided,
- The settings of the protection have to be archived and approved regularly in accordance with the substation documentation.

> *the subsequent voltage collapse. Again the requirement for better observability of the transmission network comes up. Furthermore, the N-1 criterion has to include busbar faults and also consider the connected power generation .5.1.5 The Italian Blackout 200*
> show annotation

5.2 Control Areas and System Services

- TSO: transmission system operators
- DNO: Distribution network operators

> *ontrol Areas and System Services As operators of the transmission system, the TSOs are responsible for the secure and reliable operation of the*

> *electricity network in their respective control area, and for interconnections with other electricity networks.* *In Continental Europe, the*
> [show annotation]

> *bility at the Transmission Level* *The TSOs are obliged by law to operate their control area in a manner which assures the most secure, economical and environmentally sound network-dependent supply of electric power in the public interest* *.This includes the following mai*
> [show annotation]

TSO (输送系统的操作者) 有责任以最安全、经济和环保的电力供应方式经营其控制区域，包括：

1. *Secure operation* of the transmission network ensuring the N-1 criterion at all times.
2. Management of the *balance of generation and load* at all times, provision of the interface to the liberalized electricity markets and carrying out the basic physical work necessary for the commercial power transfers.
3. Control of the *import/export of electric power* between the underlying networks and the neighboring control areas.

> *d the neighboring control areas.* *With regard to maintaining the proper operation of the control area, the TSOs provide system services to network users that decisively determine the quality of the electricity supply.* *The most important of these sys*
> [show annotation]

The service to network users:

- Power system management,
- Frequency control,
- Voltage control,
- Restoration of supply.

5.2.1 Power System Management

> *y.5.2.1 Power System Management The power system management at the transmission level involves two aspects, namely the operational planning and execution of the network related tasks and the generation–load balancing .First, the top priorities of th*
> *show annotation*

The power system management at the transmission level involves:

1. the operational planning and execution of the network related tasks
2. the generation-load balancing

> *the generation–load balancing. First, the top priorities of the network related tasks are: • the supervision and contro*
> *show annotation*

First, the top priorities of the network related tasks are:

- the *supervision and control* of the network topology including monitoring the bandwidths of voltages and power flows,
- the *assurance* of the network N-1 security,
- the recognition of *emergency* situations and the initiation of *congestion management*,
- the requesting and execution of *switching operations*,
- the *voltage/reactive power and power/frequency control* operations and the commissioning and maintenance of all the network assets, including the requisite facilities for metering and pricing regarding the horizontal energy exchange between the transmission system operators and the vertical energy exchange relating to the connected sub-transmission networks.

> *ected sub-transmission networks. Secondly, the power system management includes the generation and load bal-ancing. This involves the operational implementation of the agreed upon power exchange based on the schedules of the "Balancing Groups" and the generation schedules for power stations, also keeping in mind the requirements for reserve power provisions. 183The*

> *control area consists of*
> [show annotation]
>
> *“平衡组”的计划、发电站的发电计划、保留电力供应的要求*

The control area consists of an arbitrary number of balancing groups containing:

- power injection nodes (usually metering points for the generating units of power stations) and
- withdrawal nodes reflecting the demand.

BGM (Balancing group managers)

> *wal nodes reflecting the demand. The energy balance of the control area is subject to the responsibility of a number of balancing group managers (BGM). The balancing groups work toget*
> [show annotation]

In commercial and administrative terms, the BGM has the responsibility to

- inform in a timely manner the responsible system operators about injection and withdrawal points assigned to his balancing group,
- aggregate the electrical energy exchanges in such a way that only one schedule is exchanged between two balancing groups,
- deliver day-ahead schedules between 2 and 4 p.m. to the TSO. The schedules contain 96 values of the average power within each 1/4 h of the following day.

> *the pertinent metered values.I n conclusion, the significant power system management functions include the load and the renewable generation predictions for the control area, the manag-ing of the interrelations with the electricity markets to cover the load schedule, the congestion forecasting and management, the observation of the instantaneous deployment of the power stations, and the co-ordination or utilization of system services .The*

> *central functions of po*
> *show annotation*

5.2.2 Frequency Control

> *network.5.2.2 Frequency Control In an electric power system, power generation must be constantly adjusted to follow the demand. Changes in demand or power station disturbances impair this balance and cause a deviation of the system frequency. To meet the requirements Contro*
> *show annotation*

> *e system sta-bility in general. Accordingly, the TSOs have an obligation to permanently main-tain sufficient control power within three categories, the time characteristics of which are presented in Fig*
> *show annotation*

- Primary control (or reserve) power
- Secondary control (or reserve) power
- Tertiary control power or Minutes reserve

> *trol and minutes reserve power). These three categories have different origins, parameters and targets of application. The purpose of the primary contr*
> *show annotation*

- The purpose of the primary control is the assurance of the frequency control in emergency situations after the unplanned outages of important power plants.
- The secondary control power may be positive or negative. Both kinds of secondary power have to be contracted in parallel
- The TSOs shall deploy minutes reserve power in the event of large imbalances between generation and consumption and/or for the restoration of a sufficient secondary control band.

> e measured frequency from 50 Hz. The secondary control power may be positive or negative. Both kinds of sec-ondary power have to be contracted in parallel .The TSOs shall deploy minutes r
> show annotation

> ve to be contracted in parallel. The TSOs shall deploy minutes reserve power in the event of large imbalances between generation and consumption and/or for the restoration of a sufficient sec-ondary control band. The request for and delive
> show annotation

5.2.3 Voltage Control

> Yes Yes1875.2.3 Voltage Control Voltage control forms part of the measures for provision of a secure supply, for which the network operators at all levels of the power system (transmission system operators TSO and distribution network operators DNO) bear responsibility. The network concerned, the ge
> show annotation

> he responsible network operator. The TSO and DNO shall bear responsibility for balanced reactive power man-agement in his network installations, including the demand of the connection users. The TSO and DNO shall eit
> show annotation

5.2.4 Restoration of Supply

> evel5.2.4 Restoration of Supply The TSO is responsible for reliable system operation and its prompt restoration following large-scale failures and to draw up appropriate plans for preventive and operational measures, with due respect to the respective system infrastructure, in conjunction with adjacent TSOs or with subordinated DNOs and power station operators .The providers of preventive mea
> show annotation

> ell as power station operators. According to the measures required, the providers must take technical measures for the restoration of supply and

> demon-strate the efficiency of their facilities to the TSO. The TSO has to resort to t
> show annotation

5.2.5 Generation Scheduling: Merit Order Principle

> cheduling: Merit Order Principle Based on the schedules delivered by the balance group managers, each afternoon the TSO completes the day ahead load schedule for the control area. A significant part of the lo
> show annotation

> schedule for the control area. A significant part of the load is normally covered by contracted electricity delivery (for exam-ple in the industrial sector). Furthermore, the forecasts of the balancing group “Renewable Energy” are known. The further requested generation
> show annotation
>
> 合同电力供应

5.2.6 System Service Provision by Distributed Energy Resources

> by Distributed Energy Resources The distributed energy resources (DER) are mainly based on renewable energy sources RES (wind, solar, biofuel, hydro) and on cogeneration of heat and power plants (CHP). Until 2012 they were mostl
> show annotation
>
> #DER #RES #CHP

> ity related to the peak load), a nd the generated power of the DER can exceed the weak load. This requires innovative approaches to integrate DER into the sustain-able power system operation. The contribution of DER to the provision of system services will become mandatory. Today the TSOs are

> obliged to ma
> show annotation

> services will become mandatory. Today the TSOs are obliged to manage and operate the electric power transmis-sion networks, and to do so they rely on system service procurement from the free market. However, the TSO cannot efficie
> show annotation

- VPP 虚拟电厂

> gregated offer of control power. Therefore, the provision of system services by DER requires technical solutions in the sense of a coordinated operation of DER, storage and controllable loads (Demand Side Management—DSM) within virtual power plants (VPP). The vir-tual power plant shall be able to provide system services in the same way as the traditional power plants. Today, the system services provi
> show annotation
>
> #DSM #VPP #DER

> traditional power plants.Today, the system services provided by the DNO in their networks are limited to voltage stability, the network operation as a part of the system management and the restoration of supply. In the future, the VPPs will
> show annotation
>
> #DNO

> tion of supply.In the future, the VPPs will be able to support the frequency control by offer-ing control power to the TSO . The VPPs are also able to part
> show annotation

> #TSO #VPP

> SI) is pre-sented in Table 5.2. DSI consists of DSM (Demand Side Management)—the active control of loads and DSR (Demand Side Response)—the influence on the demand by dynamic tariffs. The photovoltaic plants, for
> show annotation
>
> #DSI #DSM #DSR

> bed for the photovoltaic plants. DSM can provide positive control power by switching-off the load for a cer-tain time. Many enterprises use such oppor
> show annotation

> bility at the Transmission Level DSR is not actively controllable and therefore it is not suitable for the control power market .Finally, fuel driven power
> show annotation

> for the control power market. Finally, fuel driven power plants and storage units are completely controllable and may provide all kinds of system services. As a rule, fuel driven powe
> show annotation

