Transmission and Distribution Power Grid

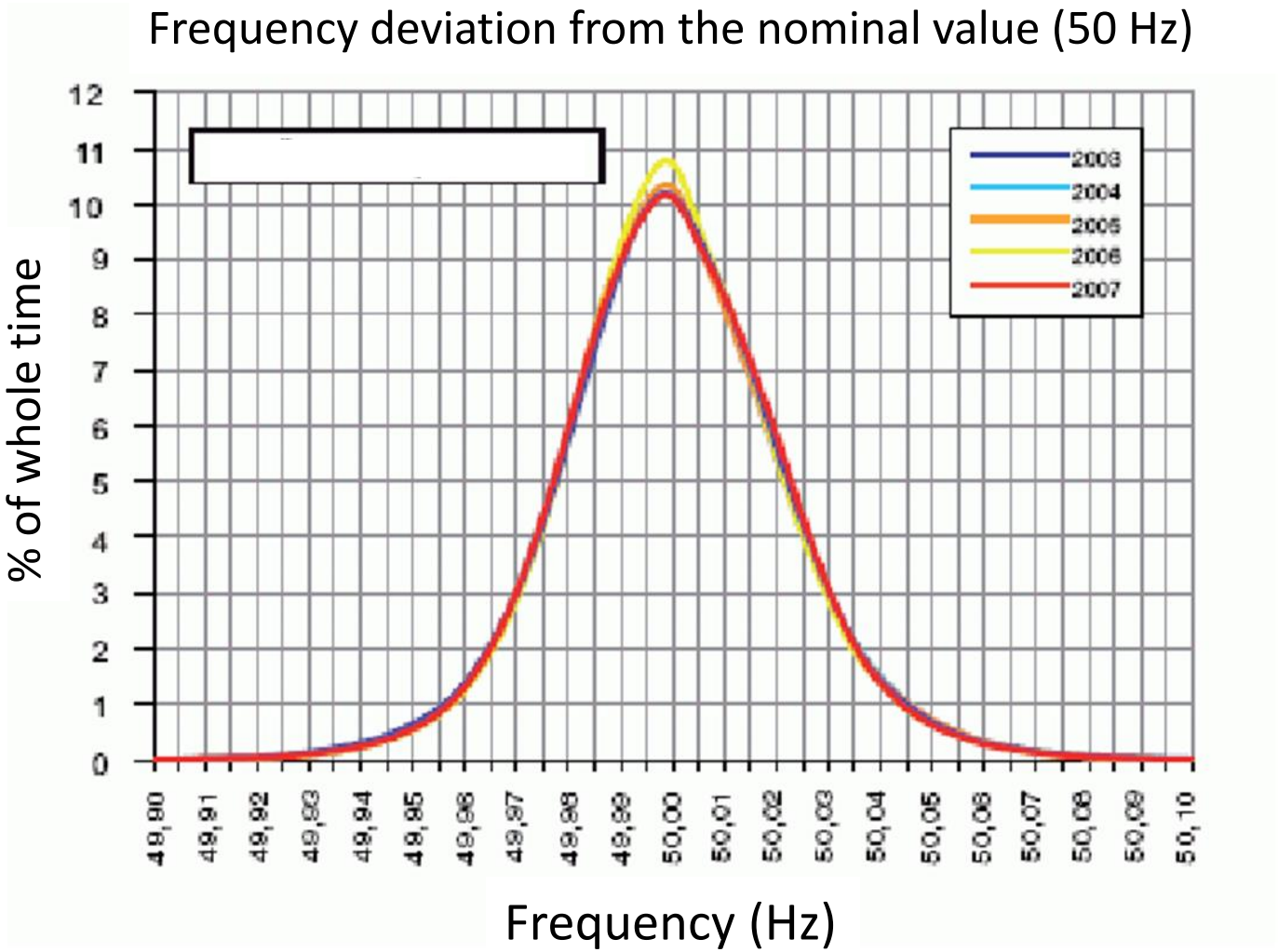
Transmission Power Grid

- Electricity transmission network transmits the power from large producers to distribution stations usually at high-voltage above 110 kV
- **Transmission system operator (TSO) is responsible for:**
  - Maintenance of the level of electrical energy quality
  - Real-time maintenance of the power balance
  - Restoration of grid operation after failures
  - Dispatch control of power grid

