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Institut für
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und Energiewirtschaft

Power System Operation and Stability

Chapter 0: Basics

Content

Chapter 0.1

GENERAL TECHNICAL ELECTRICITY GRID KNOWLEDGE

Electrical Grid

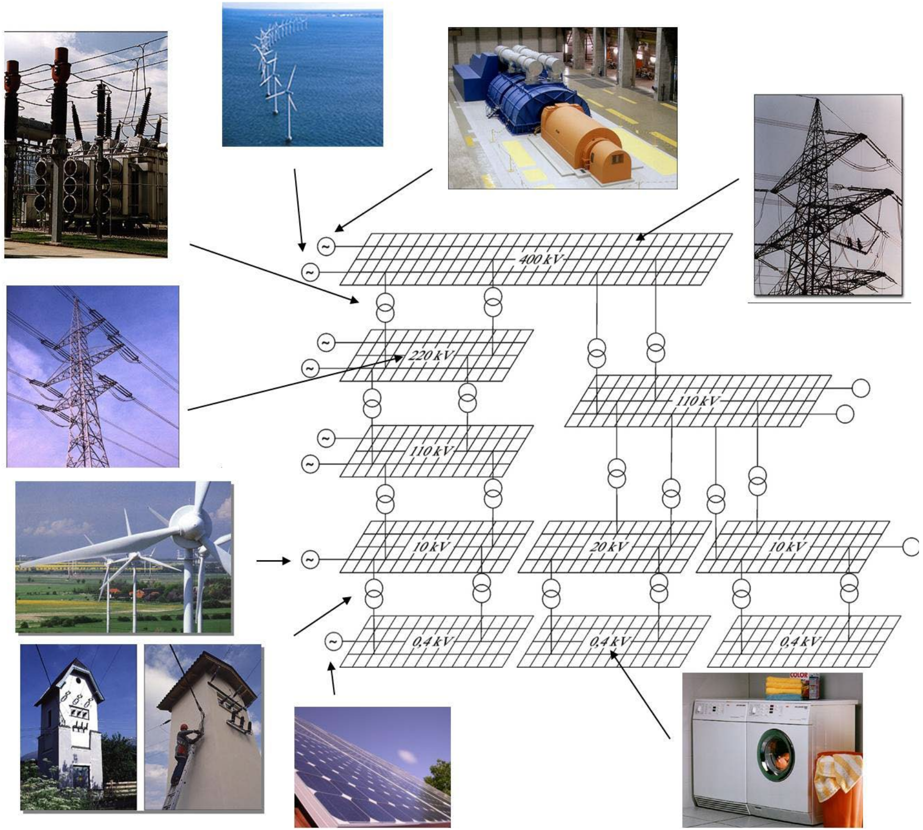
Definition

- „Interconnected network for delivering electricity from producers to consumers“

Grid Components

- Generator (producer): Production of electrical energy
- Line / Cable: Transport and distribution of electrical energy
- Substation with transformer: Transformation of voltage from high to low (or reverse)
- Load (consumer): Consumption of electrical energy

Electrical Grid Components



Three-Phase-System

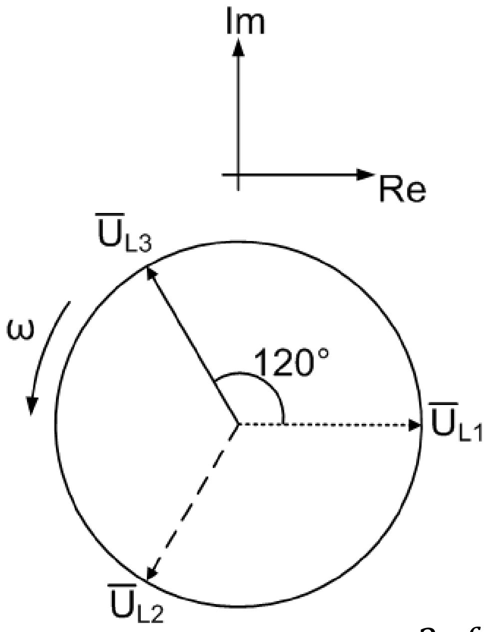
Definition

- System of three interlinked alternating currents (AC), which are shifted by 120°
- Electrical energy is brought to the consumers by a three-phase-system
- The term three-phase current is derived from generation

Compared to AC systems

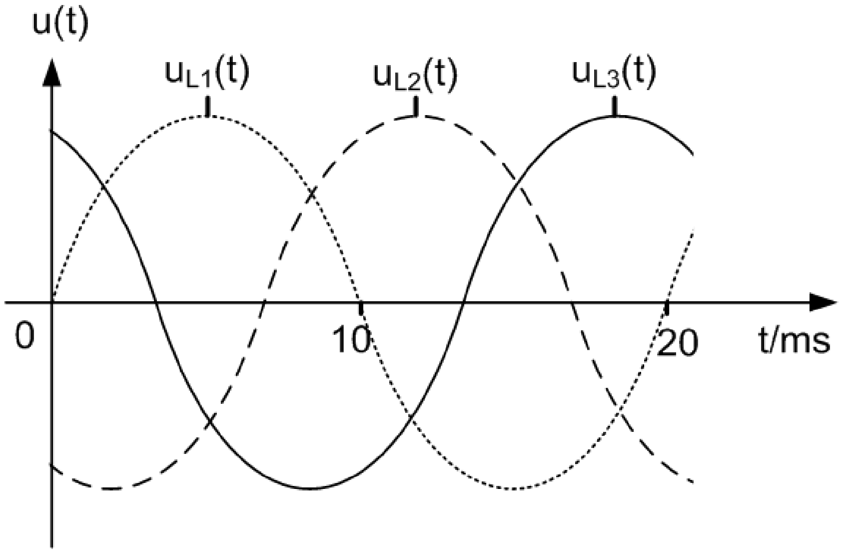
- Lower transmission losses at same power transmission
- Less conductor material at same transmission capacity
- Three-phase generators require less maintenance and can be built more efficiently for higher performance
- Transmission of temporally constant active power