> ce with the rules of Table 5.1. Consequently, the fuel driven power plants can participate in both markets at the same time—for energy and for reserve power .In the low energy price pe
> show annotation

> ent respond to the requirements. For all kinds of CHP—fossil fuel and RES—a thermal storage is the key to an electrical driven operation. Mostly CHP plants are desi
> show annotation

> less from the heat demand. A thermal storage allows an active storage man-agement and therefore thee CHP plant is able to produce heat in advance to

> *fill the storage while electrical power could be generate following a schedule. Additionally, thermal storages have much lower investment and operational costs than electrical storage plants.* *The storage size should fit*
> show annotation

> *gent thermal storage management.* *VPPs may play a significant role in supporting the quality of supply regarding the voltage quality and the reliability* *. Figure 5.23 presents a rural 2*
> show annotation

5.3 Power System Observation and Intelligent Congestion Management

5.3.1 Need for More Observation in the Power System

> *and the Mediterranean area.* *As a result of the liberalized energy markets and the extremely fast growth of vola-tile renewable energy production the power flows through the networks and the interconnection nodes between the control areas has become strongly volatile* *. The strengthening of the ne*
> show annotation

> *a rural network by a VPP [13]195* *These elements have to be included in the online security assessment calcula-tions. The neighboring TSOs are obliged to deliver:* *• the related parameters of the*
> show annotation

These elements have to be included in the online security assessment calculations. The neighboring TSOs are obliged to deliver:

- the related parameters of the transformers, lines, power stations,
- the real time measurements of voltages, power flows and
- the topology data of the related network parts.

5.3.2 Prediction Methods for a Secure Power System Operation

> *wer Injections from Volatile RES* *In accordance with the growing contribution of volatile RES in the power balance the prediction of the RES injections will become more and more important for the network security* *[12].<100ms 20ms - 1 s 1*
> [show annotation]

Two developing trends have to be considered:

- The further growth of the installed power of *photovoltaic plants and smaller wind power parks* will affect the distribution and sub-transmission network operations.
- The number of *large scale wind parks* with installed power of some 100 MW that are erected in *onshore and offshore locations* and have direct access to the transmission network will continue to increase.

Consequently, the further development of prediction systems has to be focused on:

1. The improvement of the *prediction accuracy*,
2. The introduction of prediction methods in the *distribution level*,
3. The *extended data exchange* between the transmission and distribution networks

> *ssion and distribution networks.* *Network security will require more interaction between the TSO and the DNOs because of the volatility of the power flows at the coupling nodes between the net-work levels.* *Prediction tools have been d*
> [show annotation]

> *des between the net-work levels.* *Prediction tools have been developed and implemented since 2000 especially for the wind power production within the control area of the TSO.* *The TSOs have established a*
> [show annotation]

> *n error may occur during 9 h.* *The security of the power system operation requires the parallel execution of the day-ahead predictions and the short-*

> *term predictions to be prepared in advance for possible congestions caused by such strong deviation*
> show annotation

> *d by a weighting coefficient wi: Significant improvements of the prediction quality are achievable if intelligent weighting methods with regard to the weather situation are applied. Here the ben-efits and weakness*
> show annotation

#DACF

Day-Ahead Congestion Forecast (DACF) in the Interconnected Transmission System

> *terconnected Transmission System Within the interconnected transmission network in Continental Europe the DACF approach was implemented to estimate critical network conditions in advance. This approach realizes the prediction of the operation conditions for the whole power system 2 days in advance (2DCF) and for the current "intra-day" (IDCF). The network condition predict*
> show annotation

Prediction operation:

- The intra-day predictions use load and generation data from actual snapshots.
- At the moment of the predictions for d + 2, the schedules for the power plants are still not available.
- Each TSO prepares for 6 time points (Germany-24) of the day-ahead data sets including the loads and injections of all network nodes.
- In the next step, the snapshot of the network conditions of the reference time points are taken from the archive.
- The power producers provide the predicted power injection schedules to the TSO taking into account the load schedule.
- To balance the load and generation, the loads in all nodes will be adapted in proportion to compensate the deviations between the reference and the

predicted power plant schedules

- The predicted data sets of all TSOs and the overall data set for the interconnected system are available for all network operators on a common server.

> *redicted power plant schedules. The predicted data sets of all TSOs and the overall data set for the intercon-nected system are available for all network operators on a common server. The Common Information Model a*
> *show annotation*

The Need for Network Level Overlapping Congestion Forecasts

> *Overlapping Congestion Forecasts The growing share of DER feeding into the distribution networks means that the distribution networks may be stressed above their capability limits (see also Fig. 4.39). The nee*
> *show annotation*

> *tion 201networks is growing. Currently, though, the application of congestion forecast tools is still not common in distribution networks. However, the prediction of the o*
> *show annotation*

> *common in distribution networks. However, the prediction of the of the distribution network conditions will play an increasingly important role for the general power system operation. The volatile bi-directional load flows at the coupling nodes between the network levels has a growing impact on the security of the whole power system. It is an urgent need that the ne*
> *show annotation*

> *urity of the whole power system. It is an urgent need that the network operators on the different levels cooperate in the prediction of RES power injections and the prediction of congestion condi-tions in a common way .The common "level overlappin*
> *show annotation*

Steps:

1. accurate predictions of the load and the power injections have to be performed for the local distribution networks at the MV level
2. the predicted data of the several connected nodes has to be transferred to the planned topology of the MV network.
3. the predicted network conditions of the HV sub-transmission networks create the power flow conditions at the coupling nodes with the transmission network at the EHV level.

> *ission) network at the HV level.* ***The power flow estimations serve as the inputs for the network condition fore-casts at the upper network level which is based on the planned topology, the pre-dicted loads and power injections.*** *Finally, the predicted network c*
> *show annotation*

> *bility at the Transmission Level* ***5.3.2.4 The Cellular Approach for Predictions, Balancing and Schedule Management*** *The weakness of the current*
> *show annotation*

The weakness of the current balancing and prediction processes described in the previous chapters consists of the following aspects:

1. The suppliers are mostly the balance group managers for the withdrawal nodes.
2. The reference day principle used for the DACF congestion forecasts is also of low accuracy. The TSOs increasingly need the coupling node oriented forecasts for the secure system operation within their control area.
3. The TSO is responsible for balancing all of installed RES in its control area.
4. The prediction of the power injections from RES is based on the general weather forecasts for larger regions. However, the weather conditions may differ greatly within one region. The prediction accuracy can be significantly improved if the predictions for the RES power injections are performed for smaller territori

- SSC: Smart Supply Cells 智能供应细胞

> *on level is considered in [12]. The SSCs sup-port the TSO to reduce the complexity of power system operation self-balancing, provide the cellular balancing group responsibility and offer system services as presented in Fig. 5.31.An S*
> [show annotation]
>
> #SSC

> *ces as presented in Fig. 5.31. An SSC may cover one or more distribution networks containing DER that are fully involved in the balancing processes. They are obliged to predict and deliver their individual schedules. If the DERs have to provid*
> [show annotation]

5.3.3 Modern Protection Concepts

> *the dis-turbance enlargement. T he protection schemes have to be prepared for the Smart Grid challenges regarding the • increasing complexity, extent*
> [show annotation]

he protection schemes have to be prepared for the Smart
Grid challenges regarding the

- increasing *complexity*, extent and loading of the power systems,
- change of the *generation structure* by use of DER with partly volatile power injections,
- *energy trading* which does not consider the limitations of the network capacity.

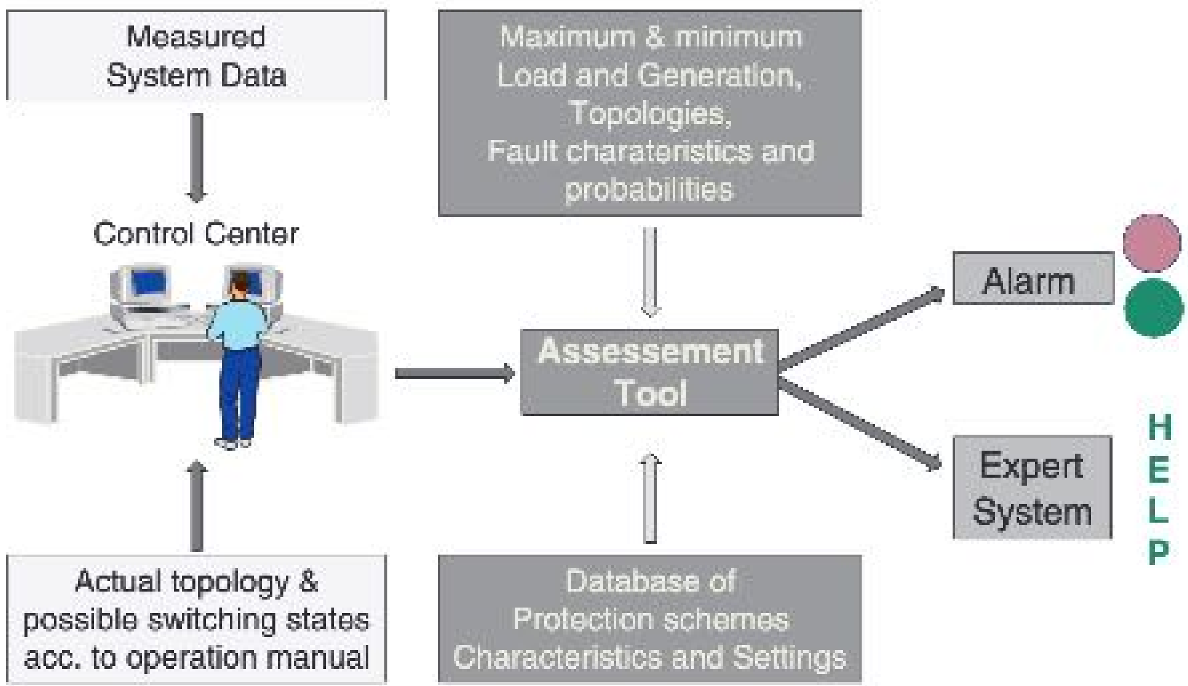

Fig. 5.34 Protection security assessment approach

> *twork conditions.Consequently, it will become more and more important for the general secu-rity of network operations to observe the selectivity of the protection schemes. An important instrument for the prevention of disturbance enlargements is the "Protection Security Assessment" (PSA), demonstrated in Fig. 5.34.First*
>
> show annotation
>
> #PSA

