Electrical Parts of Power Plants

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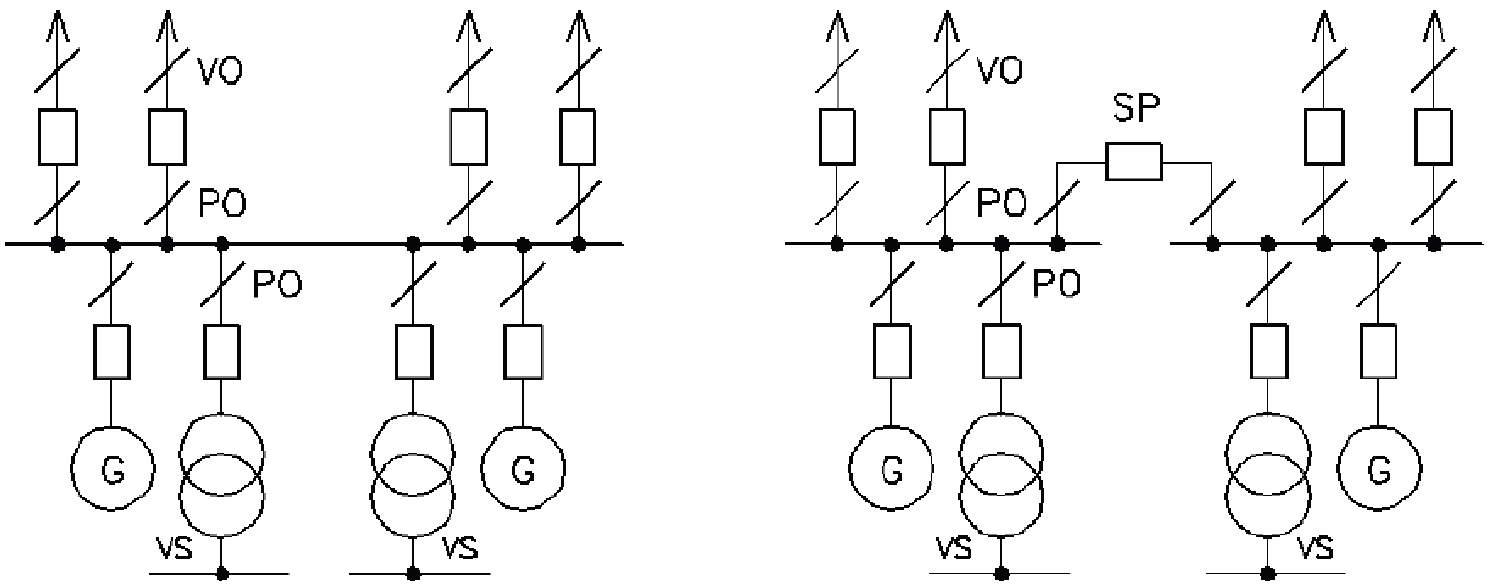
- Main tasks are:
  - **Take the power out –** connection between generator and transmission grid
  - **Self-consumption** – providing supply for main production facilities and auxiliary operations of electricity production
  - **Assuring control and safety functions of electricity production**

Bus-bar systems

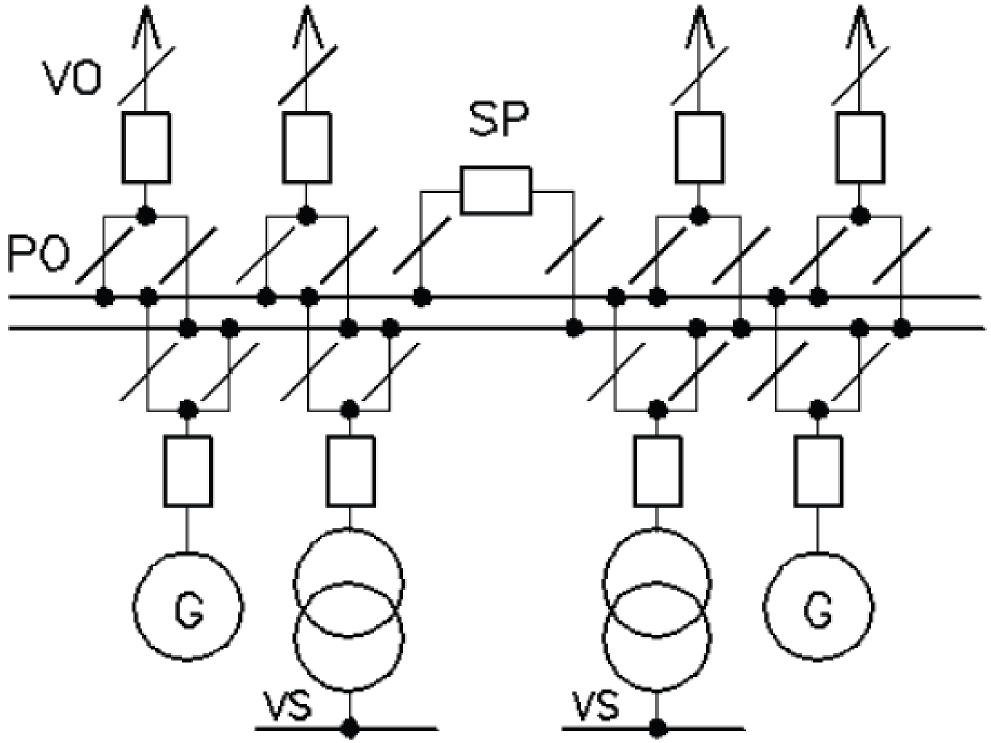
- Single bus-bar system (with/without sectionalization)