Phase Voltages of a Three-Phase Generator



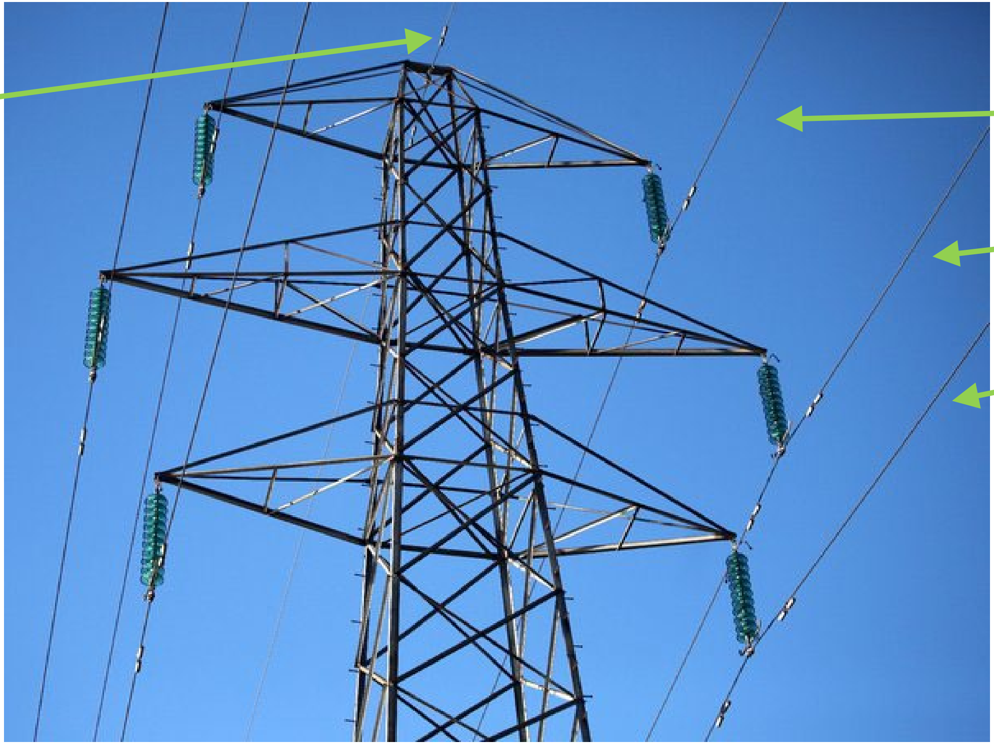
$\omega = 2\pi f$

$f = 50\ \text{Hz} \rightarrow T = \frac{1}{f} = 20\ \text{ms}$



Overhead Line with Two Three-Phase-Systems

ground wire

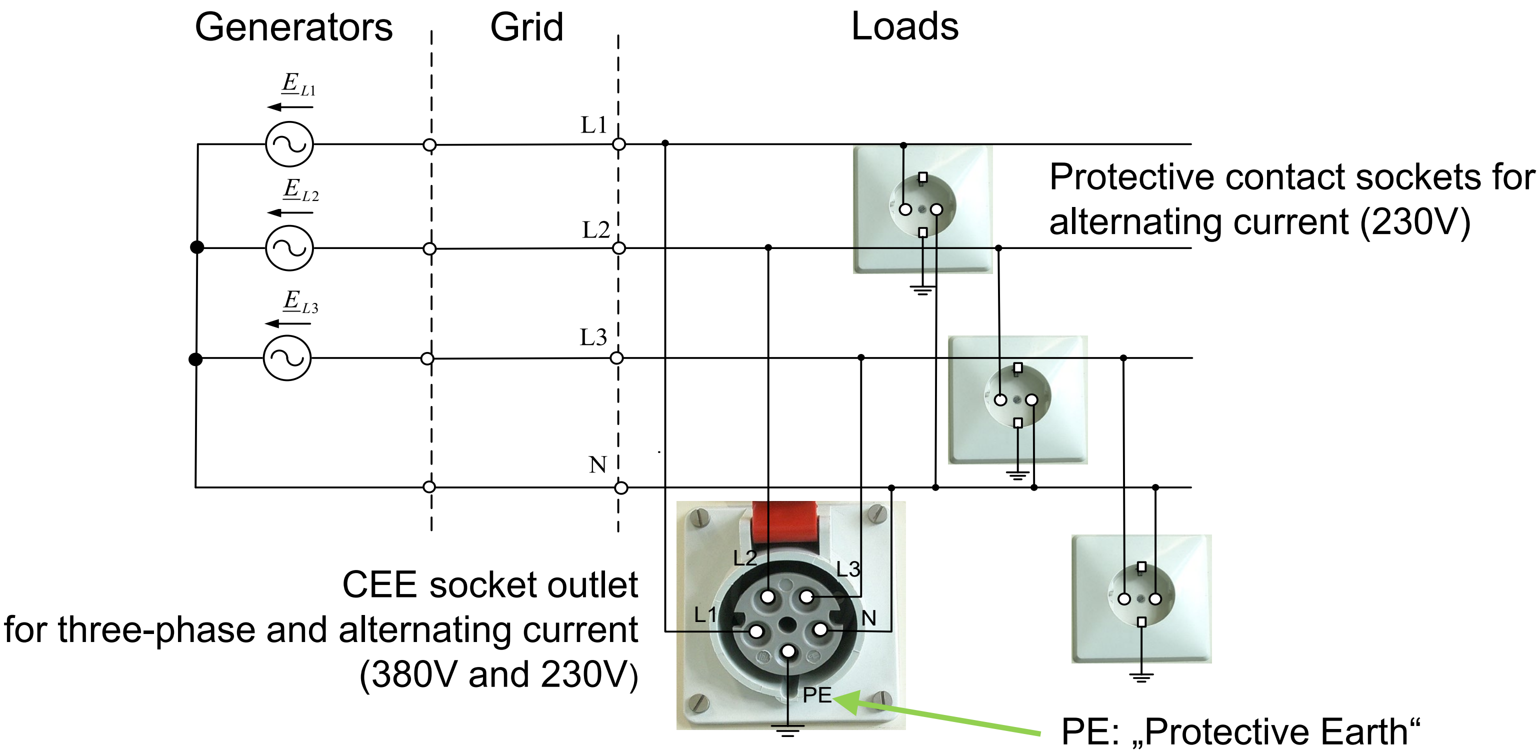