Maintenance of the level of electric energy quality

- **Voltage level in pilot nodes:**
  - 110 kV ± 10 %
  - 220 kV ± 10 %
  - 400 kV ± 5 %
- **Frequency**
  - 50 Hz ± 1 % during 99.5 % of the time
  - 50 Hz + (-6,+4) % during 100 % of the time
- **Harmonics distortion**

Frequency fluctuation



Harmonics distortion

- Total harmonic distortion (THD) should be kept as low as possible

$$THD = \sqrt{\sum_{h=1}^{40} u_h^2} \qquad u_h = \frac{U_h}{U_1}$$

where U_h is the magnitude of h-th harmonic and U_1 is the magnitude of the first harmonic

(110 kV THD ≤ 2.5, 220 kV ≤ 2, 400 kV ≤ 1.5)

Power Balance equation

$$P_s = P_v \pm P_{sal} - P_z$$

where P_s is consumed active power, P_v is produced active power, P_{sal} is saldo export/import, and P_z are transmission losses

Restoration of grid operation after failures

- Exceeding of the stability limit (static or dynamic) causes loss of power grid synchronicity and breakdown of the network to so called „isolated islands“
- The power grid restoration could be done from:
  - neighboring transmission power grids
  - power station that are able to start „from darkness”
  - distribution system „from the bottom“

System services

- System services are provided by TSO in order to ensure the quality requirements and reliability of electricity supply at the transmission system level
- **Primary frequency control** – automatic change of power of power plant depending on system frequency deviation from nominal value
- **Secondary power control** – change of power of power plant according to requests from secondary controller (on dispatch center of TS) which must be done in up to 10 min
- **Tertiary power control** – change of power of power plant by dispatch center of TS which must be done in up to 30 min
- **Dispatch backup** – dispatcher backup available reach maximum power in up to 60 min or 6 h

System services

- **Secondary voltage regulation** – automatic change of reactive power of power unit to keep the requested voltages in reference (pilot) nodes
- **Ability to work in "Island regime"**- the power unit can work isolated from the outer network
- **Ability to start "from darkness"**- ability to start power unit without outer voltage

Interconnected power systems

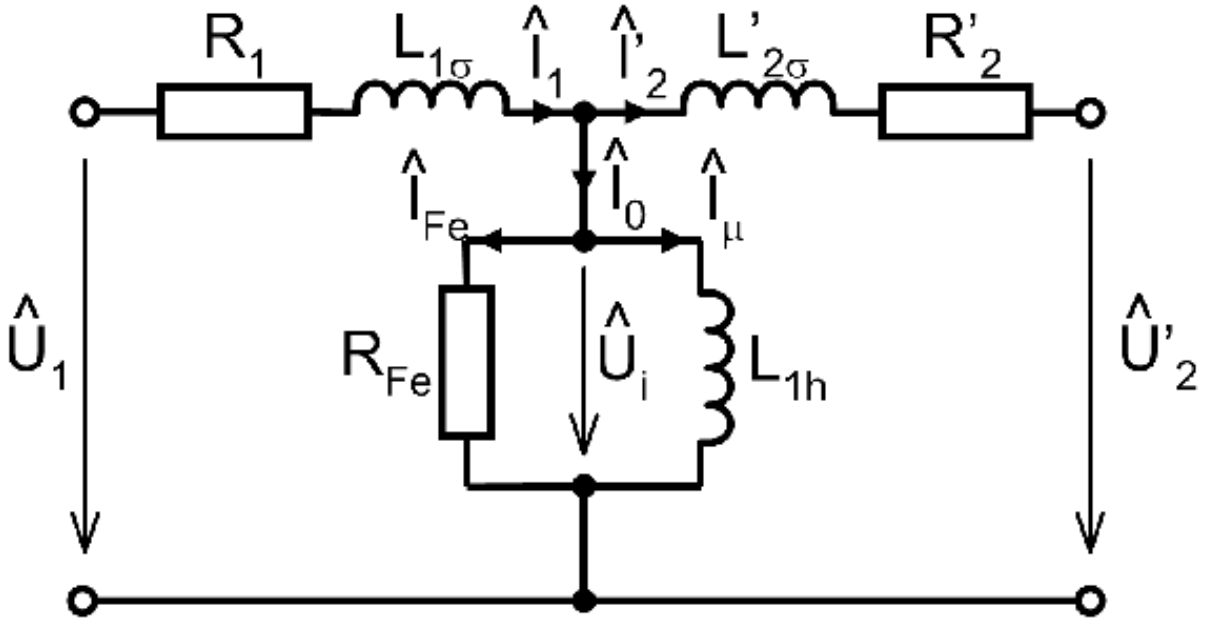
- **Solidarity principle** – all power units connected in primary regulation participate in covering of power unbalance in interconnected networks
- **Non-intervention principle** – only the secondary control of affected area reacts on power covering of power unbalance in interconnected networks