VO – feeder disconnecter, PO – Bus-bar disconnecter, VS – bus-bar of self consumption, G – generator unit, SP – Bus – bar circuit breaker

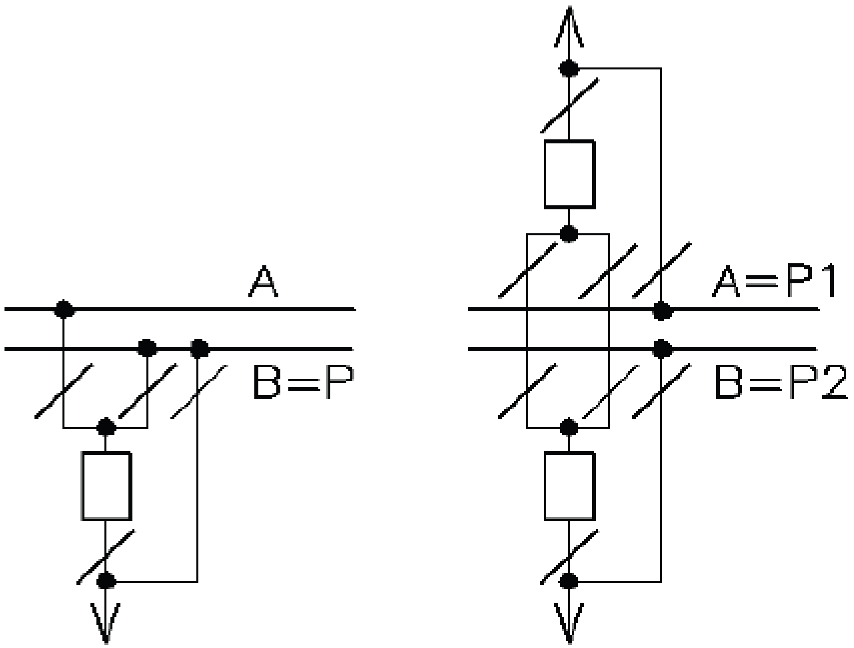
Bus-bar systems

- Duplicate bus-bar system



Bus-bar systems

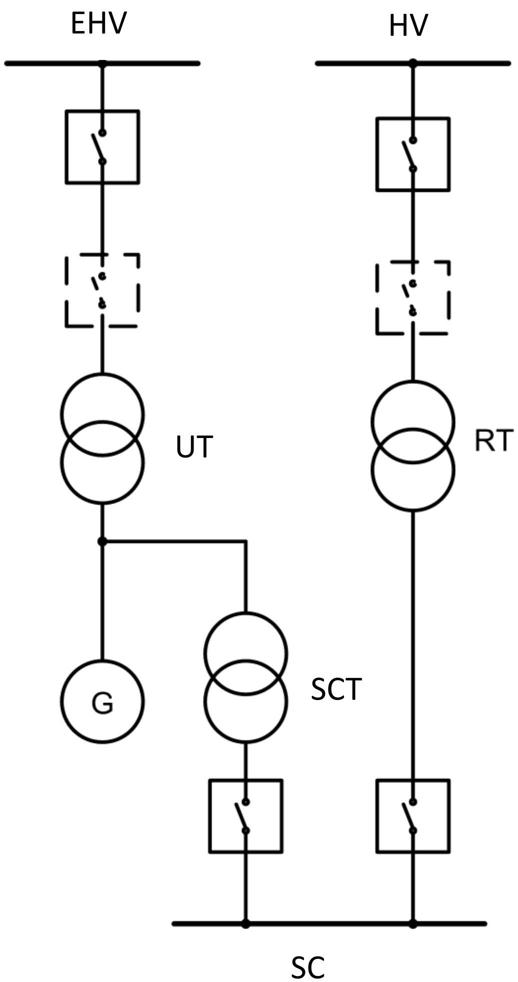
- Systems with auxiliary bus-bar

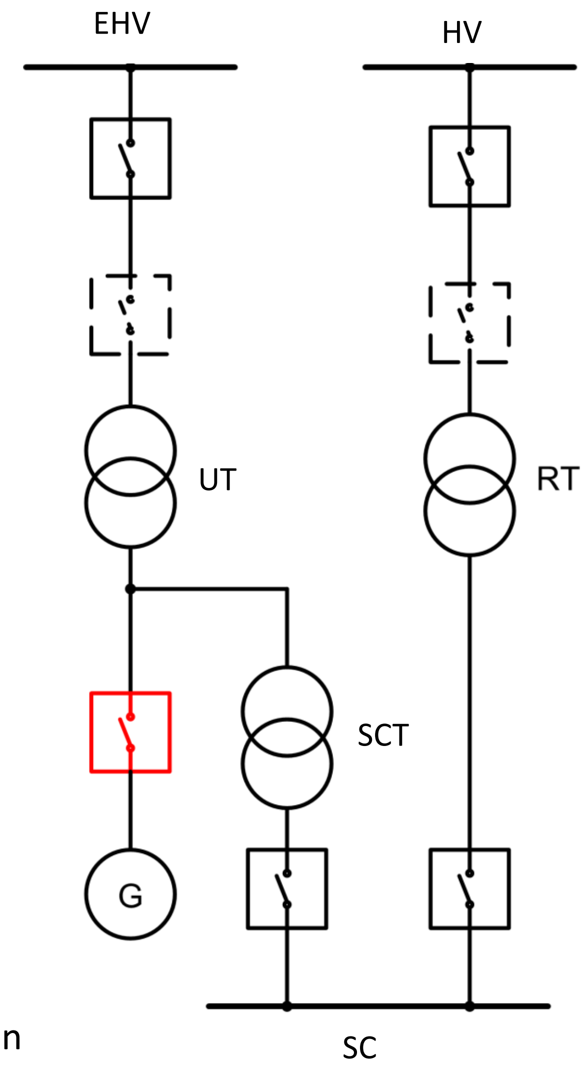


Self-consumption (SC) supply

- Starting source of SC
  - Power plant is started from an idle state, SC usually supplied from power grid or, in special cases, from hydro power plant, dieselagregate, gas turbine generator etc.
- Operating source of SC
  - The power plant SC is supllied at normal operating condition from its own generator
- Backup source of SC
  - The power plant SC is supplied, in case of fault of operating source, usually from the power grid
- Emergency source of SC
  - Rundown of powerplant in case of fault of operating and backup source of SC

Fundamental electric scheme of SC supply





UT – unit transformer, RT – reserve transformer, SCT – Self consumption

Transformers

- Unit transformer
  - Oil filled transformers with power from tens to thousand MVA (the same value as the power of power plant unit)
  - The vector group is usually Dyn, connection D (delta) is on the generator side –> suppression of third harmonics and its multiples propagation
  - Size of unit transformers is limited by transport possibilities (large transformers are usually delivered as three one phase units)

Transformers

- Self-consumption transformers
  - Transformers for self-consumption supply, construction is given by the structure of SC
  - Minimal apparent power of transformer is specified as the sum of coincident power of devices in self consumption
- Reserve transformers
  - Transformer for self consumption supply in case of outage of operating sources

Self consumption design

- Power of SC source is evaluated in accordance with power summation of all electrical appliances:

$$S_P = \frac{\sum_i P_{ni}}{cos\varphi_n}\beta$$

where the demand factor $\beta = \frac{k_z k_s}{\eta_m \eta_s}$

η_m is the mean of efficiency of appliances at given utilization, η_s is the supply grid efficiency, k_z and k_s are the utilization and diversity factors