1. First of all, the PSA method requires a detailed data base of all protection schemes, characteristics and settings of the network.
2. Secondly, a data base for condition simulations has to be established containing
   - the load and generation conditions,
   - the possible network topology changes and
   - fault characteristics, disturbance records, fault probabilities

> *ce records, fault probabilities.* *Based on the described data the assessment tool may provide a stepwise off-line event simulation including all protection devices, all possible faults and ground resistances at various locations along the network considering also the fault proba-bilities and breaker failure conditions* *.As a result of the simulat*
> *show annotation*

If large networks with tens of thousands of protection devices have to be approved, the results should be presented separately in three levels:

1. the main protection schemes,
2. the back-up protection schemes,
3. the main and back-up protection schemes together

Adaptive Protection

> *f what modern pro-tection means.* *In the past, the protection schemes were designed to protect the assigned asset against damages caused by faults by tripping the faulted network elements rapidly and ensuring in the same way the secure continuation of the network operations. The only criterion for activities was the detection of faults that exceeded the pickup settings.* *Now, however, due to the qu*
> *show annotation*

> *at exceeded the pickup settings.* *Now, however, due to the quickly changing network conditions the protection behaviour has to become smarter and provide more flexibility.* *The protection takes part in*
> *show annotation*

> *bility at the Transmission Level* *The target of this new role is that the protection automatically recognizes that the actual settings and characteristics may cause over or under function.* *The adaptive protection is a*
> *show annotation*

System Protection

> *plied.5.3.3.3 System Protection* *In addition to the traditional tasks of the rapid, secure and selective fault elimi-nation, the protection schemes may perform system protection tasks ensuring the power system stability in emergency situations and avoiding the enlargement of disturbances into blackouts* *.The practice of under-freque*
> show annotation

5.3.4 Wide Area Monitoring by Phasor Measurement

> *Monitoring by Phasor Measurement* *Wide area monitoring systems (WAM) are based on accurate measurements of voltages, phase angles, currents, frequency and frequency sags and reactive and active power flows by phasor measurement units (PMU) installed in selected nodes of the network system.* *The innovative idea of this*
> show annotation
>
> *广域检测系统；相量测量单元*
>
> #WAM #PMU

> *l form of the system protection.* *The results of the phasor measurement analysis by the data concentrator provide:* *• a real-time state estimation a*
> show annotation

The results of the phasor measurement analysis by the data concentrator provide:

- a real-time state estimation and stability observation of the networks,
- the detection of power oscillations, their analysis and the generation of appropriate countermeasures,
- the dynamic load flow control,
- improved accuracy of the analysis of faults and the fault location,
- the monitoring of asset condition for their higher utilization,
- detection of islanded networks through frequency comparison.

> *first pilot project have begun.* ***The interactive user interface of the data concentrator has to be designed to provide an optimum support to the dispatchers.*** *The following design rules*
> show annotation

The following design rules are common in the advanced WAM systems of different vendors:

- fast identification of the system conditions (okay, critical, alarm),
- free selection of the desired measurement records or phasor diagrams in a configuration field,
- setting of thresholds to be observed,
- simple shift between on-line and off-line mode for the interactive analysis of events,
- geographical presentation of the network with the allocation of PMUs allowing the fast location of areas with stability problems,
- gateways for data export and import to allow the cooperation with other assessment tools.

5.3.5 Steady State and Dynamic Security Assessment

> *ne measured data of the network.* *Security calculations today are mostly performed as load flow contingency calcu-lations (sequence of N-1 violations using the current network conditions). As a result the operator is getting an overview of the situations in which overloads of equipment and congestions may occur. All decision making is the responsibility of the operator.* *However, the on-line steady stat*
> show annotation

> *ls for stabilizing actions.* *Both the steady state assessment (SSA) and the dynamic security assessment (DSA) methods have to be enhanced and intro-duced as a combined method to provide better support to the network dispatcher* *.In emergency situations it is n*
> show annotation

> #SSA #DSA

> *as only of a qualitative nature. A security assessment could provide the quantitative request of load reduction. For example, lowering the pump storage load by 50% would not affect the con-sumers. The Italian blackout could*
> show annotation

The advanced steady state security assessment has to be executed on-line. It consists of the following steps:

- on-line performance of subsequent N-1 *contingency load flow* calculations,
- consideration of the *volatility of power injections* with a time horizon of minimum 1 h,
- indication of possible *congestions and emergency* situations,
- start of an *optimized load flow calculation* for the indicated N-1 violation conditions taking into account the available control opportunities (e.g. change of grid topology, reactive power control etc.),
- recognizing the *differences* to the current operation conditions,
- creation of *recommendations* for how to shift the system to secure N-1 conditions.

Dynamic security assessment (DSA)

> *may be generated for guidance.T he dynamic security assessment is based on advanced power system simula-tion methods. In many cases it has been demonstrated that the simulation deliv-ers a highly accurate depiction when compared with the recorded disturbances . In Fig. 5.49 such a comparison*
> show annotation

> *rol areas of France and Germany. This example demonstrates that the dynamic system behavior is accurately predictable using simulation tools. Furthermore, the countermeasures for stability enhancement may also be simulated and their efficiency may be approved. The dynamic investigation*

> of the
> show annotation

The dynamic investigation of the power system has to consider the three major aspects of stability disturbances:

- the voltage stability (avoidance of voltage collapse according to Sect. 5.1.1.)
- the small signal stability (when the system is near to the initiation of un-damped power swings according to the eigenvalue method, or if the voltage angle difference between the neighboring nodes is close to 90°),
- the transient stability reflecting the damping of power oscillations after faults.

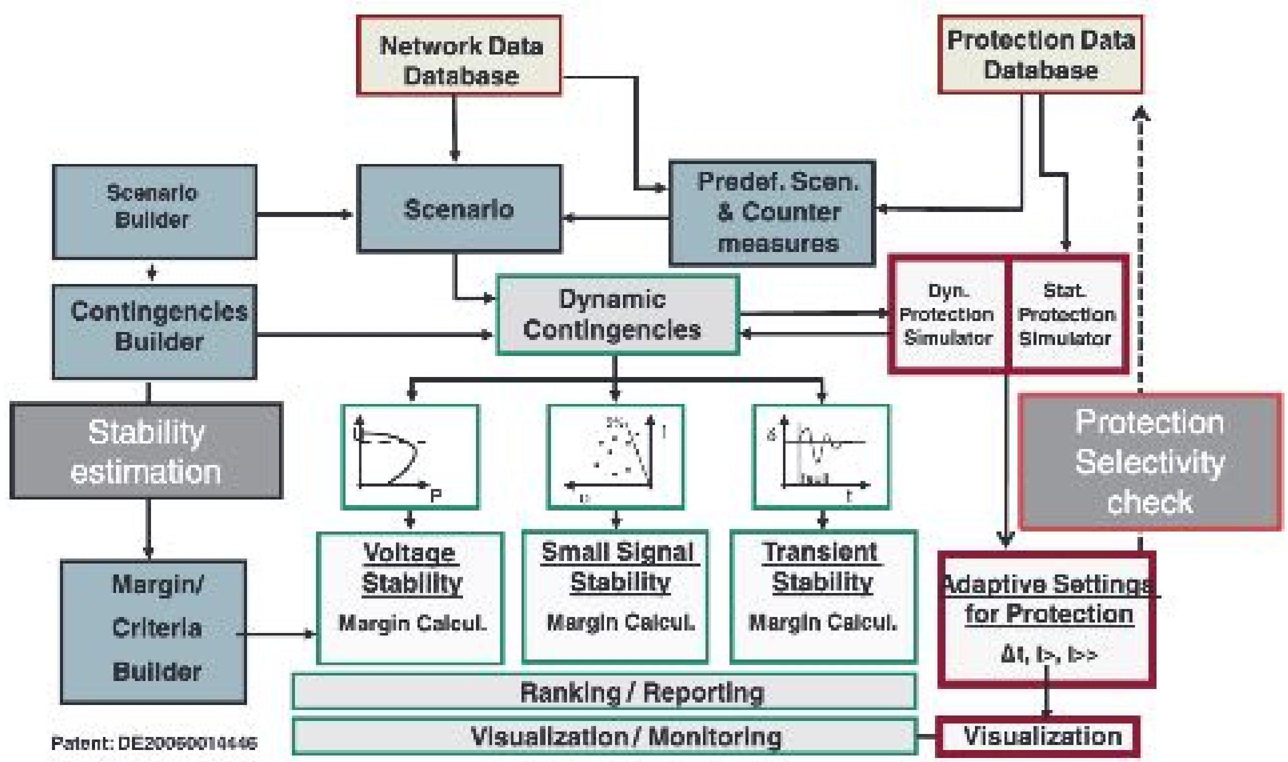

Fig. 5.50 General scheme of the dynamic security assessment. *Source* R. Krebs, Siemens AG