Fundamental Elements of Transmission System

- Power Transformers
  - Transfer the power from transmission grid to distribution network
  - Mainly three phase autotransformers with tertiary compensatory winding
  - Typical voltage ratios and powers (Czech TS)
    - 400/220 kV, 400 MVA,630 MVA
    - 400/110 kV, 200 MVA,250 MVA,330MVA
    - 220/110 kV, 3x66 MVA

Fundamental Elements of Transmission System

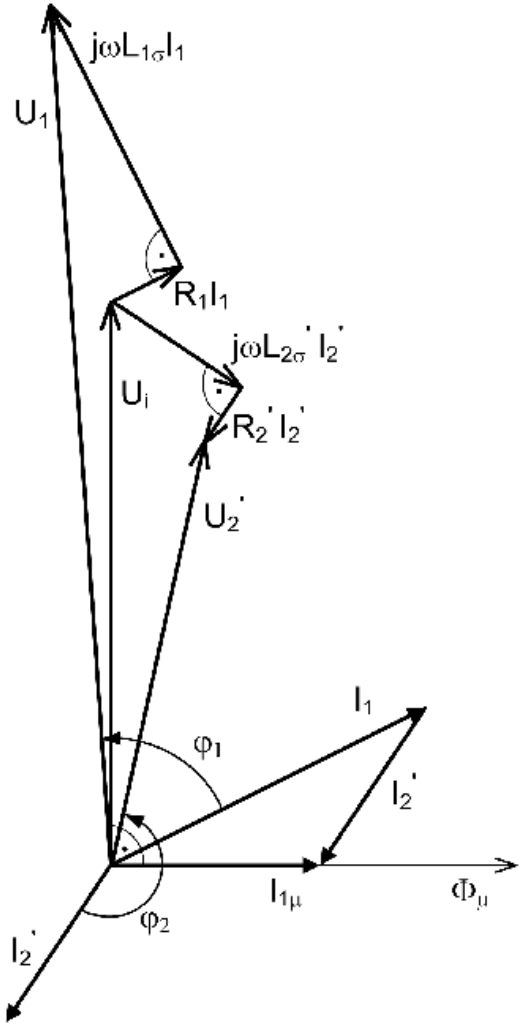
Fundamental Elements of Transmission System



