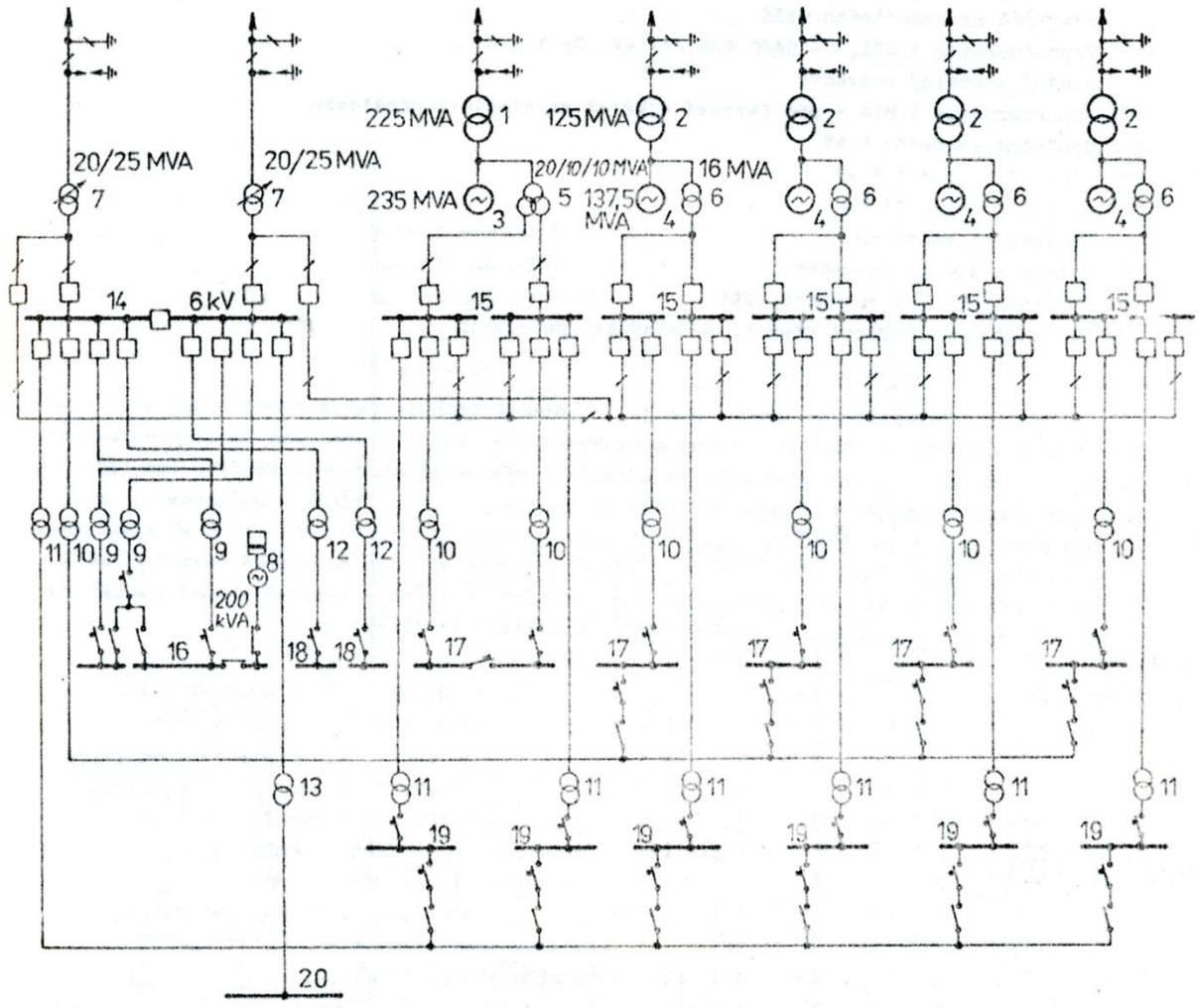
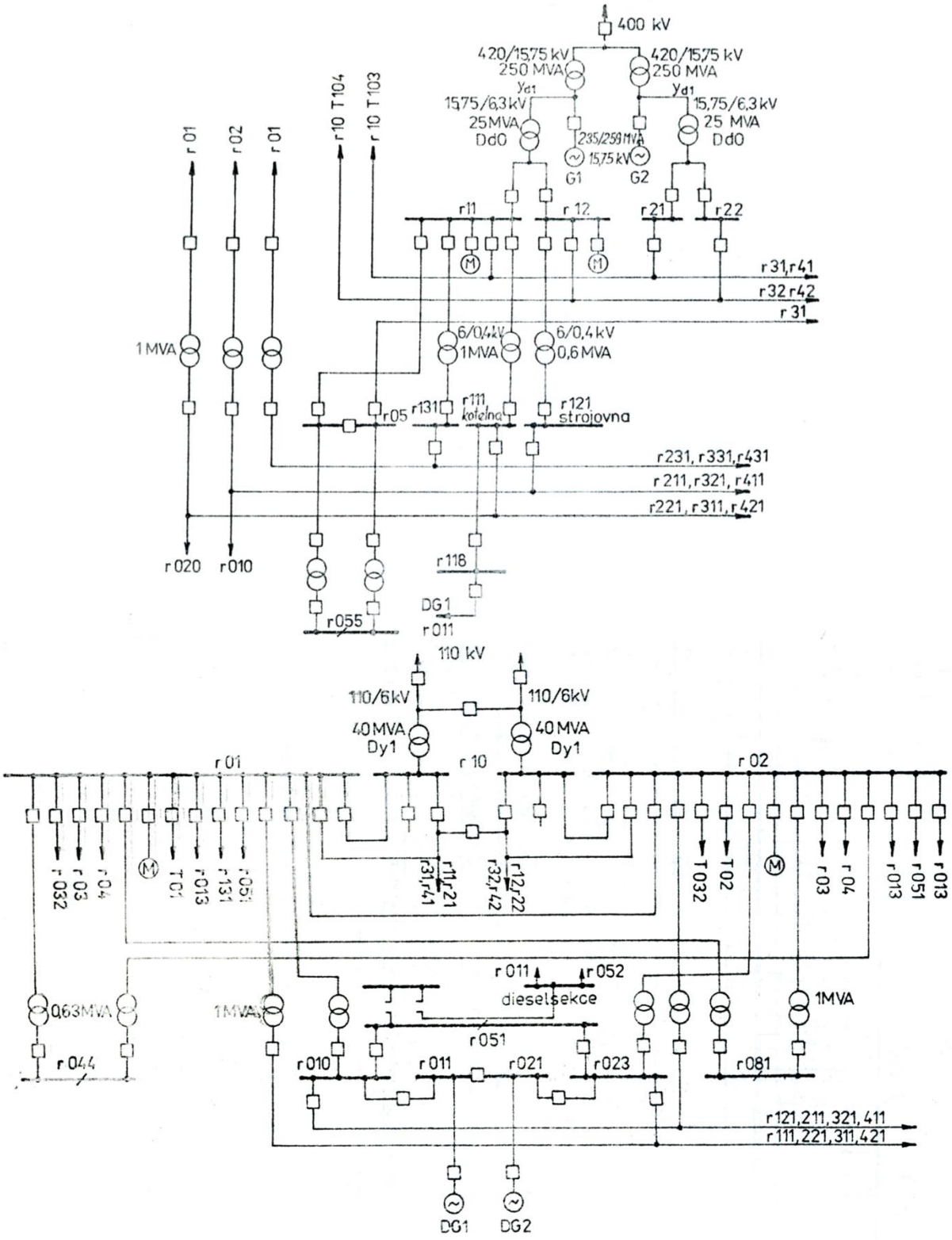
4. Examples of electricity self-consumption schemes for condensing power plants and heating plants

An example of a schematic of a Czechoslovak conventional power plant with a 200 MW unit and four 110 MW units. The power is output to the voltage level of 220 kV and 110 kV respectively.