Self consumption design

- The rated power of SC source S_z must then be:

$$S_Z \geq S_P$$

- Moreover, the following must be guaranteed:
  - Voltage across terminals of electric motors must be in the range ±5% of V_n
  - During the start of the most powerful machine the minimal voltage drop should not be below 0.85 V_n and must not be below 0,8 V_n
  - Voltage drop during the start of machine group must not be below 0,65 V_n

Self consumption design

- For backup sources::
  - At least one backup transformer must be available for two units, two backup transformers for more units
  - At the same time, each backup transformer must assure regular operation of one unit, no-load operation of a second unit and 50 % of common self consumption
  - For nuclear power plants, the backup transformer must be able to shut down the second unit safely as well

Dimensioning of conductors

- Dimensioning respecting permanent current I_n
- Dimensioning respecting short-circuit currents I_k (thermal and dynamical effects)
- Mechanical stresses
- Voltage stresses (cable insulation)
- Environment condition and non-standard modes of operation

Dimensioning for permanent current

- Balance equation of thermal powers

$$P_J + P_S = P_C + P_R$$

- Where
  - P_J are Joule losses
  - P_S is thermal power from the Sun
  - P_C is the heat transferred by convection
  - P_R is the heat transferred by radiation

Joule losses

$$P_J = I_n^2 R_{AC}$$

- Where
  - $R_{AC} = kR_{DC}\left(1 + \mathrm{b}\left(t_p - 20\right)\right)$ is AC conductor resistance, *k* is a coefficient that respects skin effect, proximity effect and hysteresis losses, *b* is the temperature coefficient of resistance and t_p is the temperature of conductor
  - $R_{DC} = \frac{\rho_{20}}{S}$ is DC conductor resistance, ρ_{20} is specific resistivity at 20 °C, S is cross-section of conductor

Solar radiation

- Maximum intensity of solar radiation incident on a plane perpendicular to sun beams is A_m= 1200 W/m^2
- In the CE region A_m=1000 W/m^2

$$P_S = A_m D a$$

- Where
    - a is coefficient of absorption of sun radiation
    - D is diameter of conductor

Heat convection

$$P_K = F\alpha\left(t_p - t_0\right)$$

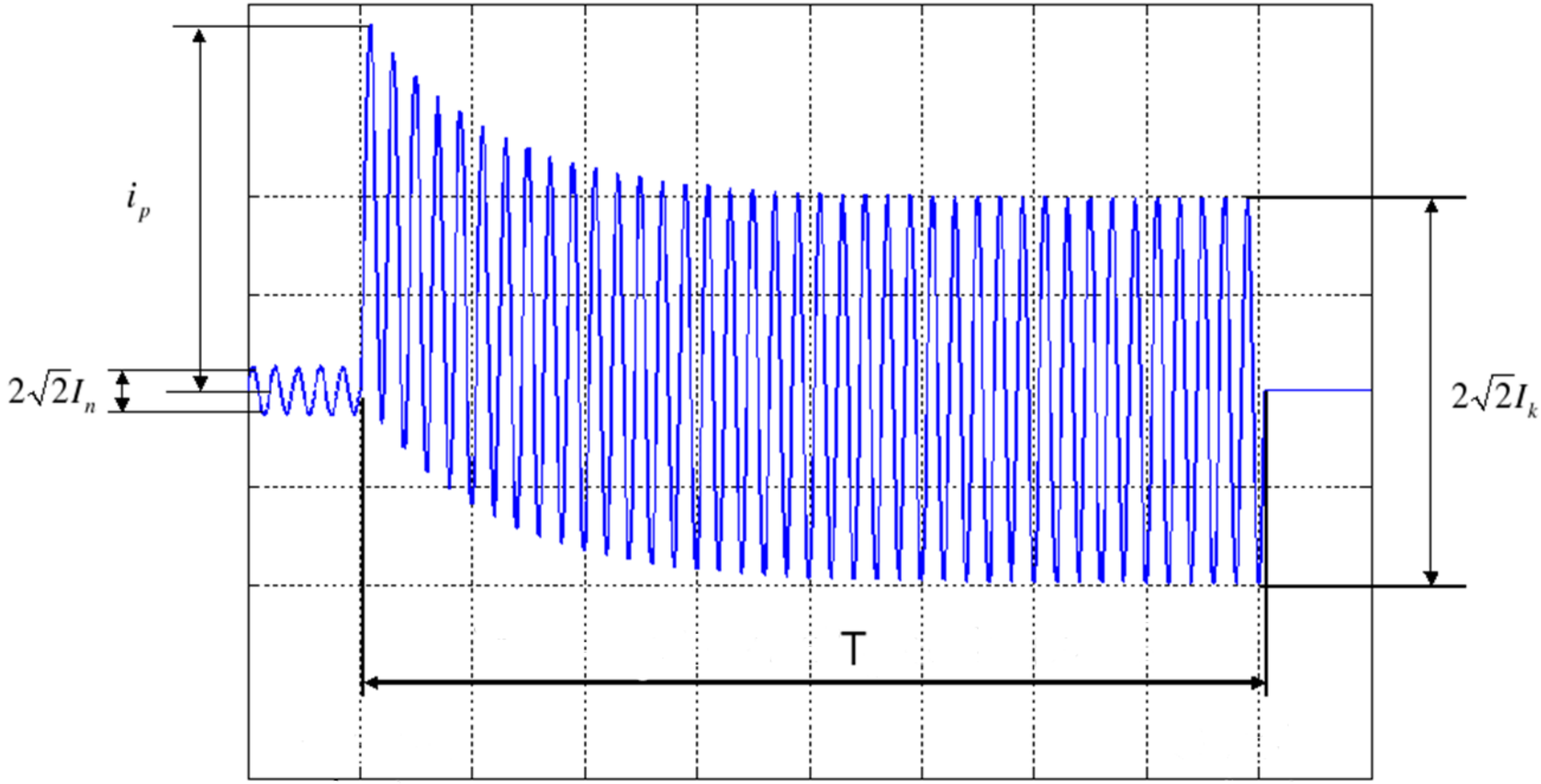
- Where
  - F is the cooled surface related to 1 m of conductor length
  - α is the heat transfer coefficient
  - t_{p} is temperature of the conductor
  - T_0 is temperature of the environment