$$\hat{U}_1 = R_1\hat{I}_1 + j\omega L_{1\sigma}\hat{I}_1 + \hat{U}_{i1}$$

$$\hat{U}_2 = R'_2\hat{I}'_2 + j\omega L_{2\sigma}\hat{I}'_2 + \hat{U}'_{i2}$$

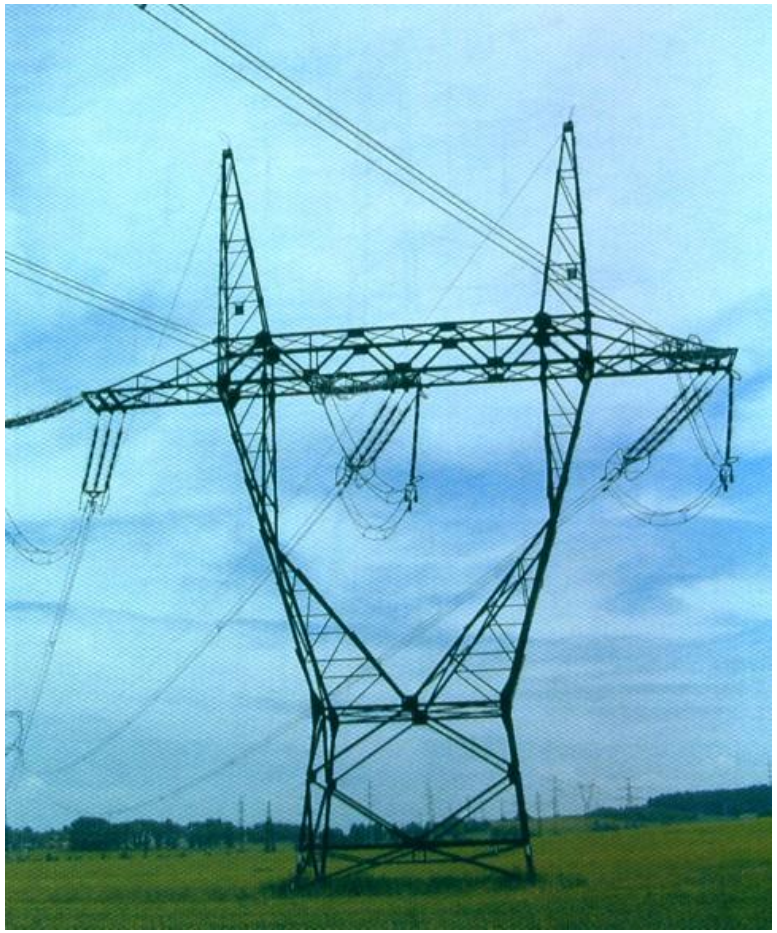
Fundamental Elements of Transmission System



Fundamental Elements of Transmission System

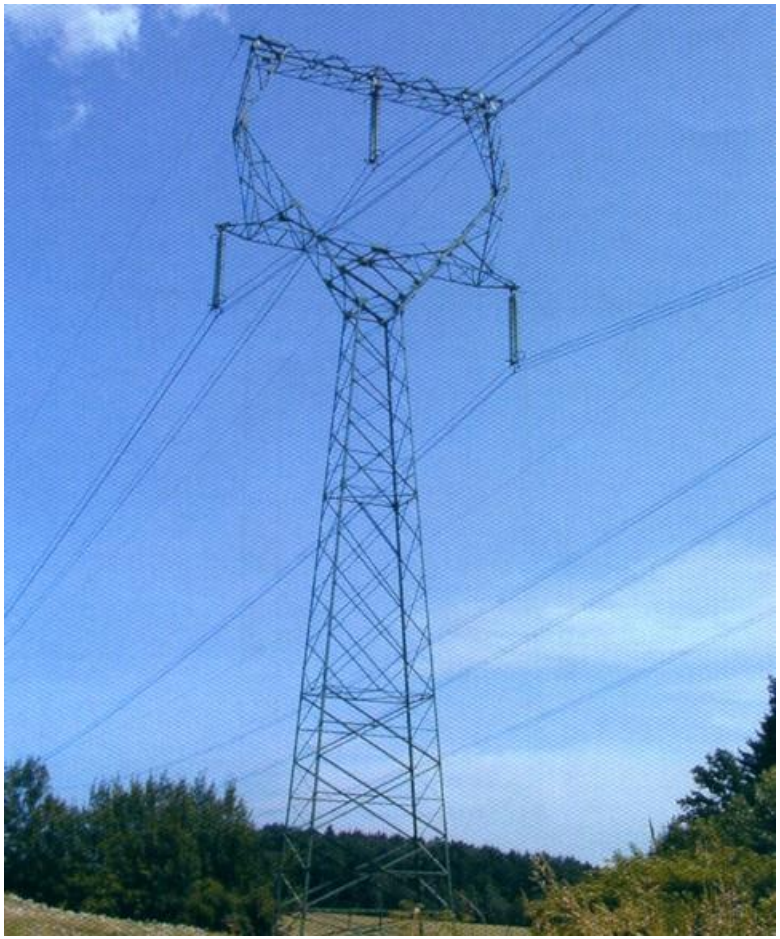
- Transmission overhead lines
  - Towers
    - Construction
    - Function (dead-end angle tower, support tower)
  - Insulators
    - Porcelain, glass, plastic or composite materials
    - Long rod insulators, disk type insulators
  - Conductors
    - AlFe (Aluminum/Ferrum), High Temperature Low Sag (HLTS) conductors
    - Bundled conductors (for 400 and 220 kV)