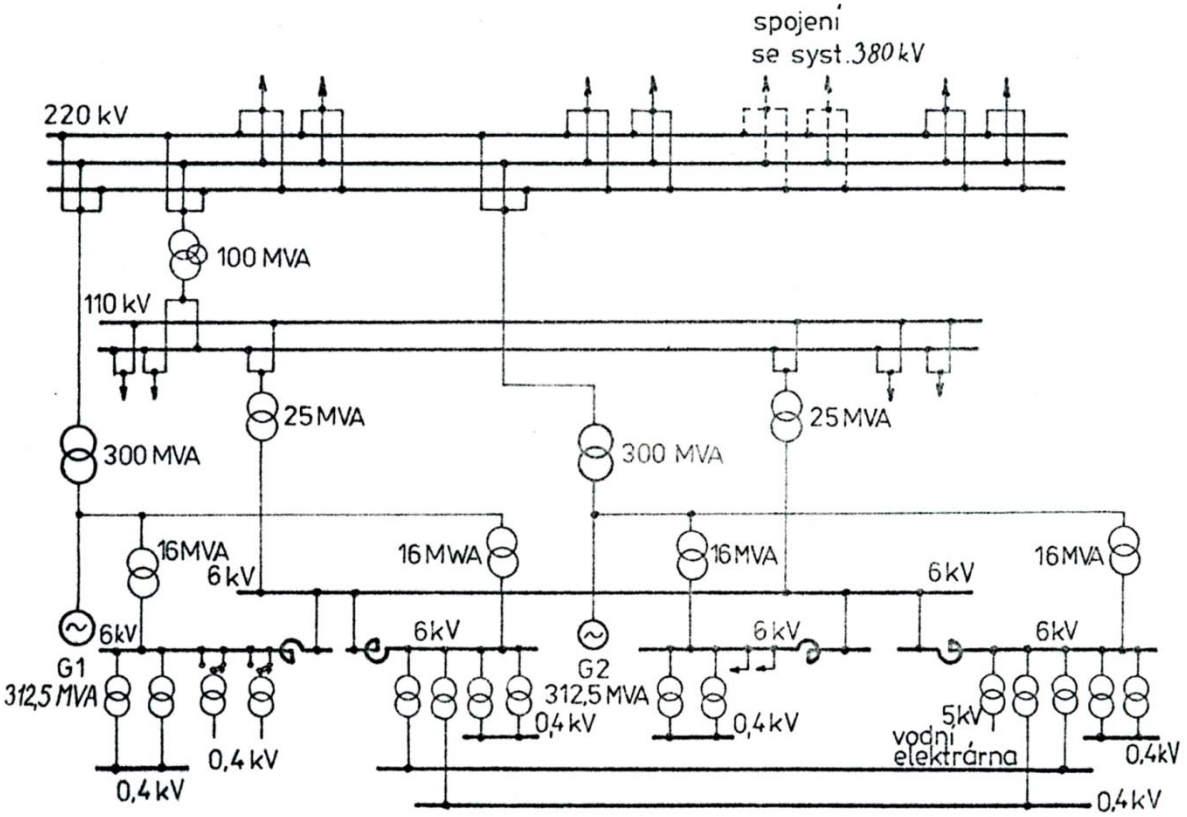
- The block transformers are: 3x 75 MVA 242+-5%-15 kV Yd1 (1), respectively 1x 125 MVA 121+-5%/13.8 kV Yd1 (2).
- Self-consumption transformers 20/10/10 MVA 15+-5%/6.3/6.3 kV Dd0d0 (5) and 16 MVA 13.8+-5%/6.3 kV Dd0 (6) respectively.
- The standby control transformers are 20/25 MVA 110+-16%/6.3 kV Yd1 (7).
- Transformer of common LV switchboard 1,25 MVA 6+-5%/0,4 kV Dy1 (9)
- 1 MVA 6+-5%/0.4 kV Dy1 (10) transformer
- Transformer of cooling tower switchboard 1,6 MVA 6+-5%/0,4 kV Dy1 (11)
- Transformer of LV light switchboard 1 MVA 6+-5%/0,4 kV Dy1 (12)
- 1 MVA 6+-5%/0.4 kV Dy1 (13)



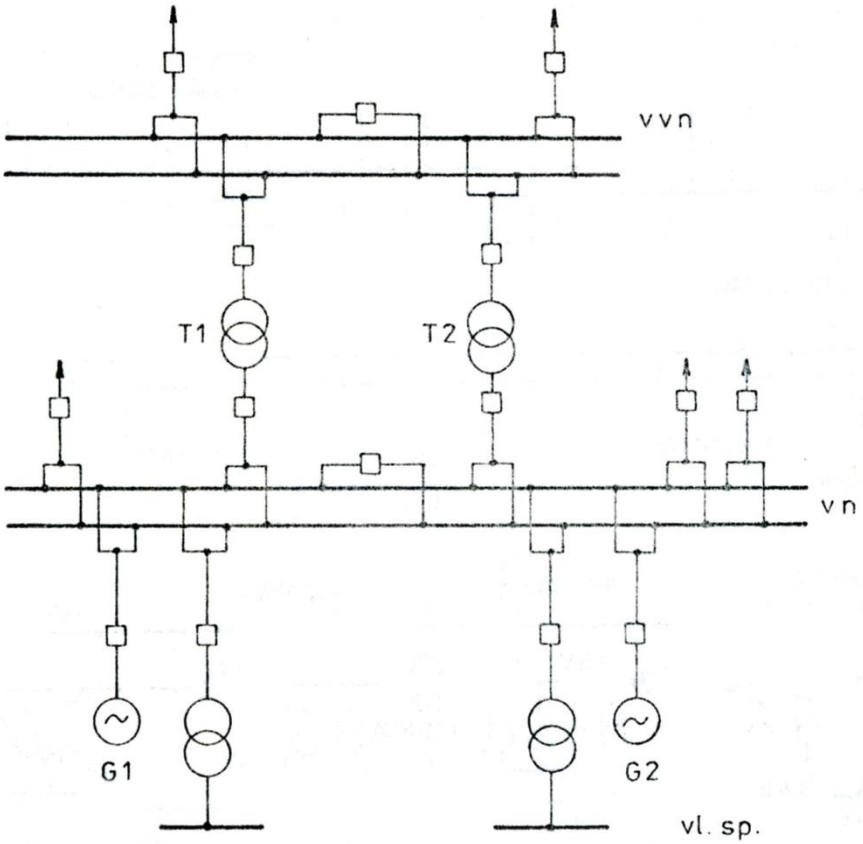
Example of a schematic of a Czechoslovak conventional power plant with 200 MW units. The power is output to a voltage level of 400 kV to a nearby substation.