> ndations for adaptive settings. *The 1st priority of the dynamic security assessment is to provide detailed infor-mation of the power system stability and to create alarms in critical situations.* Worldwide research and develo
> show annotation

> *possible improve-ment actions.* *For such expert systems a broad knowledge data base of the dynamic system behavior has to be developed. The neural network is able to select the appropriate countermeasures for improving a recognized critical situation using the knowledge data base* *.Figure 5.51 demonstrates the DS*
> show annotation

5.3.6 Weather Condition Monitoring and Flexible Line Loading

> *toring and Flexible Line Loading* *The maximum loading of transmission lines is limited by the temperature of the conductors which is influenced by the weather conditions and the current flow.* *The thermal threshold is calcul*
> show annotation

> *ot exceed the thermal threshold.* *However, the worst case conditions are very rarely valid. In practice, the tradi-tional thermal overload protection avoids the full utilization of the physical trans-port capability of the transmission lines. In the case of lower temperature or higher wind speed, an increase of the line loading will be possible without exceeding the thermal thresholds* *.Monitoring the meteorological*
> show annotation

5.4 Conclusions

> *everal projects.5.4 Conclusions* *The new conditions of network operation with volatile power injections lead to a higher loading of the network assets and the growing danger of stability violations.* *Maintaining the high level of r*
> show annotation

Maintaining the high level of reliability has to be performed in two ways:

- *network enhancement* by advanced primary technologies,
- improved monitoring and intelligent *congestion management*.

> *telligent congestion management.* ***The new tasks of network planning are directed at defining the optimum ratio between both approaches.*** *The intelligent congestion ma*
> [show annotation]

- Intelligent congestion management

> *ratio between both approaches.* ***The intelligent congestion management is based on the set of the above described methods and instruments allowing better observation of the network conditions, more efficient utilization of the installed assets and adaptation of the network control/automation/protection according to these conditions.*** *However, the described methods c*
> [show annotation]

However, the described methods cannot stand alone. It is necessary to manage their mutual interaction in order to gain optimum efficiency and operational benefits.

- monitoring and communication of the *weather conditions* to the control center,
- integration into the *state estimation* procedures of the control center,
- approval by the *dynamic security assessment* and protection security assessment to avoid, for example, voltage collapse or stability problems and the
- dynamic adaptation of the *thermal overload protection* characteristics.

> *ethods of network planning.* ***Intelligent congestion management is requested to ensure the efficiency of the transmission network enhancement and the stability of the entire interconnected transmission system.*** *References 1. U.S.–Canada P*
> [show annotation]

> *load protection characteristics.* ***The intelligent congestion management supplements the network extension by using primary assets.*** *The appropriate*

> *measures hav*
> show annotation

6. The Three Pillars of Smart Distribution

6.1 The Relationship Between Smart Grids and Smart Markets in Distribution Systems

> *rational processes accordingly. The coor-dination of all network users in the sense of the Smart Grid definition seems to be useful to ensure the economic feasibility, the reliability, the sustainability and the reduced ecological impact of the electricity supply processes. The question arises, how the opt*
> show annotation

The question arises, how the optimum relationship can be found between:

- the network enhancement required to respond to the requested bidirectional power transfers with *extremely high variability*, and
- the impact on the network users to *adapt their behaviour* to the available power transfer capacity

> *ee also Sect. 4.7.2, Fig. 4.39). However, the coordination of the connected consumers and the distributed energy resources (DER) has an impact on the market processes. It will become necessary to*
> show annotation

It will become necessary to approach such challenges like:

- *balancing* the intermittent *power injections* of the DER with the *demand*,
- monitoring and controlling the *voltage increase* at the connection points of DER,
- observing the *loads*, especially the charging of electric cars to avoid any overloading of network equipment,

- maintaining the *reliability* of supply at today's high level despite the changing conditions.

> *despite the changing conditions. The quality of supply including the voltage quality and the reliability may be maintained under the new conditions in two ways: 1. Extremely strong enhancem*
> *show annotation*

The quality of supply (voltage quality and reliability):

1. Extremely strong enhancement of the network to meet all possible, including very rare varieties, of load flows or
2. Smart interaction between grid operations and market activities concerning the producers and consumers.

> *as "Smart Supply", see Fig. 6.1: The relationship between the markets and the distribution network operators (DNO) is complex and diverse .Traditionally, the network u*
> *show annotation*
>
> #DNO

> *s (DNO) is complex and diverse. Traditionally, the network users had to compensate the operational expenses (OPEX) including the return of investment (ROI) through the markets and, in exchange, the DNO offered a high power quality consisting of three compo-nents—voltage quality, reliability of supply and service quality . The liberalized markets now*
> *show annotation*
>
> *运营费用；投资回报*
>
> #OPEX #ROI

DNO offers a high power quality consisting of three components:

- voltage quality
- reliability of supply
- service quality

> *processes227On the other hand, the economy of the grid operation expenses will require the adaptation of loads or generation to the available network capacity in the environ-ment of volatile power in-feed and strong simultaneous demands. In this sense, the DNO will*
> *show annotation*

> *ion of heat and power—CHP).T he stakeholders of the markets are the traders, the power plants, the virtual power plants (VPP—aggregating and coordinating distributed energy resources, switchable loads and storage), providers of electricity storage and the consumers. The consumers will be integ*
> *show annotation*

The establishment of Smart Grids in the distribution level has to include the following three pillars:

1. 配电自动化 *Distribution Automation*—Network automation and remote control to avoid over voltages or overloads and to *improve the reliability* by speeding up the supply recovery after fault induced trips （故障跳闸），
2. 智能聚合 *Smart Aggregation*—*Energy management* on the distribution level to coordinate the DERs, storage units and controllable loads for balancing and participation in markets for energy, ancillary and/or flexibility services and carbon certificates,
3. 智能计量 *Smart Metering*—*Consumer involvement* in the electricity market as a motivation for higher energy efficiency via variable tariffs and the visualization of tariffs, demand and costs.

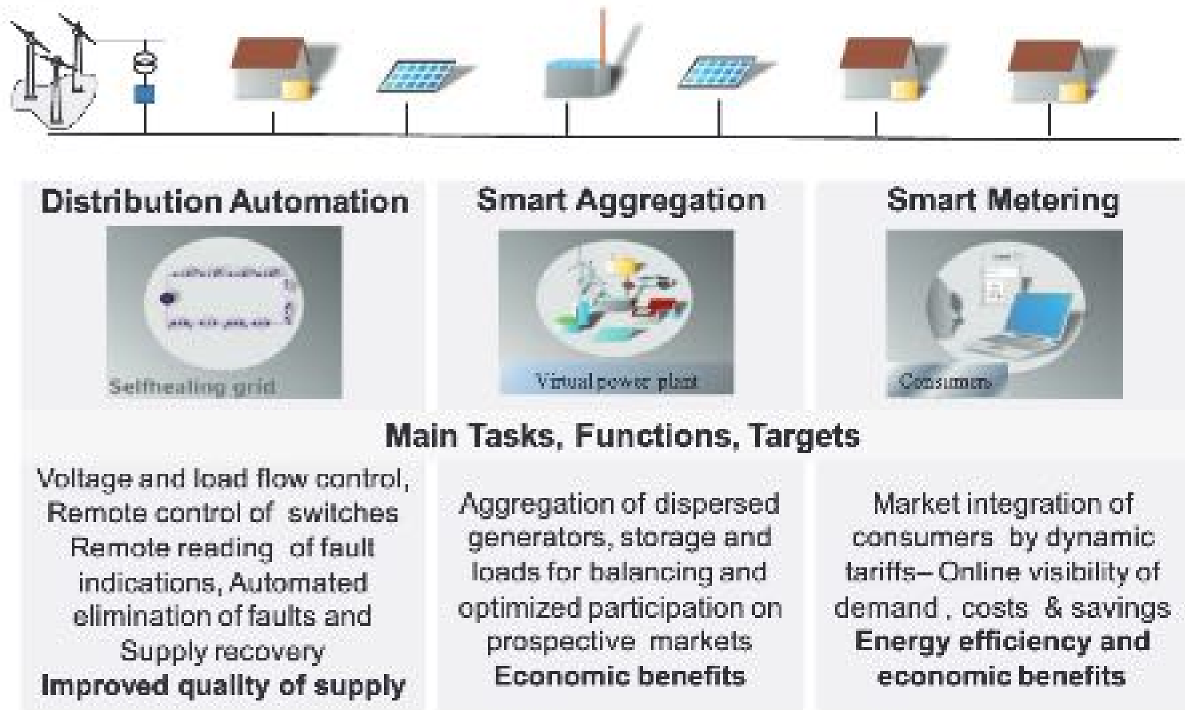

Fig. 6.3 The three pillars of smart distribution

Table 6.1 Smart grid flexibility provision and smart market activities

Activity	Smart Grid	Smart Market
Network automation	Ensuring power quality	Unlimited access of users
DER	Load flow/Voltage control	Energy and flexibility services
Electricity storage	Load flow/Voltage control	Energy & flexibility services
DSM	Load flow/Voltage control	Reserve power & flexibility services
VPP	Load flow/Voltage control	Optimum on various markets
DSR	Load flow/Voltage control	Consumer market integration