Fundamental Elements of Transmission System



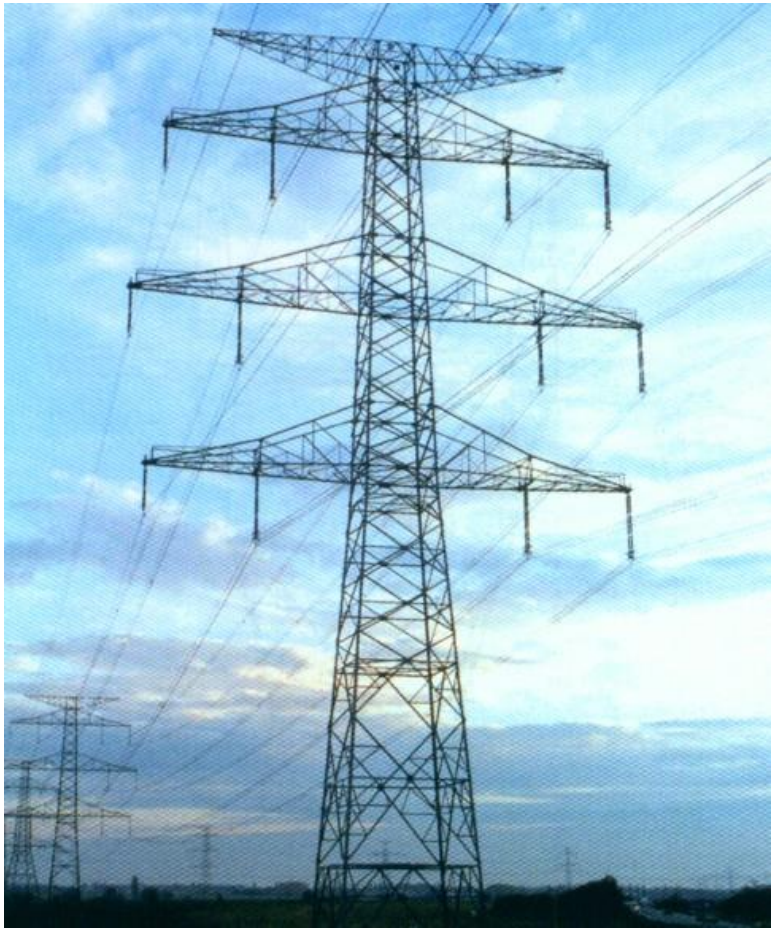
Cat design – dead-end tower

Fundamental Elements of Transmission System



Delta design – suspension tower

Fundamental Elements of Transmission System



“Barrel” design – suspension tower

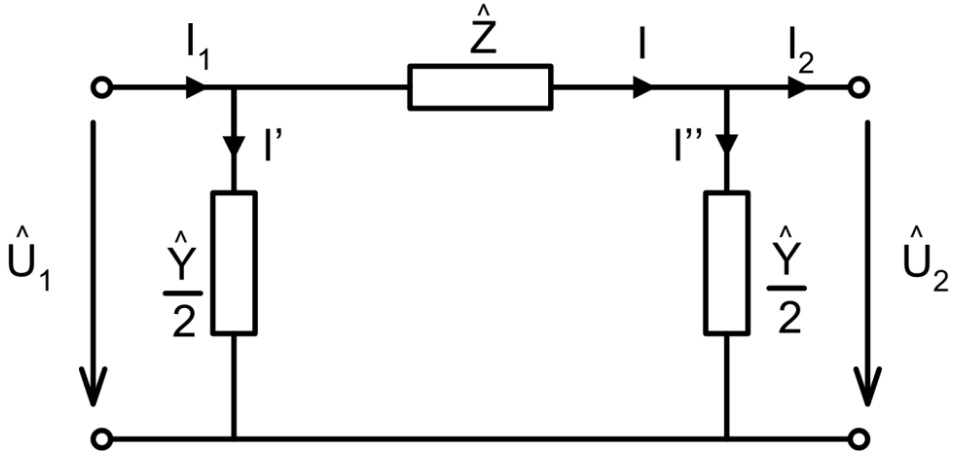
Fundamental Elements of Transmission System

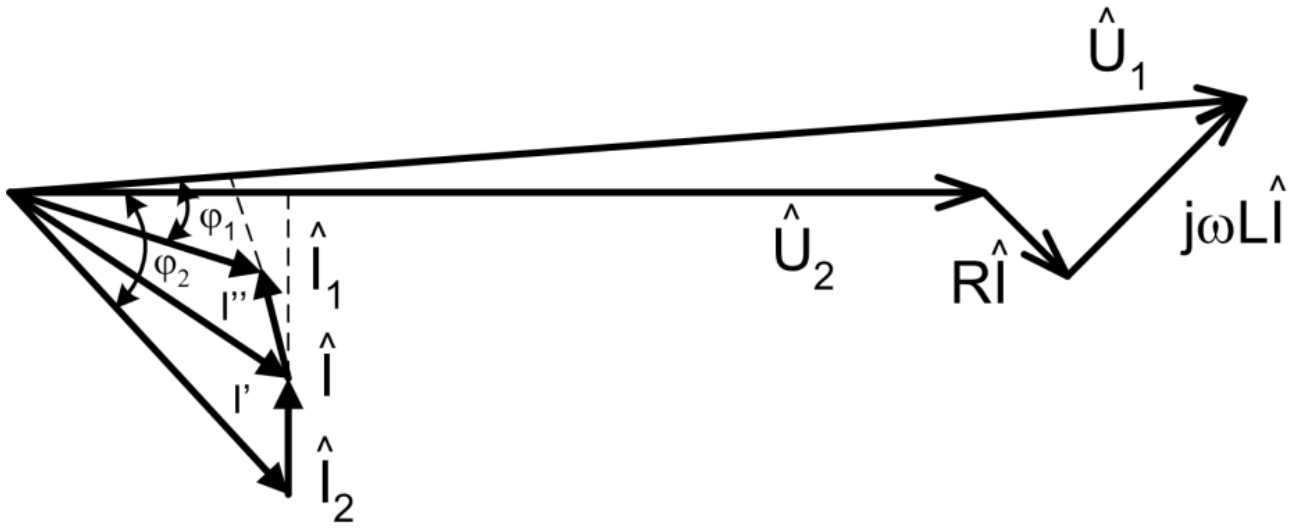
Suspension insulator string

Fundamental Elements of Transmission System

Dead-end insulator string

Fundamental Elements of Transmission System





Distribution Power Grid

- 110 kV – super grid for urban and industrial networks
- 35 kV, 22 kV, 10 kV – transport of electrical energy closely to consumers – to distribution substations with transformation MV/LV
- 1 kV, 400 V – LV network, transport of electrical energy from MV/LV substation to consumers

Reliability of Distribution Power Grid

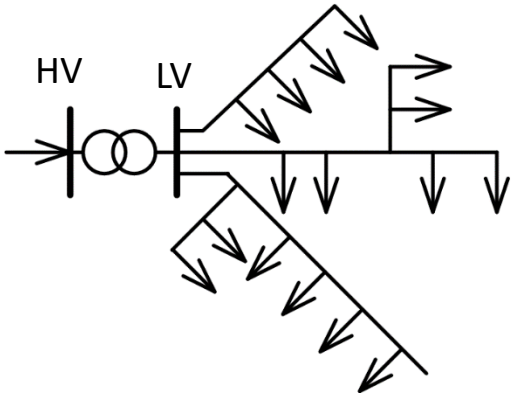
- with or without backup (backup line, parallel connection of transformers, ….)
  - manual switching of reserve (interruption of power delivery)
  - automatic switching of reserve (uninterrupted power delivery, usage of remote control elements like reclosers, disconnecters, …)