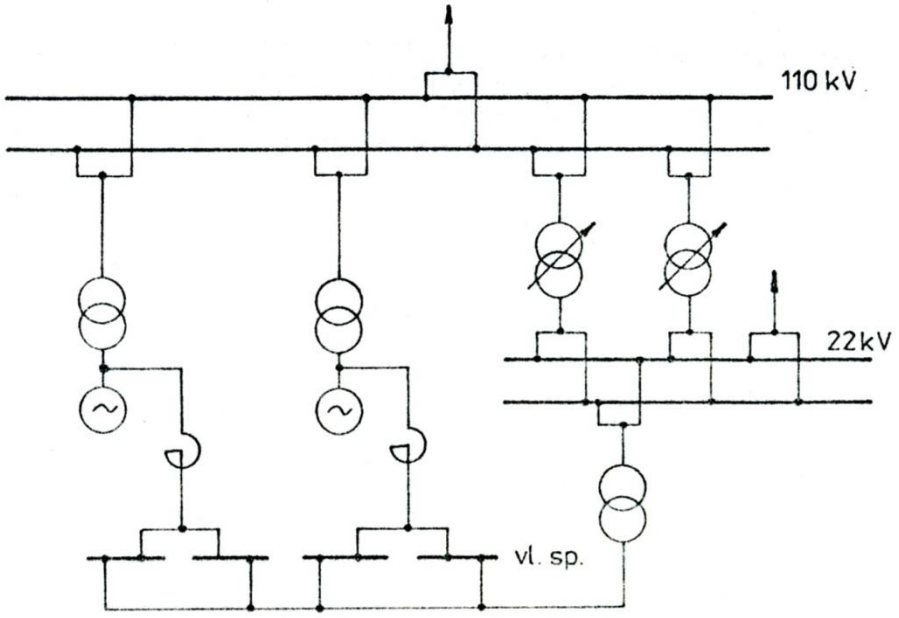
Implementation of a 2x 300 MW condensing power plant in Germany:



The electrical scheme is typical for thermal power plants which, due to the proximity of the agglomeration, also have an outlet for the customer on the overhead line.