DER Distributed Energy Resources, *DSM* Demand Side Management (switching load), *DSR* Demand Side Response, *VPP* Virtual Power Plant

6.2 Pillar 1: Automation and Remote Control of Local Distribution Networks

> *l of Local Distribution Networks The main tasks of the distribution network automation include voltage control, power flow control, remote executed operations for changing the network topology and the improved fault elimination/restoration of supply. 6.2.1 Voltage Control6.2.1.1 T*
> show annotation

The traditional voltage quality control parameters:

- As a first priority, the algorithm of the voltage controller requires the voltage measurement at the MV busbars.
- The second influencing parameter is the measured current
-

> *oltage control in Smart Grids233 In principle, the smart meters will be installed at the connection nodes of the majority of network users to provide dynamic tariff systems (pillar 3 in Fig. 6.3).Smart m*
> *show annotation*

Involvement of the Network Users into Voltage Control

> *art Supply in the following way: If over-voltages occur which are caused by strong power injections (mainly from photovoltaic plants at noon), the voltage may be decreased by an increased active and/or reactive power demand near to the power injection node. Three methods may generate su*
> *show annotation*

Ways to mitigate:

1. Low tariffs are offered during midday on sunny days.
2. The DNO may install storage batteries at the affected nodes. They can be charged during high power injections and decrease the voltage in this way.
3. The DER, including storage batteries, may be operated with under excitation and demand reactive power.

> *roofs is depicted in Fig. 6.8b. Contrarily, if it is necessary to increase the voltage because a peak load/low generation situation occurs with under-voltage, then the three actions should be reversed to control the load, namely: offering higher tariffs, discharging batteries and DER operation with over excitation. However, all of these method*
> *show annotation*

> *operation with over excitation. However, all of these methods require the remote reading of measurements, status indications and remote control. Communication networks have to be intro-duced at the distribution level for the smart distribution network operation. 6.2 Pillar 1: Automation and Rem*
> show annotation

6.2.2 Opportunities for Power Flow Control

Overloading of network assets may occur bi-directionally in cases of:

- weak load/strong generation situations (e.g. on a sunny day at noon in a network with large scale connection of photovoltaic units) in the direction bottom up, or
- peak load/weak generation situations (e.g. in evening when people come home from work and simultaneously cook, wash and charge the electric cars) in the direction top–down.

> *s) in the direction top–down. The first priority of the power flow control requires the remote monitoring of the currents and/or the power flow measurements at the MV/LV transformer terminals. The power flow control may also be executed by network operations and market activities .The network operations for powe*
> show annotation

> *ili-ties need to be established. The market driven power flow control activities may be categorized as definite (hard) and probable (soft) methods. The definite methods are based on special contract or tariff conditions and consist of the: • Reduction or increase of the p*
> show annotation

Reduction or increase of the power output of DER by using the reserve power mechanisms on the distribution level,

- Switch-off or increase of controllable loads like air conditioners in summer or heat pumps in winter, which are offered on the positive reserve power market,

- Controlled discharging or charging of storage units, including the batteries of connected electric vehicles,
- Switch-off of previously contracted load or generation in emergency situations.

6.2.3 Automated and Remote Controlled Recovery of Supply After Fault Trips

> *s demonstrated in Sect. 4.6.2, t he fault location and elimination in MV networks is traditionally executed manually by driving along the faulted feeder and check-ing the short circuit indicators of the MV/LV transformer terminals (Fig. 4.37). The average ti*
> show annotation

6.2.4 Enhanced MV Protection Concepts

> *anging Protection Conditions [1] The connection of DER in MV distribution networks provides a significant impact on the protection behavior .239Impact on the protection sel*
> show annotation

> *DER at the lower voltage busbar. 6.2.4.3 Phasor Measurement in Distribution Networks The application of phasor me*
> show annotation

The main application areas for PMUs (phasor measurement units，相量测量单元) are seen as:

- Central voltage controller in distribution networks,
- Master power controller for the DER connection by power electronic converters,
- Voltage quality monitoring,
- Islanding detection,
- Synchronism check for re-connection of islanded network parts,

- Shaping awareness for system stability with the visualization of phasor measurements.

6.2.5 The Economy of the Smart Grid Enhancement in Distribution

> *nds of transformer terminals. The enhancement of such a large number of terminals for controllability requires a significant investment. But, is it economically useful to enhance all transformer terminals? In this sense, a new optimizatio*
> *show annotation*

in this sense, a new optimization task for the network planning appears by selecting:

- the terminals which require enhanced *voltage control*,
- the terminals which require enhanced *power flow control*,
- the terminals which provide the best benefit--cost ratio for *reliability improvement*

> *contribution of volume effects. In conclusion it can be stated that a Smart Grid does not require the complete introduction of new technologies in all network parts. However, the Smart Grid approach does require the economic intelligent weighting of the efficiency. A detailed analysis of the econo*
> *show annotation*

> *s and highest for human efforts. It was detected that the majority of the expenses is caused by human efforts for: • Engineering and design,• Devel*
> *show annotation*

It was detected that the majority of the expenses is caused by human efforts for:

- Engineering and design,
- Development of utility standard solutions,
- Installations and mounting,

- Approvals, tests and commissioning.

6.3 Pillar 2: Flexibility by Virtual Power Plants: Smart Aggregation

6.3.1 Basics of Virtual Power Plants

> *Basics of Virtual Power Plants* *The growing shares of volatile renewable power in the annual electricity consump-tion require the introduction of new methods to compensate for fluctuations and prediction errors* *(see Sect. 5.3.2). The aggr*
> *show annotation*

The main task of the VPP is directed to the electricity market and contains the following basic tasks:

- Forecasting, balancing and coordination of all *aggregated assets* like generators, storages and controllable loads including the highly volatile wind and photovoltaic generation,
- Completion of the *day-ahead schedules* of the whole VPP and sale of the scheduled energy on the electricity market,
- Online *monitoring* of the electric power production and *estimation* of schedule deviations,
- *Decision making in an optimization process* about the use of its own resources (control of the power generation and/or Demand Side Management DSM to adapt the controllable loads) for the compensation of fluctuations or for paying the charges for the use of external reserve power provided by the control area manager.

> *lity for schedule deviations.* *In this sense, the VPP can provide the balancing services to the power produc-ers for significantly lower expenses than the single producers can* *.The DERs normally sell electric*
> *show annotation*

The optimization goal and mathematical target function is to maximize the benefit by using all possible market indications taking into account network fees and must run requirements due to heat or electric power:

- Electric energy day-ahead and intraday markets,
- Reserve power markets,
- Flexibility service provision to the DNO,
- Fuel costs,
- Charges for network use,
- Heat energy market (by optimized operation of Cogeneration of Heat and Power (CHP) plants on the electric energy market and storage of heat energy which is not required in periods with high electricity prices),
- CO2—Certificate trade

> *prices), • CO2—Certificate trade. The aim is to achieve benefits for each VPP component which a single asset could not address alone. For this, the VPP coordination is based on optimization tools. The inputs and outputs of such*
> show annotation

6.3.2 Demand Side Management: The Role of Storage and Controllable Loads

> *f Storage and Controllable Loads The adaptation of the demand to the available power generation will gain impor-tance in the environment of fluctuating power generation. The demand has to be integrated into the power system management in general. The Demand Side Integration*
> show annotation

#DSI #DSM #DSR

The Demand Side Integration (DSI) has two aspects:

1. DSM—*Demand Side Management* is the active switching of load either on a contractual basis with the VPP provider or based on offers on the reserve power market if the offered switchable power corresponds with the requirements accordingly Table 5.1.

2. DSR—*Demand Side Response* is the impact on the consumer behavior by dynamic tariffs coupled with means to achieve consumer awareness regarding the changing tariffs, the current demand and the related costs. However, the DSR depends on the willingness of the consumers to shift intensive load into periods with low tariffs. The DSR outcome can be estimated by predictions only and cannot be applied to perform the VPP function.

