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Course KEE/PDS

Transmission and distribution grids

Electrical Power Systems
Structure and Components

The supply system

The primary aim of the electricity supply system is to meet the customer`s demands for energy. Power generation is carried out wherever it gives the most overall economic selling cost. The transmission system is used to transfer large amounts of energy from the main generation areas to major load centres. Distribution systems carry the energy to the furthest customer, utilising the most appropriate voltage level. Thus an electricity supply system contains three different functions.

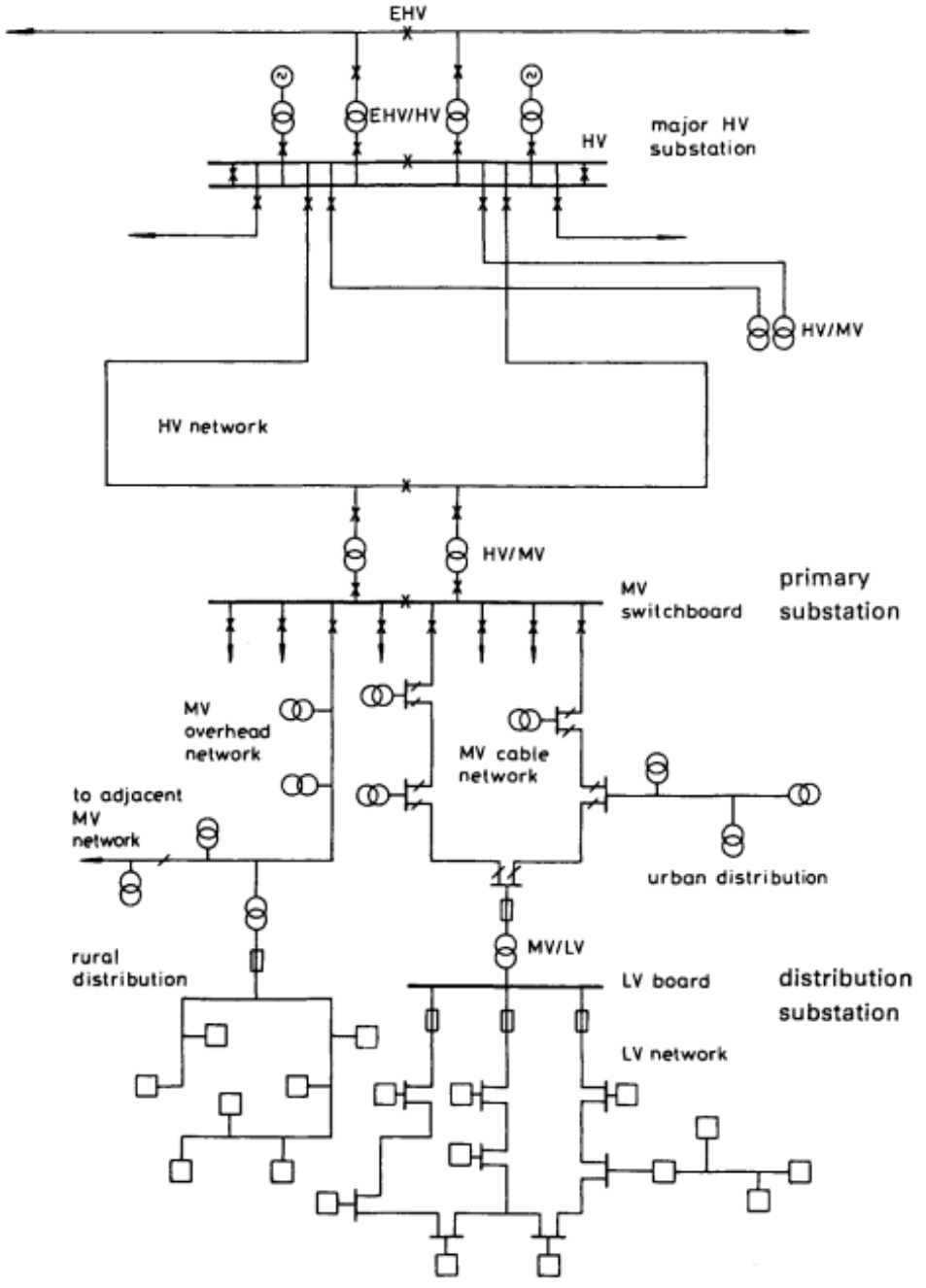


Figure 1.6 EHV/HV/MV/LV network arrangements

Generator | Transformer | X Circuit breaker | / Disconnector | Feeder | Fuse | LV Customer