Phase L_1

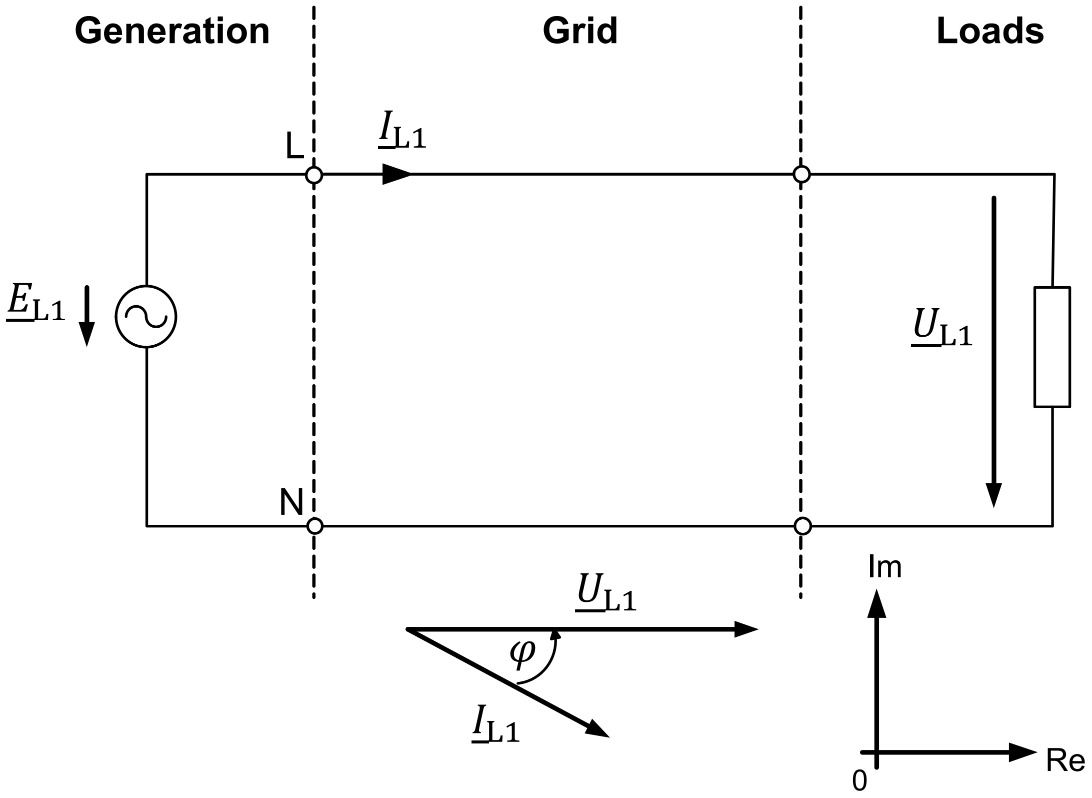
Phase L_2

Phase L_3

Three-Phase and AC Connections in Households



Single-Phase Equivalent Circuit



Active and Reactive Power

Source: cliparts.co

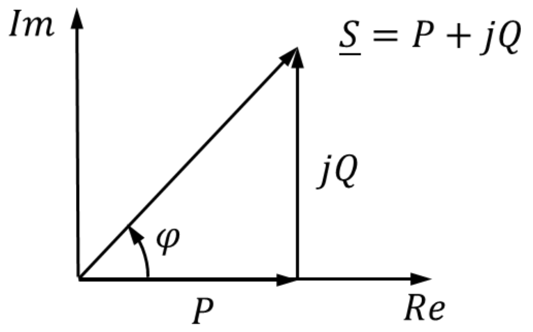
Reactive power (Q)