> *-tric and thermal storage units. Electric storage capabilities will play a significant role in the Smart Grid envi-ronment. Electric storage providers can act on the electricity market by benefitting from the spread of electricity prices (charging in low price periods, discharging in high price periods) and on the markets for reserve power or flexibility services within a VPP. Thermal energy is often produced*
> *show annotation*

> *eduction of the network charges. On the other hand, during the weak load time the storage units are charged and the DSM groups are switched on. These actions increase the demand of the supply area when the prices for electricity are low .Consequently, the load profi*
> *show annotation*

6.3.3 Business Models of Virtual Power Plants on Prospective Markets

> *n a supply area accordingly [2]. Due to the strong volatility of the market conditions the stability of VPP bene-fits will be higher as it becomes possible to apply more business models. The overview of the investigated*
> *show annotation*

6.4 Pillar 3: Smart Metering and Market Integration of the Consumers

6.4.1 Basics of the Digital Metering Technology

> *the Digital Metering Technology* *The digital technology was successfully introduced for protection and control and has been in use since the late 1980s* *(Sect. 3.2.2.1). This was*
> *show annotation*

> *ee Pillars of Smart Distribution* *offering economic and technical benefits compared to the previous analogue elec-tronic and electro-mechanical technologies.* *The digital metering technol*
> *show annotation*

> *of the Smart Grid philosophy.* *A Smart Meter is mainly an electrical meter that records the consumption of electric energy in short time intervals (from minutes to one hour) and then com-municates that information to the traders for monitoring the demand profiles and for billing* *.The digital technology has now*
> *show annotation*

> *ring are presented in Fig. 6.34.* *Additional important features include voltage quality monitoring, load profile recording, gateway to home automation facilities (for energy management) and security functions.* *With the introduction of smart m*
> *show annotation*

With the introduction of smart meters the following objectives are often targeted:

- Significant *benefits* for market participants,
- Market driven approach with the *integration of DER–RES*,
- *Energy savings and climate protection* by giving more real-time consumer feedback,
- *Limiting the peak power* of segments of the grid by enabling *Demand Side Response*,
- Competition in the metering data collection service and customer care,
- As fast as possible widespread distribution of intelligent measuring systems,

- Acceptable cost-benefit ratio by *automating the metering processes*,
- Smart Grid "Readiness"

6.4.2 Dynamic Tariffs

> *nd Sweden.6.4.2 Dynamic Tariffs The expectation regarding the introduction programs is that smart metering will offer a number of potential benefits to the consumers, traders and network operators. 6.4 Pillar 3: Smart Metering and*
> *show annotation*

These benefits concern both the commercial and the electricity supply processes, and provide:

- an end to estimated bills, which are a major source of complaints for many consumers,
- a tool to help consumers better manage their energy use—stating that Smart Meters with an in-house display could provide up-to-date information about the actual electricity consumption and, in so doing, help people to manage their energy use and reduce their energy bills and carbon emissions

> *for "not privileged consumers". In the future such averaging mechanisms to create the tariff cannot support the above mentioned expectations regarding the adaptation of the demand to the energy availability. Dynamic tariffs will be bas*
> *show annotation*

Dynamic tariffs will be based on the hourly changing energy prices:

- to compensate energy deficits by applying higher tariffs,
- to utilize excesses of renewable energy by offering lower tariffs.

6.4.3 The Impact on Consumer Behavior: Demand Side Response

> *households 2 0.2Sum 8.2 0.88271 In general, the introduction of dynamic tariffs in combination with home auto-mation will become advantageous if, within the next 10–20 years, all consumers obtain home automation facilities and can adapt their electricity consumption automatically in the same way as the best practice consumers did within the W2E project .6.4.4 Electric Vehicle Managem*
> *show annotation*

6.4.4 Electric Vehicle Management

> *d of the basic load of the area. The question arises again: Is it necessary to enhance the network capabilities in a way that such simultaneous charging will become possible or it is more useful to introduce innovative methods for the electric vehicle management? A traffic light system for*
> *show annotation*

> *and the electric networks. The charging stations are connected via com-munication links with a control system—the mobility control center (MCC) . The MCC receives information*
> *show annotation*

The MCC receives information about

- the current electricity prices from the traders,
- the current loading situations of the parts of the network that contain charging stations,
- the appropriate charges for additional network use from the DNO

6.5 Communication Needs for Smart Distribution

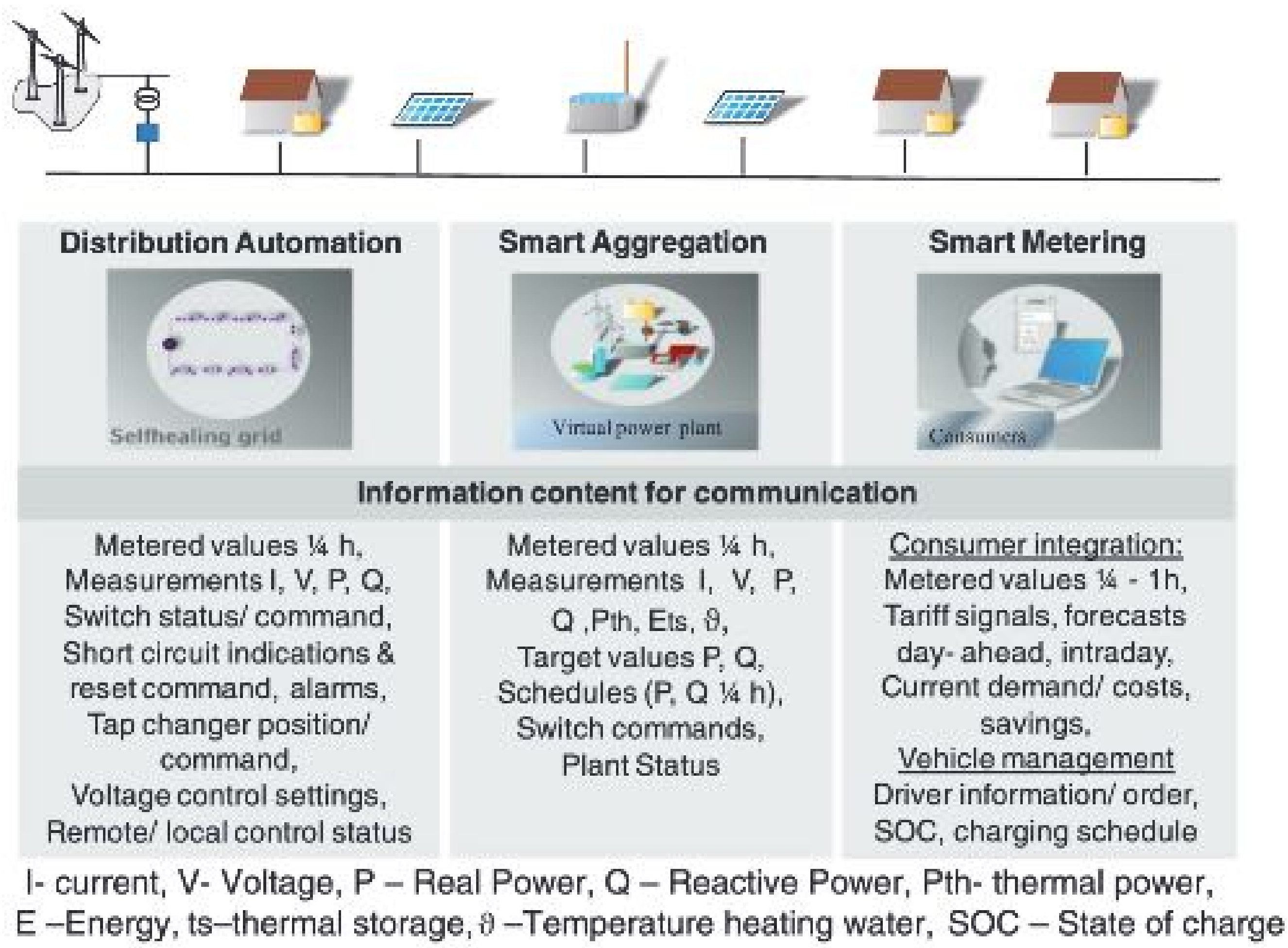

Fig. 6.47 The information exchange needed for the three pillars of Smart Distribution

> *ion Needs for Smart Distribution* *Traditionally, the local distribution networks are mostly operated without remote control mechanisms and automation functions. The distributed energy resources (DER) feed in the maximum possible generation corresponding to the weather conditions* *.Fig. 6.46 Diesel-electric-hyb*
> *show annotation*

> *res. (Copyright Hessen Mobil)277* *The introduction of the three pillars of distribution is aimed at improving the traditional approaches and requires a deep paradigm change. This will change the role of the distribution system from a passive to an active one that takes more responsibility in the overall power system* *.In the future the distribut*
> *show annotation*

> ity in the overall power system. In the future the distribution will have the important role of keeping the local balance between energy production and energy consumption. The enhancement of distribution
> show annotation

> ponents and the control centers. Consequently, information and communication technologies (ICT) will play the key role to ensure the sustainable and reliable network operation in the context of an increasing share of DER and new types of consumers connected to the distribu-tion networks .The overview of the information
> show annotation
>
> #ICT