Electricity is produced from a number of **energy sources**. Plant with a high capital cost, such as hydro and nuclear stations, is economic only if operated for most of the year at maximum output. On the other hand, plant which has a relatively low capital cost but high operating costs, such as gas turbines, may be more economic for short periods of operation to meet peak loads. Fossil-fuelled stream power stations, together with nuclear power plants and hydro stations, provide the majority of electrical energy. Combined heat and power stations are favoured in some countries. In a combined heat and power station the energy normally lost in the condensation process is utilised by heat consumers. Thus overall efficiency of the power station can be markedly increased. Diesel engines, wind and wave machines, and solar cells provide only a marginal amount of electricity on a world-wide basis, although their output may be significant locally. This kind of dispersed generation is rapidly increasing in some countries, however.

Where the transport of very large amounts of power over large distances is involved, an extra high-voltage (EHV) system is required. Such systems operate in the 300 kV plus range, typical value being 400 kV. EHV interconnections have been constructed between regions and countries in order to achieves the most economic use of generation and transmission plant overall, and to cater for temporary shortages of plant in any one region. In Europe the largest of such arrangements operates under the auspices of the European association for the cooperation of **transmission system** operators (TSOs) for electricity (ENTSO-E).

Below the transmission system there can be two or three **distribution** voltage levels to cater for variety and demands of customers requiring electricity supplies. Low voltage (LV) is below 1 kV, while medium voltage (MV) covers voltage levels generally lying between 1 and 36 kV, used particularly in distribution systems, with high voltage (HV) being used for systems over 36 kV.

The HV and MV networks provide supplies direct to large customers, but the vast majority of customers are connected at LV and supplied via MV/LV distribution substations and their associated LV networks. The HV networks (e.g. 110 kV) may be operated as interconnected systems or discrete groups. When operating as interconnected systems these networks may then be used to provide back-up capacity to the higher-voltage networks. In general, the MV (e.g. 22 kV) and LV networks are operated as radial systems.

In rural areas overhead MV lines are in general used. Common practice is to use steel-cored-aluminium conductors and steel, concrete or wooden poles. Insulated conductors are more reliable and also environmentally more acceptable and are tending to be used increasingly. Of necessity underground cables are being installed more frequently in urban areas, but they are only used in rural areas for environmental reasons.

Pole-mounted transformers form the rural distribution substations. In urban areas supplied by MV underground cables the substation can be at ground level, in brick, steel or concrete enclosures, or placed in the basements of office or housing blocks. LV distribution in rural areas is by means of overhead lines with bare or insulated conductors. The use of aerial bunched conductors is becoming dominant, particularly in villages, small towns and forest areas. In town centres underground cables are predominate. In urban areas back-up supplies are often available from neighbouring distribution substations.

Source: Lakervi E. and Holmes J. – Electricity distribution network design, IEE, London, UK, 2003, ISBN 0863413099

Electric power system

Electric Power System (EPS) is a set of equipment interconnected each to the other, which includes the following:

- power stations (generating units) – i.e. nuclear, thermal, water power plants and heating plants, etc.,

- transmission, transformation and distribution of electrical energy, incl. the service lines,

- measuring, protective, governing, safeguarding, information and telecommunication systems,

- consumers – equipment used for the transformation of electrical energy into heat, light, mechanical work and the like.

The power network is a set of individual electric stations and electrical lines, interconnected each with the other, and used for the transmission and distribution of electric energy. It serves as a connection link between the power generation and power consumption.

Depending on the type of current we differentiate between:

- direct current (DC) power networks and

- alternating current (AC) power networks.

Depending on the purpose the power networks are classified into:

- **transmission networks** to ensure the transmission of high values of power across large distances. In the Czech Republic the voltage of transmission lines is 400 kV and 220 kV. ČEPS is the Transmission system operator (TSO) in the Czech Republic. It provides the operation, maintenance and development of transmission system and the real-time supervisory control of the Czech electric power system.