Schematic diagram of a larger thermal power plant with reactors with V.S. outlets to limit short-circuit currents:



5. Examples of self-consumption schemes for nuclear power plants

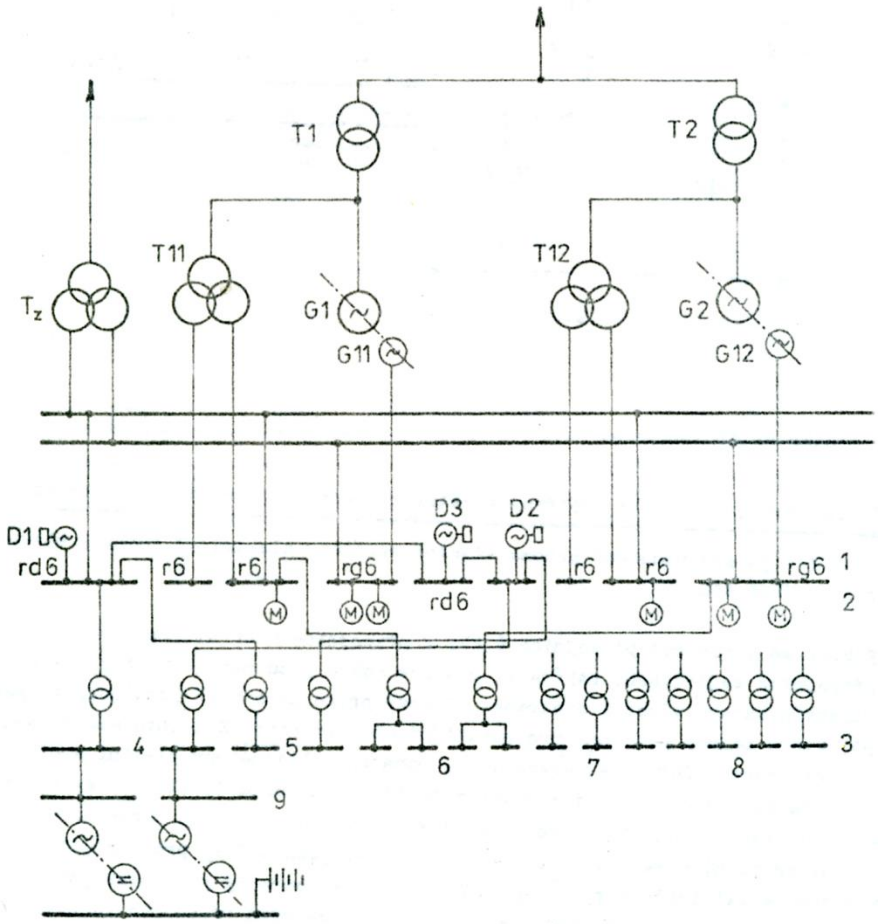
Example of V.S. block diagram of VVER 440 V1 type NPP (Jaslovské Bohunice):

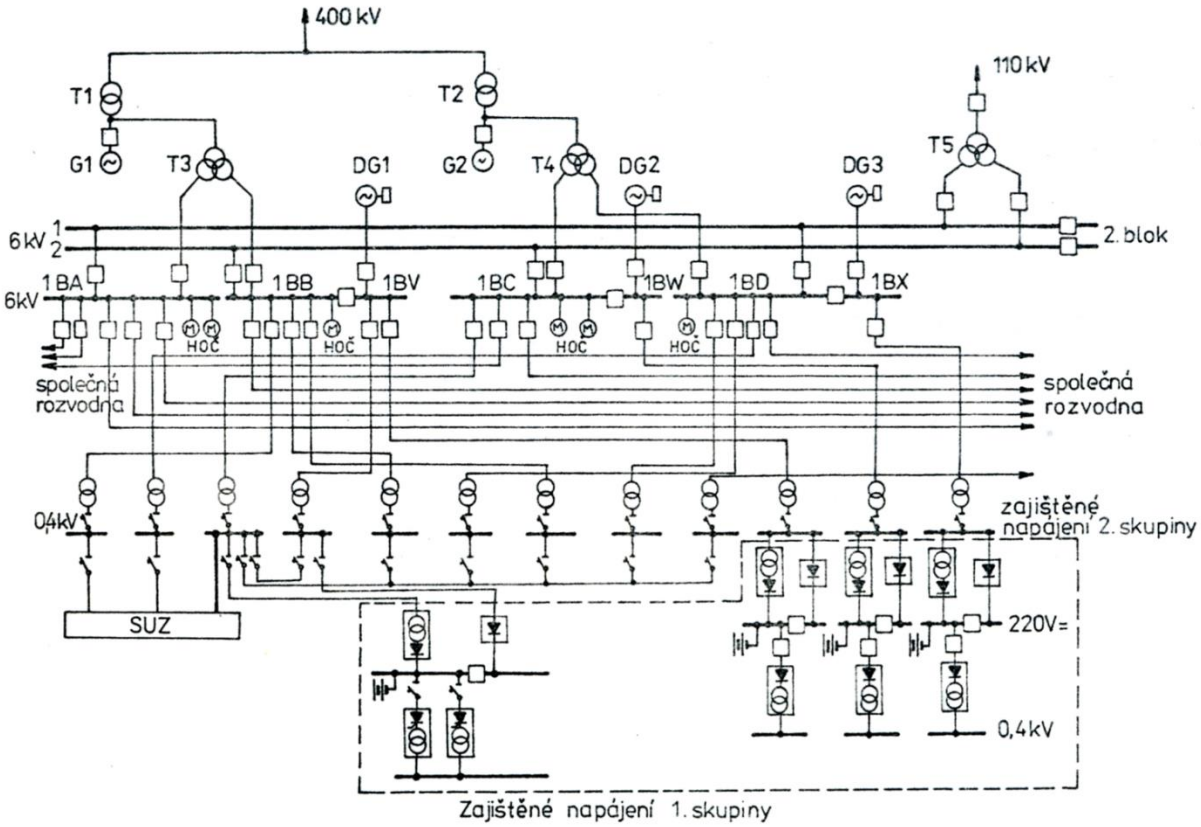
- The 6 kV block busbar r6 supplies the drives outside the emergency aftercooling of the reactor (2 main circulators)
- 6kV rg6 busbar fed by 6 MW V.S. alternators (4 main circulators), which will provide possible aftercooling for the first 100 sec. inertia of the system.