Rolling motion must be compensated for

Active power (P)

Production must cover consumption

Power in AC Systems



- Definition of active and reactive components

$$p(t) = u(t) \cdot i(t) = \underline{UI \cos\varphi \,(1 - \cos(2\omega t))} + \underline{UI \sin\varphi \,(2\omega t)}$$

→ Reactive component $Q \cdot \sin(2\omega t)$

→ Active component $P \cdot (1 - \cos(2\omega t))$

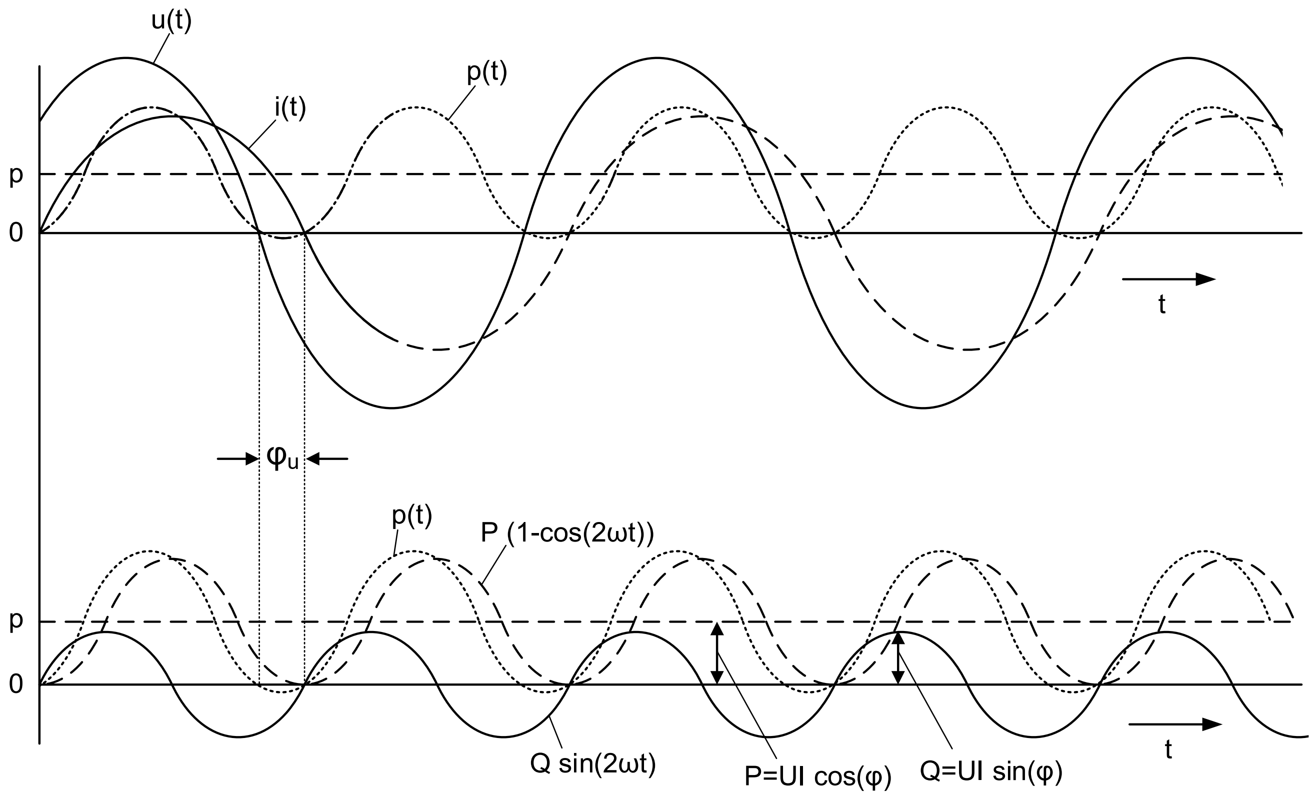
- Active component oscillates with double grid frequency around the mean value
- Reactive component oscillates around zero point with double grid frequency

- Active power: $P = UI \cos\varphi$ and reactive power: $Q = UI \sin\varphi$
- Instantaneous power $p(t)$ oscillates in the European alternating current system ($f_0 = 50\ Hz$) with a frequency of 100 Hz

Reactive Power

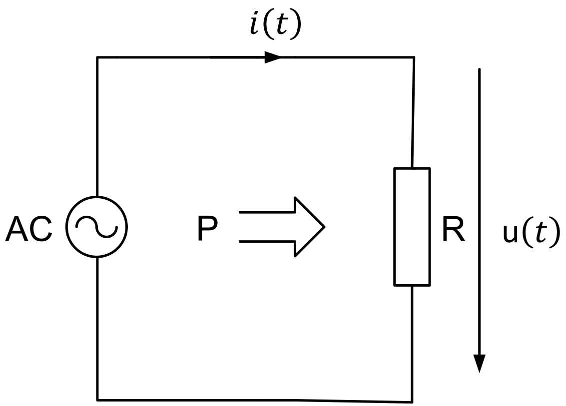
- Results from a phase shift between voltage and current in AC-systems
- Does not contribute to the actual power output in the consumer (mean value = 0)
- Is necessary to build up electric and magnetic fields
- Is caused by the capacitances or inductances of the grid and the loads
- Reduces the potential utilization of generators and transmission grids
- Causes additional losses
- Is closely coupled with the voltage magnitude in a network