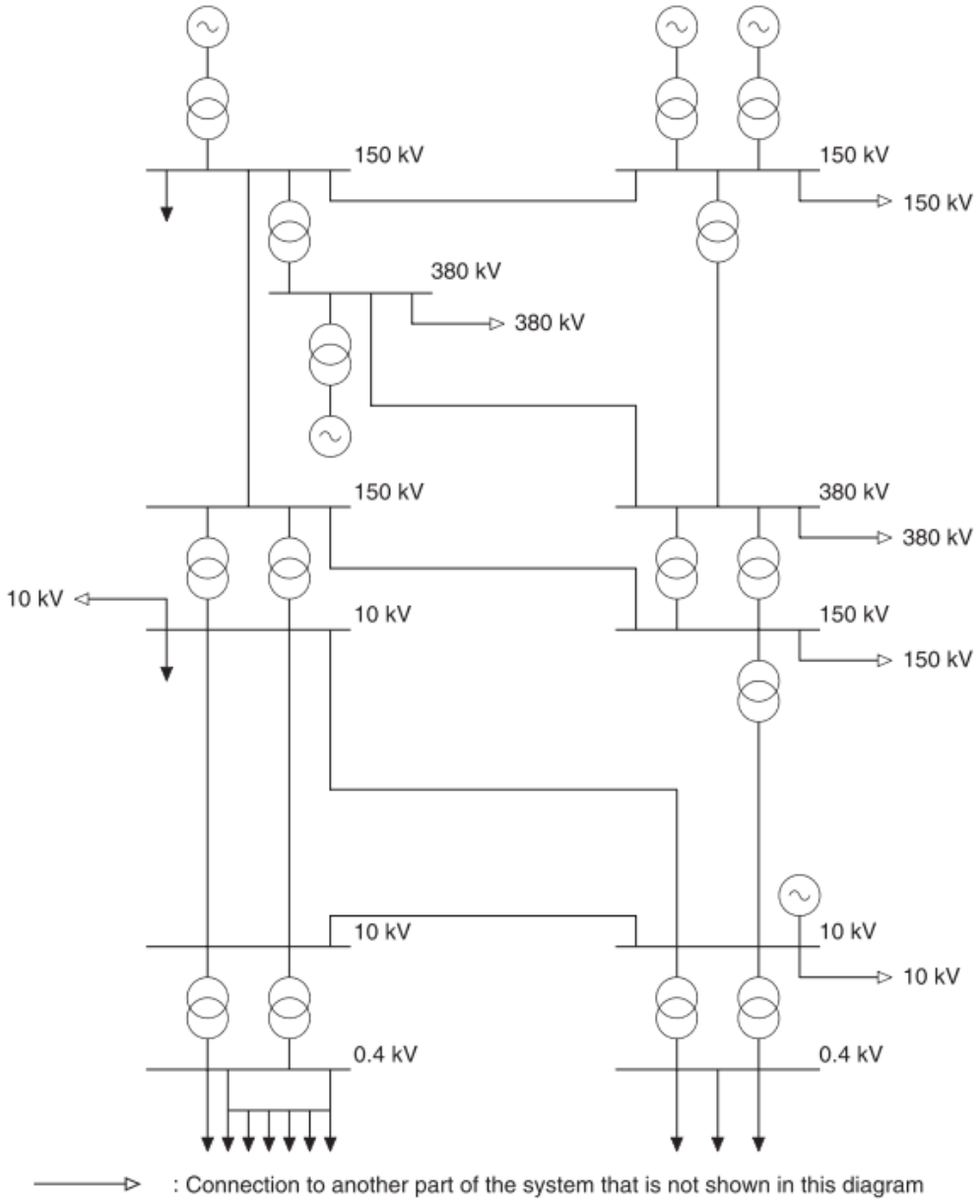
- distribution (supply) networks, consisting of a set of equipment for the distribution of electric energy from the transmission lines or from sources connected to the distribution line and leading to the end users. In the Czech Republic this concerns an equipment with voltage level of 110 kV and lower. In the Czech Republic the distribution system operates at the very high voltage level (HV) of 110 kV, medium voltage (MV) level of 22 kV, 35 kV and, now and then, also at the level of 10 kV and 6 kV, and at the low voltage (LV) level of 230/400 V. Low voltage level serves for the power distribution to small consumers.

- industrial networks used for the distribution of electric energy within industrial premises or industrial plant, starting from the object´s (plant´s) main station and leading to the corresponding power consumers. The network voltage usually corresponds to the consumer rated voltage (e.g. 6 kV, 10 kV).