7. Design of the Smart Energy Market

> ngueterverkehr (October 2019)279 Smart Grids are regarded as the pre-requisite for meeting the challenges of the electricity supply of the twenty first century with its significant share of renewa-ble energy sources (RES) in the annual electricity consumption, most of which are volatile and dependent on the weather conditions . However, Smart Grids requi
> show annotation

> s question is a resounding "NO"! The main idea of Smart Grids—namely, the intelligent integration of all their users (see Sect. 1.1)—is currently prevented by the market design in the majority of European countries that apply the "feed-in tariff" supporting scheme. Currently, three different ty
> show annotation

7.1 Prospective Markets for Power Supply: A Vision and a Case Study

> ply: A Vision and a Case Study1 The development of a prospective market design is mandatory to meet the chal-lenges of the electricity supply of the

> *twenty first century in an economic and sus-tainable way. The future (≥2030) market de*
> [show annotation]

The following aspects are considered as the foundation of the prospective market in the electricity supply processes:

1. Interaction of Smart Grid and Smart Market
2. Renewable power producers become active market players
3. More flexibility of the definite power production
4. Price growth for fossil electricity generation
5. Costs for renewable electricity generation will decline
6. Changed coverage of the load profile
7. Qualified schedule management based on the cellular approach
8. 8. Tariffs based on dynamic electricity prices and network charges
9. Motivation of the network operators

7.2 Smart Services for Network Operations and Electricity Markets

7.2.1 The Overview of the Smart Services

> *e Overview of the Smart Services The prospective interaction of smart network operations and market activities require the establishment of new services in the area of information and communi-cation technologies .The cellular concept of balanci*
> [show annotation]

> *d for billing purposes only. I n the prospective Smart Supply Cells, data from meters are also requested for the targets of the three pillars of Smart Distribution as the prerequi-site for the cellular balancing and securing the power quality (see Chap. 6):• The DNO needs me*
> [show annotation]

- The *DNO* needs metered and measured values for the load flow supervision and the voltage observation in critical nodes (digital meters are able to provide voltage measurements).
- The *party* responsible for balancing needs the online provision of the balance between load and generation to control the schedules of the Smart Supply Cell and minimize the costs for schedule deviations.
- The *VPP* needs the ¼ h meter values from the aggregated plants and controllable loads for an online schedule observation and to perform intra-day optimization decisions.
- The *traders* need load profiles of their consumers to improve the scheduling by using predictions based on the correlation between the weather conditions and the demand profiles.
- The *metering services* for other media (water, heat, gas) in a multi- utility may also be integrated into the operations of the service provider responsible for the cell.
- The charging of e-mobiles needs special supervision and influencing methods in order to avoid a large number of simultaneous charges in a limited part of a network, which would create overloading stress

7.2.2 Metering Services

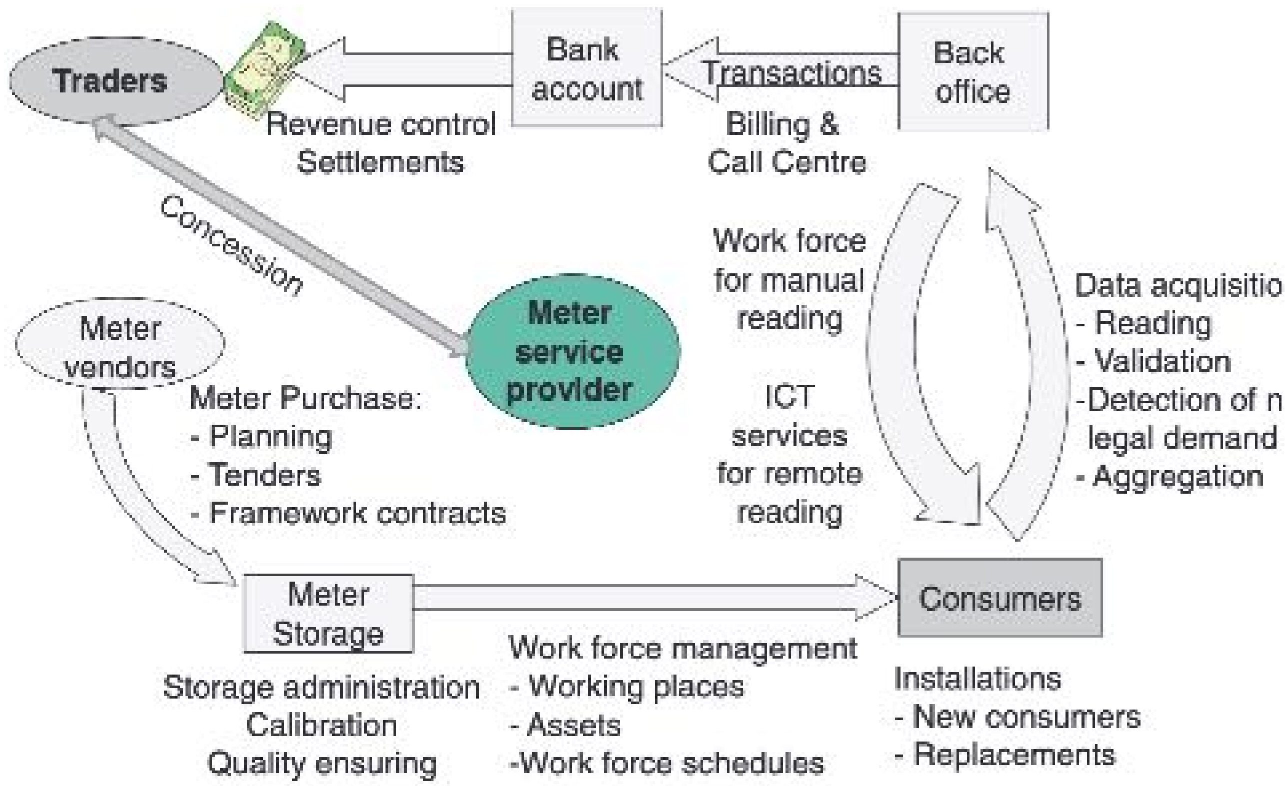

Fig. 7.11 Complete metering service value chain

> *s is assigned to the DNO by law. However, all consumers have the opportunity to select their own meter service provider. A complicated chain of contracts between the trader, the meter service provider, the network operator and the consumer has to be completed. As a result there are a larg*
>
> show annotation

7.2.3 Data Communication and Information Management

> *ation and Information Management The three pillars of Smart Distribution require the establishment of a communica-tion infrastructure in the distribution networks all the way down to the consumers connected to the low voltage networks. Furthermore, the data to b*
>
> show annotation

> *pro-vider have to be installed. The communication provider rolls out the data communication network and the data traffic according to the quality attributes for the Smart Grid and the Smart Market. In principle, the required*
>
> show annotation

> ay extend their business models. The information provider (or data access manager) receives payments accord-ing to the volume of data acquired by the customers. This new market role also
> show annotation

8. Advanced Information and Communication Technology: The Backbone of Smart Grids

8.1 The Importance of Uniform ICT Standards for Smart Grids

8.1.1 Functions of ICT Standards

> .1.1 Functions of ICT Standards The information exchange necessary to properly run Smart Grids has to cover all levels of the electric power system and will take on a new quality compared to the traditional communication methods. The immense increase in the
> show annotation

> onal communication methods. T he immense increase in the volume of data to be transferred requires the application of advanced information and com-munication technologies (ICT) in order to avoid extremely increased engineering efforts and to ensure consistency and security of the data transfer from level to level. The efficiency of the ICT s
> show annotation
>
> #ICT

he new standards have to cover the following main functions:

- Online data transfer through communication networks,

- Consistent information management and data exchange between the data bases of various enterprise management systems,
- Protection against data manipulations and to ensure information security.

8.1.2 Communication Standards

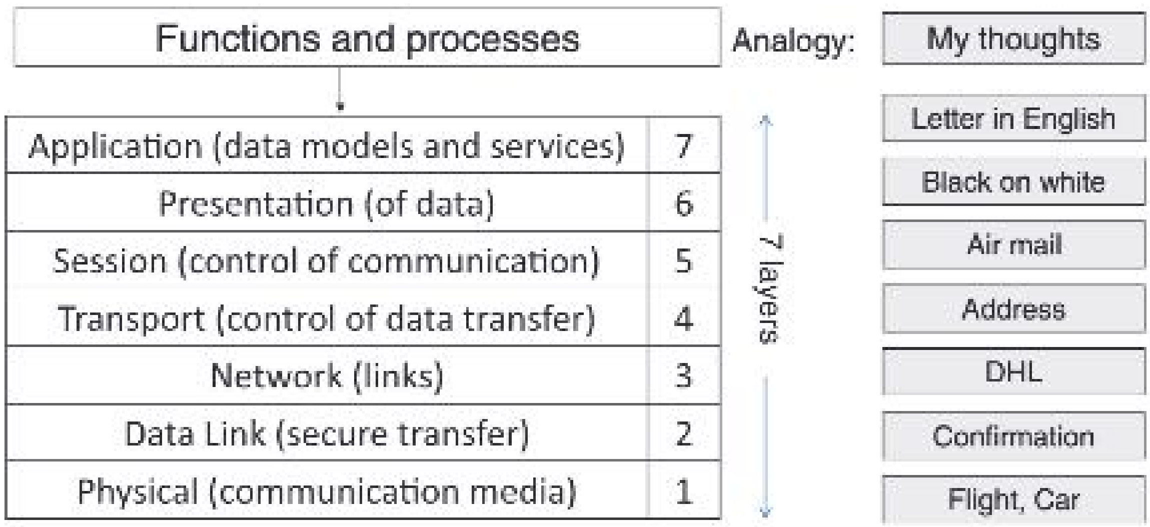

Fig. 8.2 The 7 layer ISO/OSI communication reference model

- 物理层
- 数据链路层
- 网络层
- 传输层
- 会话层
- 表示层
- 应用层

> *his is the aircraft and the car. The exact definition of all layers builds the communication protocol. Simple communication protocols may use only the layers 1, 2 and 7. However, they are limited for*
> *show annotation*