Voltage, Current and Decomposition of the Instantaneous Values of p(t) of an AC system



A Short Comparison between AC and DC

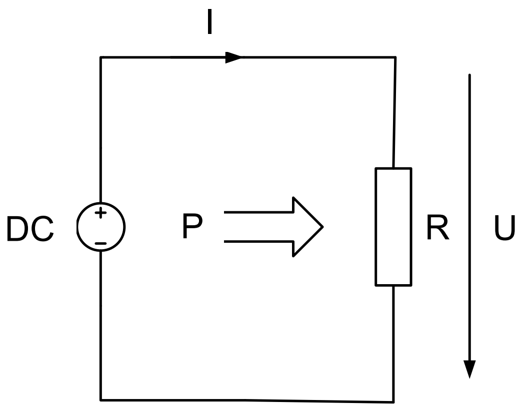
Alternating Current (AC)



- Current changes the flow direction periodically
- Transmission of active and reactive power

AC-Grid

Direct Current (DC)



- Current flows in one direction
- Transmission of active power
- Advantage for long transmission distances

DC-Components (HVDC, PV-Generator)

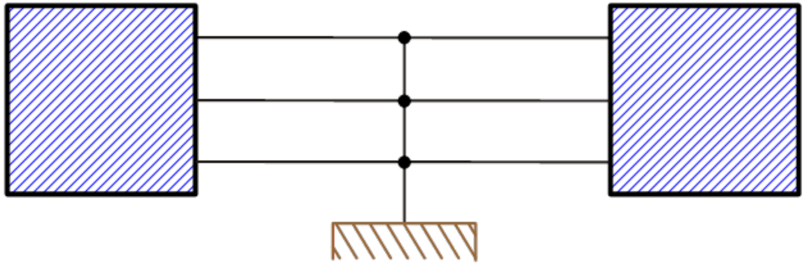
Short-Circuit

Definition based on DIN EN 60909-0 (VDE 0102)

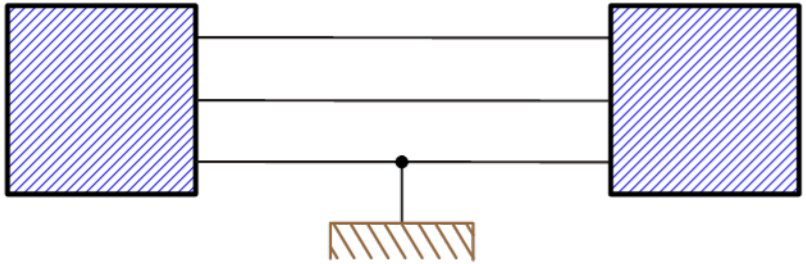
- Short-Circuit
  - A short circuit is the accidental or intentional conductive connection via a relatively low resistance or impedance between two or more points in a circuit that usually have different voltages.

- Short-Circuit Current
  - A short-circuit current is caused by a short circuit in an electrical grid. A distinction must be made between the short-circuit current at the short-circuit point and partial short-circuit currents.

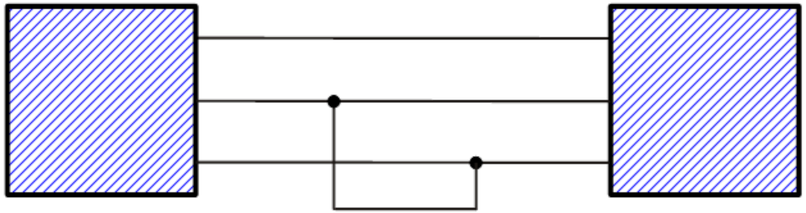
Short Circuit Types



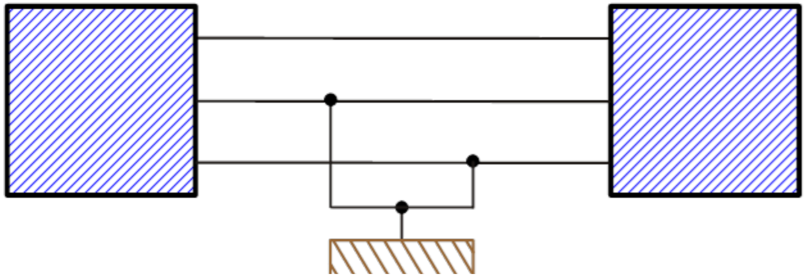
Three phase fault with (or without) ground connection