Structure of a power system

Power system has clear vertical structure: a relatively small number of large power stations supply the transmission network (380 kV and 150 kV). Besides some large industrial consumers that are connected to the higher voltage levels (150 kV), most of the power is transported and distributed to the consumption centres located at the lowest voltage levels (10 kV and 0.4 kV). Nowadays, more and more decentralized generation, i.e. small-scale

generators connected to the lower voltage levels (like the generator connected to the 10 kV bus), is being integrated in the system. Examples of such decentralized generators are windmills, solar panels or combined heat-power units (producing steam for industrial processes and electricity as a by-product).



Stucture of power system the Netherlands

Source: Pieter Schavemaker and Lou van der Sluis – Electrical Power System Essentials, John Wiley & Sons Ltd, 2008, ISBN 978-0470-51027-8

Components of a power system

Electrical line is the basic structural element of transmission and distribution networks. It consists of a set of conductors, insulation materials and structures intended for the transmission of electrical energy between two points (nodes) of the electrical network. A node is understood a connection point for a power source or consumer, or a line distribution point, or a transition point (transition from cable into an overhead line, etc.), or electrical station.

Depending on the kind the following electrical lines can be distinguished:

- cable lines, placed in the earth or mounted on cable trays, or suspended on poles,

- overhead lines, with conductors led above the ground and fixed usually to insulators and adequate supporting points (masts).

Electrical station is a set of buildings and equipment installed in the electric power system nodes, and used for:

- the transformation of electrical energy from one voltage into another one, and its distribution in transformer stations and substations,

- the distribution of electrical energy at the same voltage level - switching stations,

- the conversion of alternating current of one frequency onto other frequency, or the conversion into direct current and its distribution - converter stations,

- the compensation of electrical energy - compensation stations.

Stations of smaller extent as regards the number of switched-on lines and the values of transmitted power, with voltages up to 1000 V, are called the switchboards.

Basic issues to be resolved during the design and operation of an electric power system are linked with the economy, reliability and quality of supplied electric energy.

The term of **economy** means the minimization of acquisition and operation costs to be spent on the electric power system, for the given distribution of requirements on electrical energy, while keeping to the agreed upon quality and reliability data.

The **quality of supplied electric energy** is fulfilled if the following power criteria agreed upon have been met:

- voltage with permitted tolerance range,

- AC voltage curve distortion,

- voltage symmetry in three-phase AC systems,

- frequency fluctuation.

Reliability means the fulfilment of requirements on power consumed during the operation periods of the individual power consumers.

Table 5.1 Recommended system voltages according to IEC 60038 as applicable in German power systems.

Common name	Nominal system voltage	Supply task
Low-voltage (LV)	400 V/230 V	Household customers Small industrial consumers
	500 V	Supply of motors in industry
Medium-voltage (MV)	6 kV	HV-motors in industry and power stations
	10 kV	Urban supply, industrial power systems
	20 kV	Rural supply, industrial power systems
	30 kV	Industrial supply (electrolysis, thermal processes) Rural power supply
High-voltage (HV)	110 kV	Urban transport and sub-transmission systems
	220 kV	Transmission systems (decreasing importance)
	380 kV (400 kV)	UCTE transmission system

Economic operation of an electric power system on the producer´s side is affected by the availability of the primary sources of energy (fuel transport, fuel on stock, water level and water flow modes for water power plants, etc.), and the availability of power sources (organization of operation and repairs of power plant equipment). On the side of the power consumers the operation of an electric power system depends on the composition of the individual power consumers and the time distribution of their power demands, and the reliability and quality of supplied electrical energy. This capability of both types of exerting influence is of essential type and can render the economic operation of the system impossible or lead even to a breakdown of the electric power system operation.

The adaptation of the electric power system operation to the external influences is the task of the system´s control. The demands of the control system are quite high as some of the operation conditions are changing very quickly (error states), or more or less incidentally (equipment failures, power take-off by consumers), and it is necessary to keep a balance between the power consumption, losses and power supply in the power system at any moment, while keeping to the quality, reliability and economy requirements.

Control by system operators is taking place at various hierarchic levels, starting from the nation-wide level (Central Power Control Centre of the Czech Republic) down to the dispatcher´s control of the individual distribution systems.