- 6 kV rd6 busbar (for emergency reactor aftercooling appliances). Normally fed from block busbars, but in case of failure of the block power supply, the Group 2 appliances are fed from diesel generators of 1600 kW each or from a backup transformer Tz)
- In the 0.4 kV distribution system, Group 1 appliances are powered from rd6 busbars (for Group 2), and in case of emergency from motor-generators powered from accumulator batteries. The separation of Group 1 and Group 2 is via thyristor interrupters.

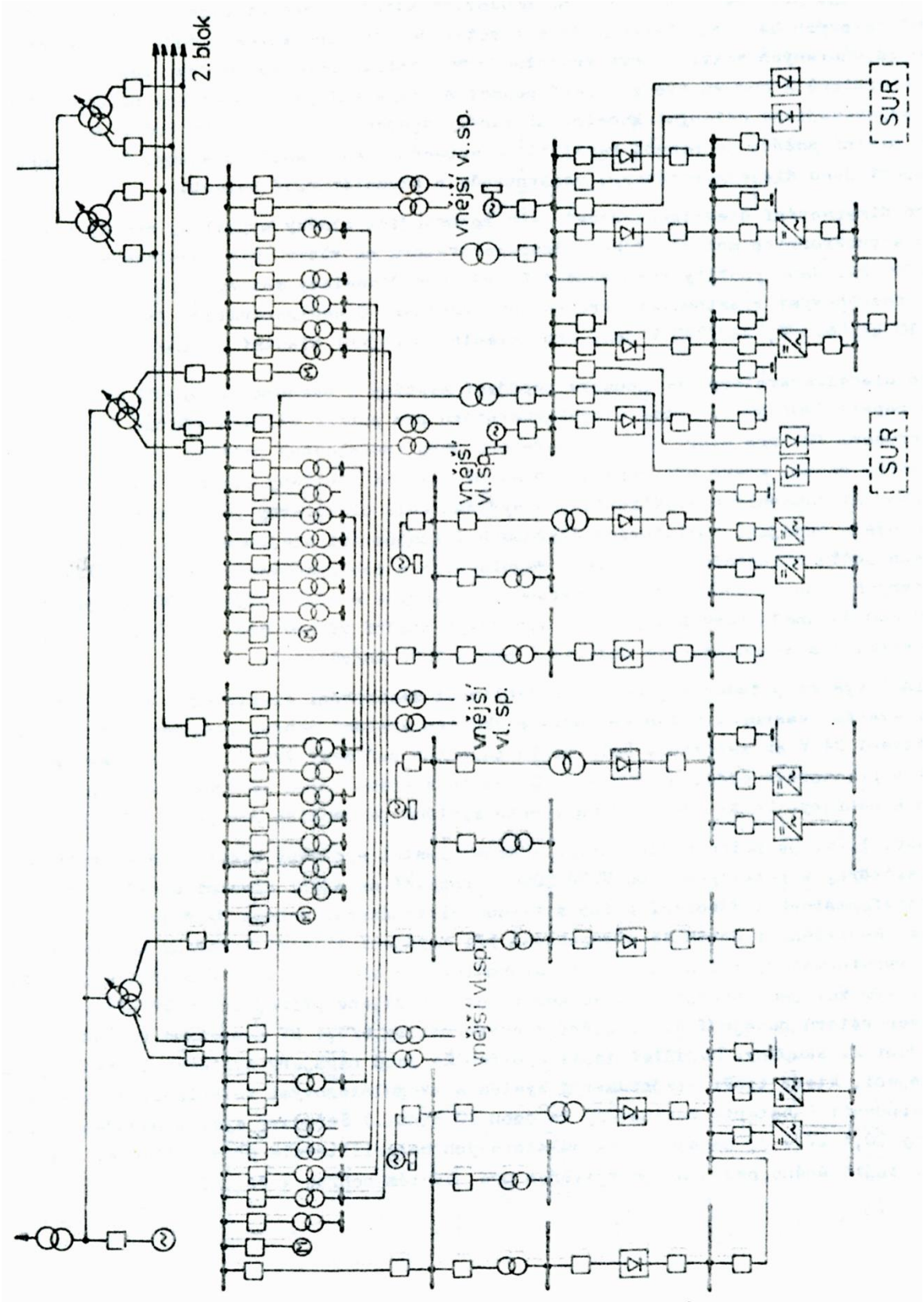
The newer version of VVER 440 (Dukovany) contains a 6 kV busbar with a longitudinal switch. The BV, BW, BX buses supply important drives for emergency shutdown of the unit. The ramp-up speed of DG1 to DG3 is approx. 30 sec. Rechargeable batteries of Group 1 units are rated for 30 min operation. The 0.4 kV switchgear is supplied via inverters.