Single phase to ground fault

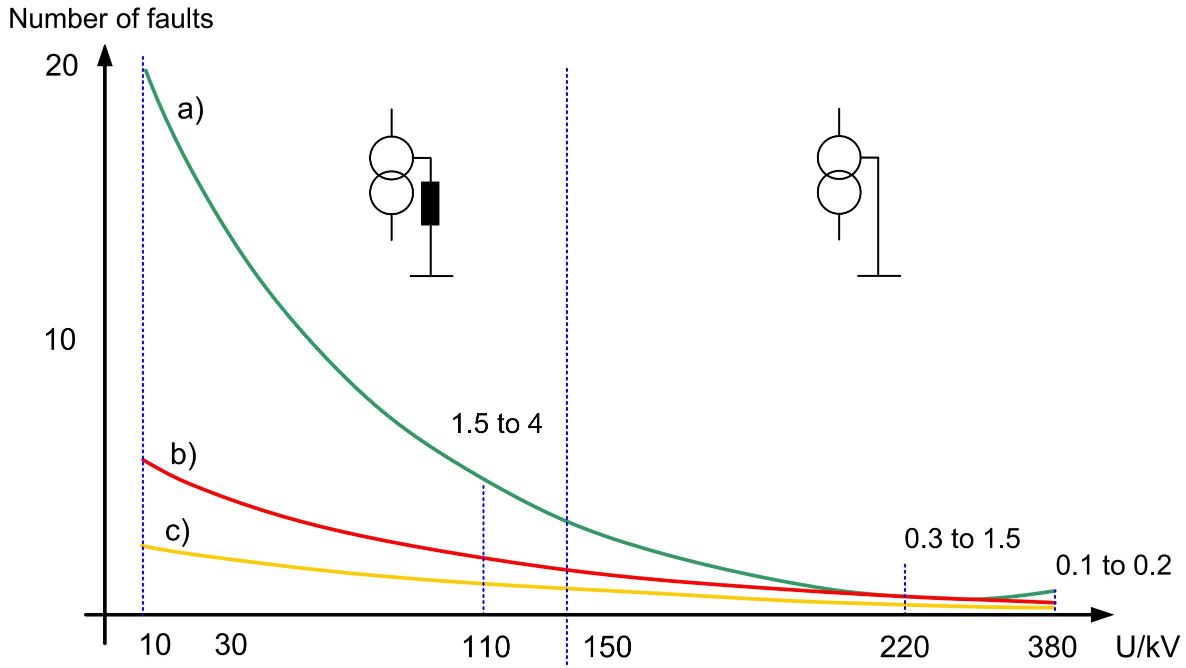


Phase to phase fault without ground connection



Phase to phase fault with ground connection

Number of Faults per Year and 100 km Line



a) Single-phase b) Phase to phase c) Three-phase

Effects of Short-Circuits on Grid Operation

- Grid:
  - Power outage
  - Voltage dip in the faulty network area
  - Load drop due to lower grid voltage, possible undervoltage load shedding
  - Frequency change due to changed load / generation situation

- Electrical Grid Equipment:
  - Destruction of plant components
  - Development of impermissible mechanical and thermal stress on electrical equipment (highest stress is caused by three-phase faults)

- ➢ Short-circuits result in a disturbance for the grid operation
- ➢ Short-circuit currents are important criteria in the design of electrical equipment and networks

Chapter 0.2

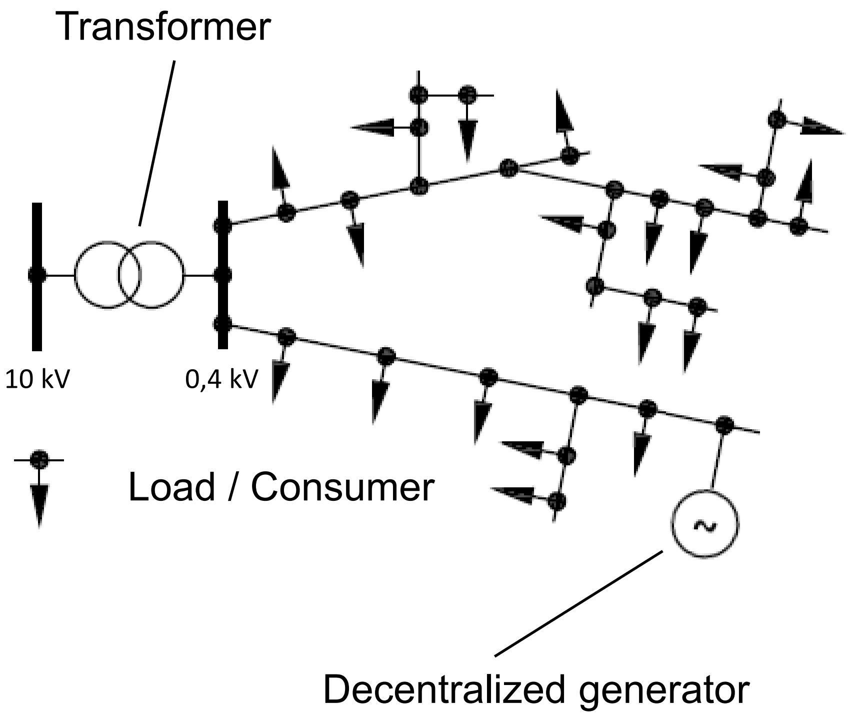
DISTRIBUTION GRID BASICS

Characteristic Values of Low-Voltage Grids

- The majority of electricity consumers are low-voltage devices
- Low-voltage networks are supplied from the superimposed medium-voltage level via distribution transformers
- Typical rated power of network stations: 250, 400 or 630 kVA
- Typical connection power of a household: 22 to 44 kW
- Low-voltage networks are designed as four-wire systems (3 phases + 1 neutral conductor) to enable the connection of single-phase loads
- Depending on the load density (power per area) different network structures are used
- Low-voltage networks are mostly pure cable networks (overhead lines are rare and only at low load densities, e.g. in rural areas)