> *nto the control center computer. The definition of uniform data models of the application layer is the mandatory pre-requisite of an efficient*

> *communication system for Smart Grids .For historical reasons, vari*
> [show annotation]

> *CADA) for the electric networks. First of all, the communication has to penetrate the distribution level down to the low voltage network users in order to perform the three pillars of Smart Distribution, as shown on the right-hand side*
> [show annotation]

> *rk related SCADA functions. The most efficient communication technologies that can be applied depend on the local conditions and may be in different physical forms: copper cables, fiber optic cables, radio .The prospective uniform comm*
> [show annotation]

The prospective uniform communication standard should offer the following aspects:

- Global acceptance,
- Less engineering by object oriented instruments and models,
- Services ensuring quality, efficiency, accuracy and security of the information exchange,
- High performance,
- Open for extensions regarding future applications,
- Flexibility in applying prospective innovative communication on the physical and link layers,
- Application of mature technologies in the 7-Layer Model,
- Interfaces to other standards and continuity in new standard extensions.

8.1.3 Standards for Data Management

> *3 Standards for Data Management Enterprise process management (EPM) systems nowadays are broadly used to manage all processes of the enterprise based on digital data bases in an efficient way. 3028 Advanced*

> *Information and Co*
> [*show annotation*]()
>
> #EPM

parameters of a transformer are used in the data bases of the following EPM systems for the network management:

- SCADA,
- EMS (Energy management systems of TSOs) or DMS (Distribution management systems of DNOs),
- geographical information system (GIS),
- network planning,
- asset management,
- maintenance management,
- outage management.

8.1.4 Information Security

> *n ...8.1.4 Information Security Electricity networks belong to the critical infrastructure systems. The remote control and supervision of electric networks are vulnerable to several security threats like :• External attacks,• Internal a*
> [*show annotation*]()

- External attacks,
- Internal attacks,
- Natural disasters,
- Equipment failures,
- Carelessness,
- Data manipulation,
- Loss of data.

> *threats to information security. The reactions to the threats can physically damage the network assets and have tremendous legal, social, and financial consequences .Information security standards*
> [show annotation]

9. Smart Grids Worldwide

9.1 Smart Grids for the World's Largest Power Systems

> *em Development Strategy in China China became the world's largest producer and consumer of electricity during the first decade of the 21st century. The Chinese electricity generati*
> [show annotation]

The need for establishing Smart Grids in China is driven by two major objectives:

1. Establishment of a unified national transmission system and
2. Significant growth in the use of renewable energy sources.

> *use of renewable energy sources. The Chinese power system is operated by seven regional transmission networks. Five of these transmission networks are managed by the State Grid Corporation of China (SGCC): • NWCG—North-West China Grid,• N*
> [show annotation]

- NWCG—North-West China Grid, 西北电网
- NCG—North China Grid, 华北电网
- NECG—North-East China Grid, 中国东北电网
- CCG—Central China Grid, 华中电网
- ECG—East China Grid 华东电网

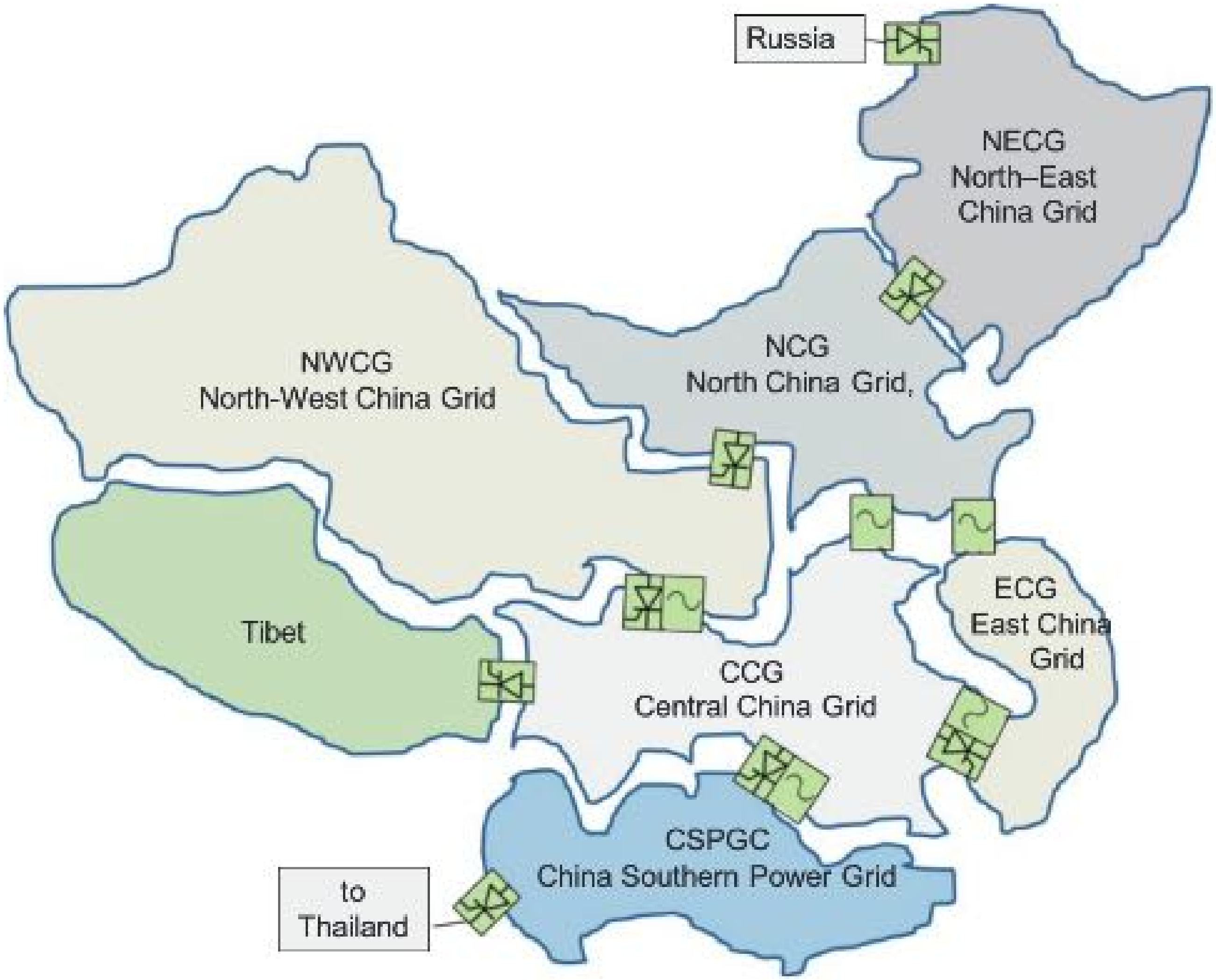

Fig. 9.1 Transmission grids in China and interconnections for establishing a unified grid [2]

> *0-9_9368 9 Smart Grids Worldwide The China Southern Power Grid Company Limited (CSPGC) is the second state owned Chinese transmission enterprise and operates the China South Grid CSG. The 500 kV transmission network*
>
> show annotation

> *d by the State Grid Corporation. The lack of a unified national transmission system with strong interconnec-tions was a barrier to the nation-wide efficient use of the power plants and height-ens the risk of local congestions. For example, the peak and weak*
>
> show annotation

> *smis-sion capacities (Fig. 9.1). China's power system is mainly based on coal fired thermal power plants (approximately 65%). However, China is also the world champion regarding the electricity generation based on renewable energy sources (RES) with shares NWCGNorth-West C*
> *show annotation*
>
> *煤粉火力电厂*

> *production from fossil fuels. The annual expansion of wind energy and PV capacities has picked up an enormous pace . In 2018, the installed ca*
> *show annotation*

> *hotovoltaics 175 GW (Fig. 2.15). Furthermore, China will soon take over the world market leadership in photo-voltaic and wind power technologies. The installed wind power capaci*
> *show annotation*

> *only one of the growth targets. The integration of China's growing RES capacity into the national power sys-tem requires the upgrade of the electric network infrastructure at all levels and ultimately, the establishment of a Smart Grid .China's Smart Grid policy is cl*
> *show annotation*