The special switchboard also has a protection and control system.

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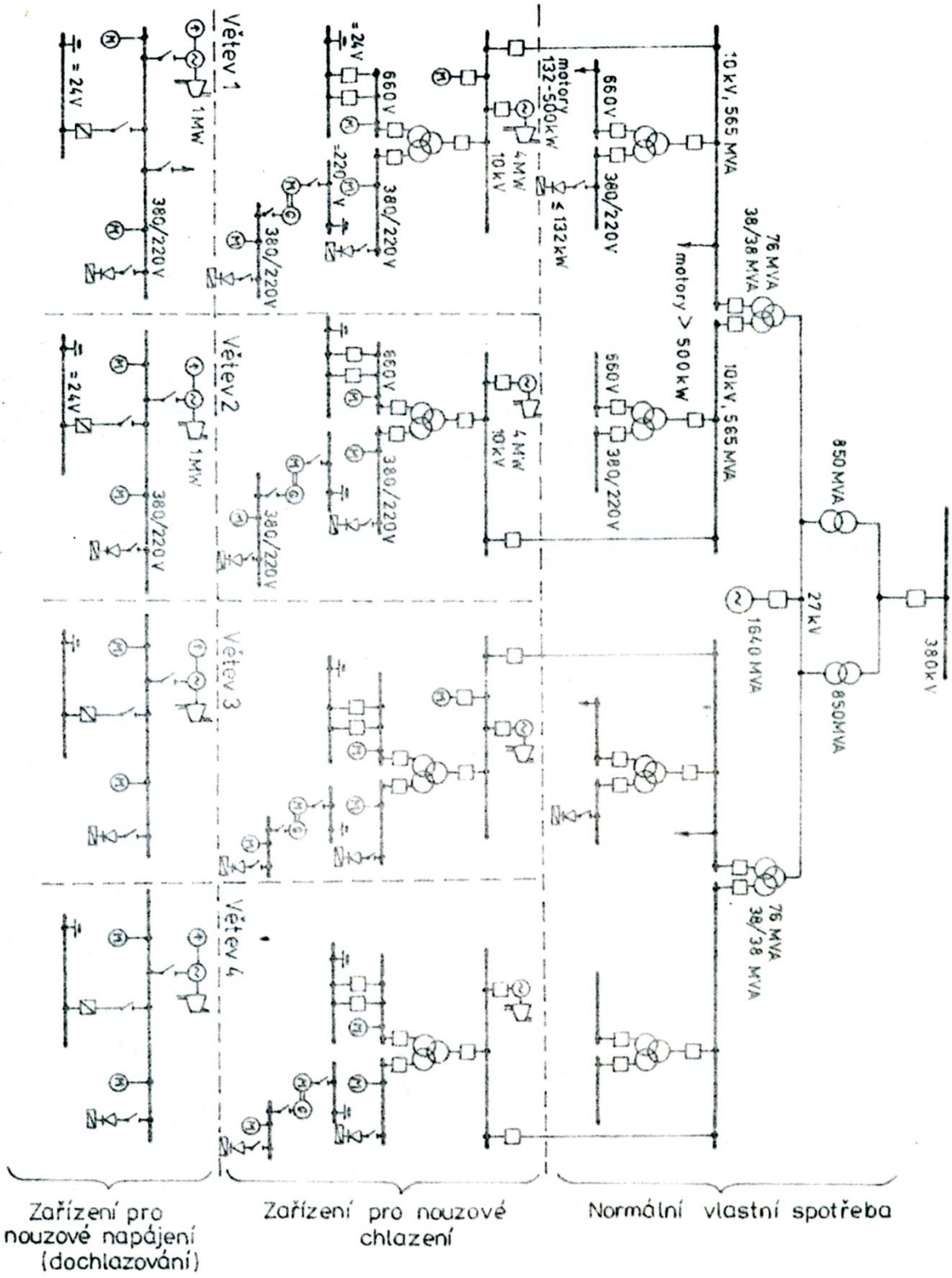