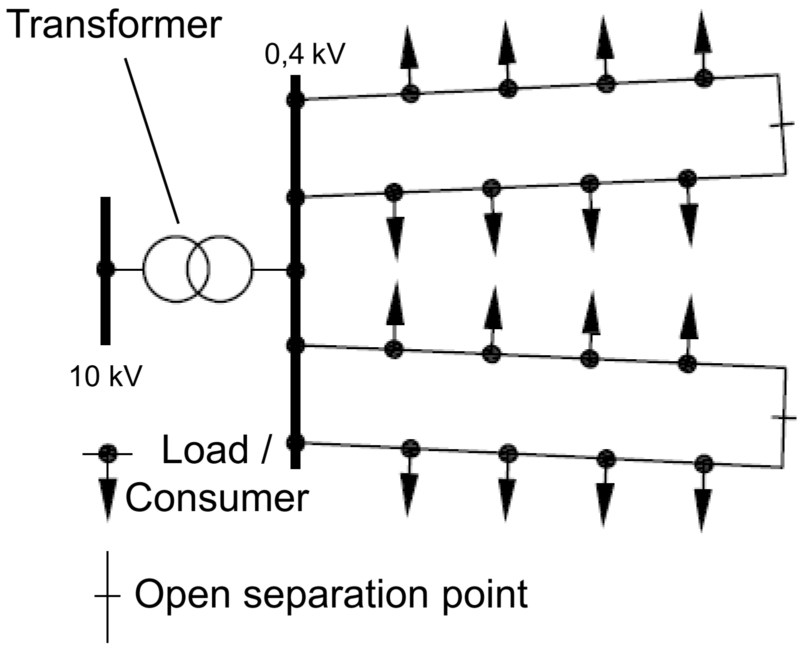
Radial Networks at Low-Voltage Level

- Low / medium load density
- Problematic: Voltage retention along the feeder with large loads at the end of the feeder
- Even simple faults can lead to supply interruptions
- If the network station fails, replacement by emergency power generators or backup power supply (if coupling line to neighbouring network is available)