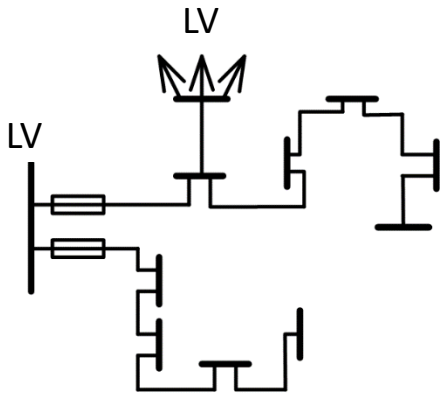
Types of Distribution Power Grid

- Cable lines (underground cables, in concrete corridors, hanged on towers, …)
- Overhead lines (concrete/wooden/metallic poles or towers)
- Mixed (combination of cable line and overhead line)

Topology of Distribution Power Grid

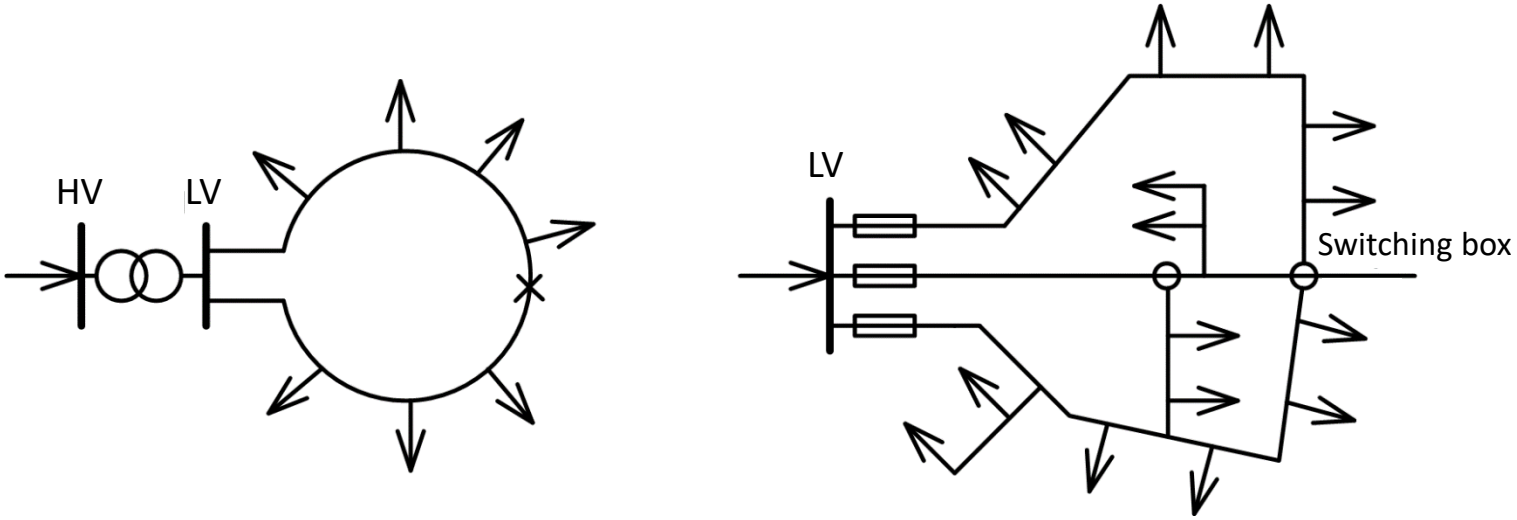
- Radial





Topology of Distribution Power Grid

- Loop



Topology of Distribution Power Grid

- Network