Heat radiation

$$P_R = \varepsilon \sigma \pi D \left(T_p^4 - T_0^4\right)$$

- Where
  - ε is the emissivity of the surface of a material
  - σ is the Stefan-Bolzman constant
  - D is the diameter of the conductor
  - T_p is the temperature of the conductor
  - T_0 is the temperature of the environment

Short-circuit current



I_p – peak short circuit current, I_k – steady state short circuit current

Heat effects of short-circuit current

Balance equation for a heat increase dW (J) in a conductor of 1 m length:

$$I_k^2 R dt = m c_0 d\theta$$

where I_k is the respective short-circuit current, R is the resistance of 1 m of a conductor, dt is the time duration of a short-circuit, c_0 is the specific heat constant, m is the mass of 1 m of a conductor and $d\theta$ is the increase in temperature

The final equation for practical purposes is then in the form:

$$\frac{I_k}{S} = \frac{1}{\sqrt{T}} \sqrt{\frac{\gamma c_0}{\rho_{20} b} ln\left(\frac{1 + b(\theta_e - 20)}{1 + b(\theta_b - 20)}\right)}$$

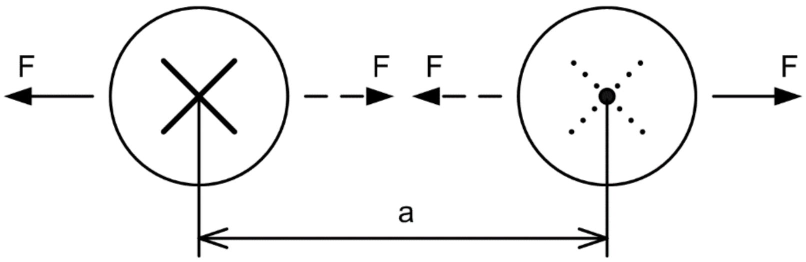
where γ is the specific mass of a conductor, S is the cross section of the conductor, ρ_{20} is the specific resistivity at 20°C, T is the time duration of a short-circuit, b is a temperature coefficient, θ_e is the temperature of the conductor after the short-circuit and θ_b is the temperature of the conductor before the short-circuit

Mechanical effects of short-circuit current

The attractive/repulsive force between two solid parallel conductors is given by equation:

$$F = \frac{\mu_0}{2\pi} i_1 i_2 \frac{1}{a}$$

where i_1, i_2 are instantaneous values of currents, a is axial distance, and μ_0 is the vacuum permeability



Mechanical effects of short-circuit current

In the case of a two phase short-circuit $i_1=-i_2=i_p$, the force between the conductors is:

$$F = \frac{\mu_0}{2\pi} i_p^2 \frac{1}{a}$$