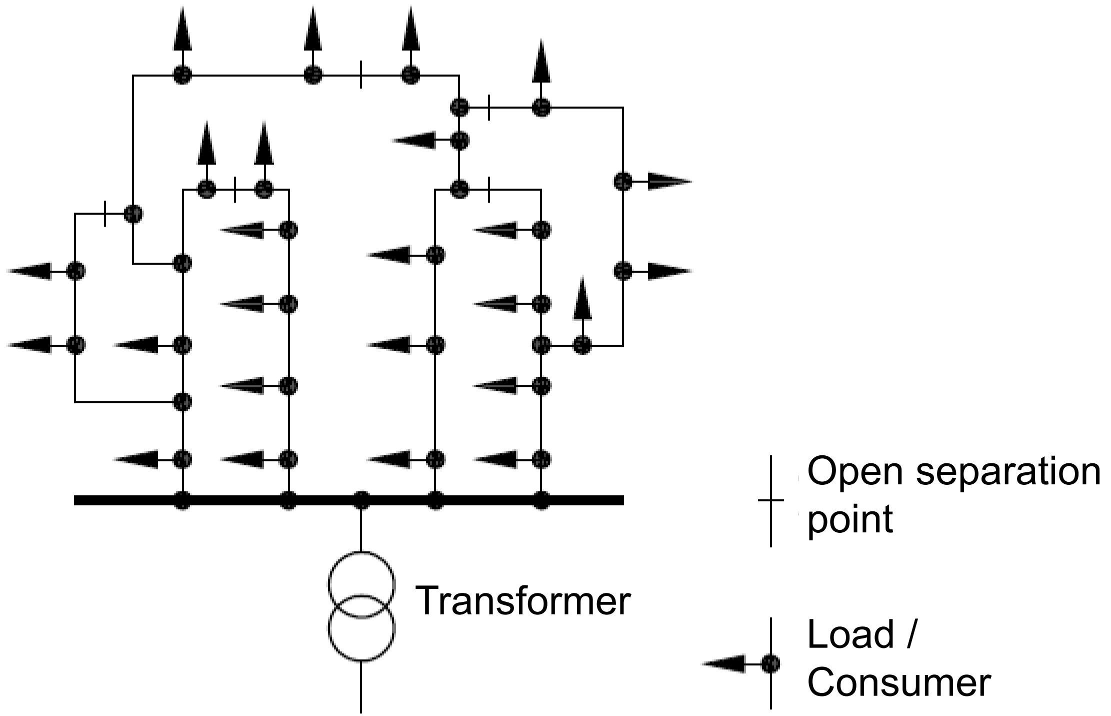


Openly Operated Ring Line at Low-Voltage Level

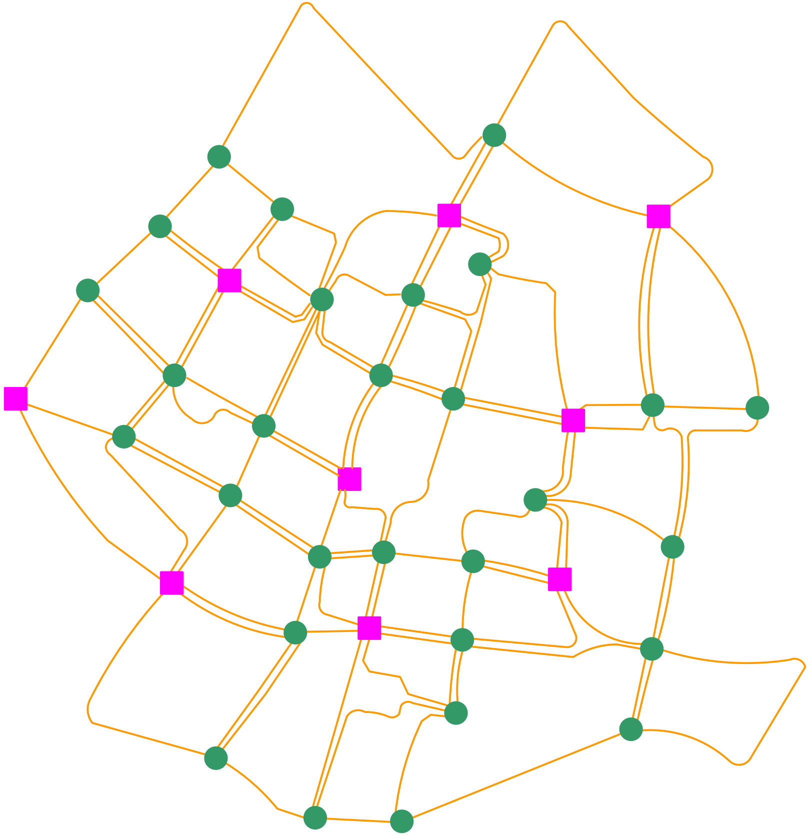
- For higher load densities than in the radial network
- In normal operation, the separation points are open so that there is practically a radial network
- Increased supply reliability, since the faulty cable section can be disconnected and the open disconnection point can be closed in the event of a short circuit in the ring circuit
- Dimensioning of lines and cables must be taken into account.



Other Network Structures at Low-Voltage Level

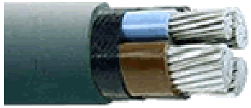


Example: Urban Low-Voltage Distribution Network



Transformer station

Cable distribution cabinet



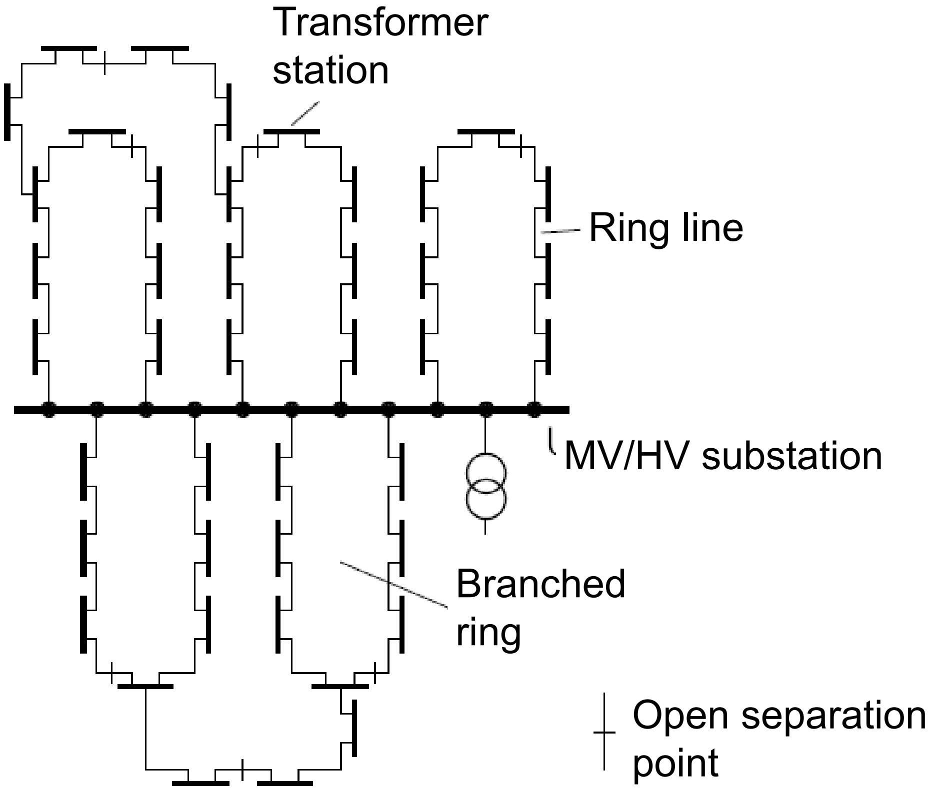
VPE cable

Characteristic Values of Medium-Voltage Grids

- The medium voltage networks are supplied from the superimposed high voltage level by means of MV/HV substations
- Typical rated power of transformers: 20 ... 50 MVA
- Direct connection of end users rare, but possible in individual cases
- Choice of nominal voltage (10 kV or 20 kV) depending on load density (power per area)
- Medium-voltage networks in cities are almost exclusively pure cable networks (overhead lines are rare and only at low load densities, e.g. in rural areas)
- Typical structure of medium-voltage networks: Ring lines or branched rings

Branched Ring Lines at Medium-Voltage Level

- Separation points open during normal operation, so that it practically is a radial network
- "Consumers" of the MV networks are transformer stations, which in turn feed the low-voltage levels
- If a fault occurs on a line, the power supply can be reestablished by disconnecting the faulty area and closing the separation point to the undisturbed area
- Redundancy in the substation necessary: two parallel transformers advisable



Thanks for your attention!

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