Schematic diagram of the VVER 1000 NPP (Temelín):

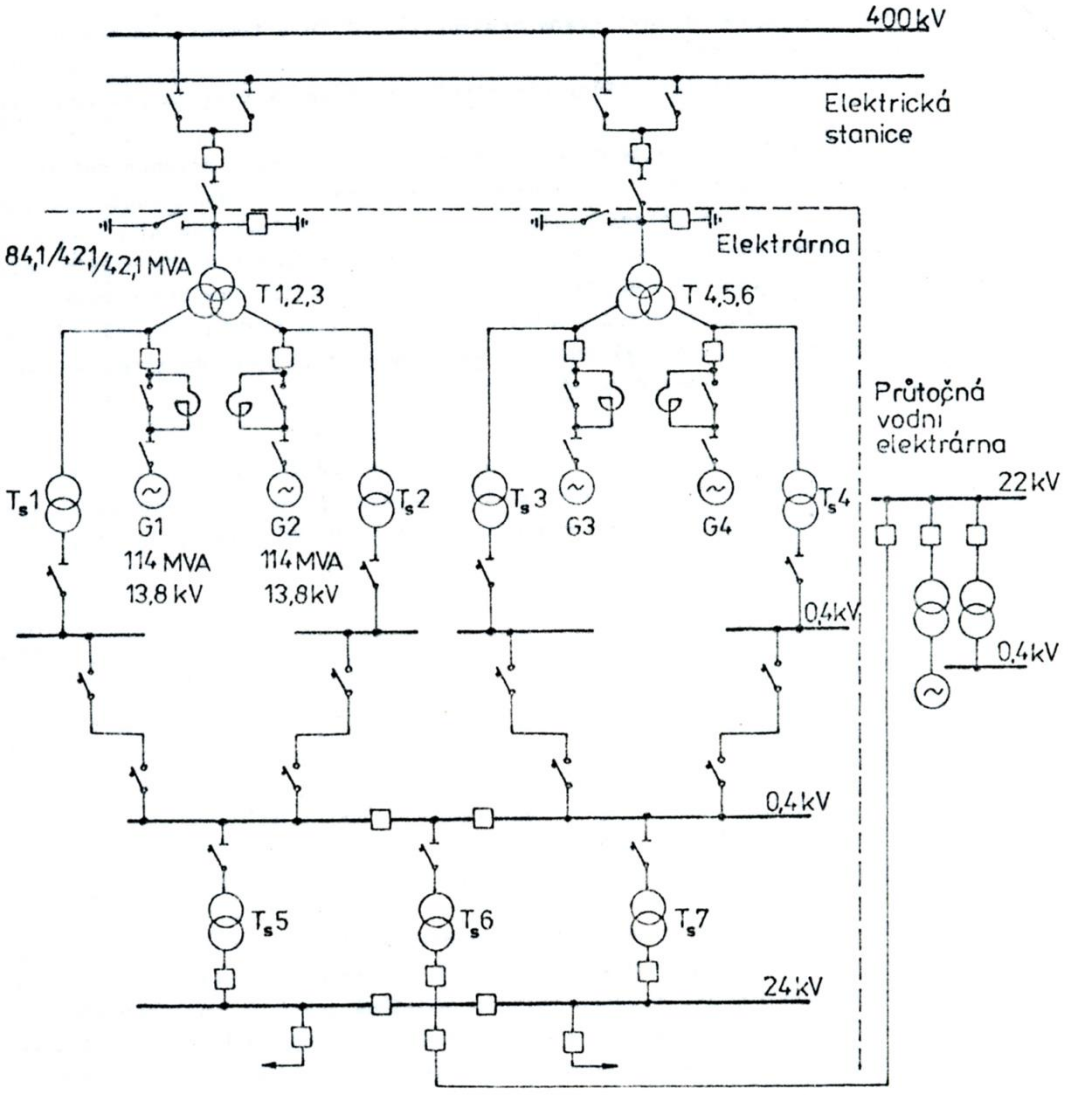
Example of the distribution of the emergency power supply of the German NPP:



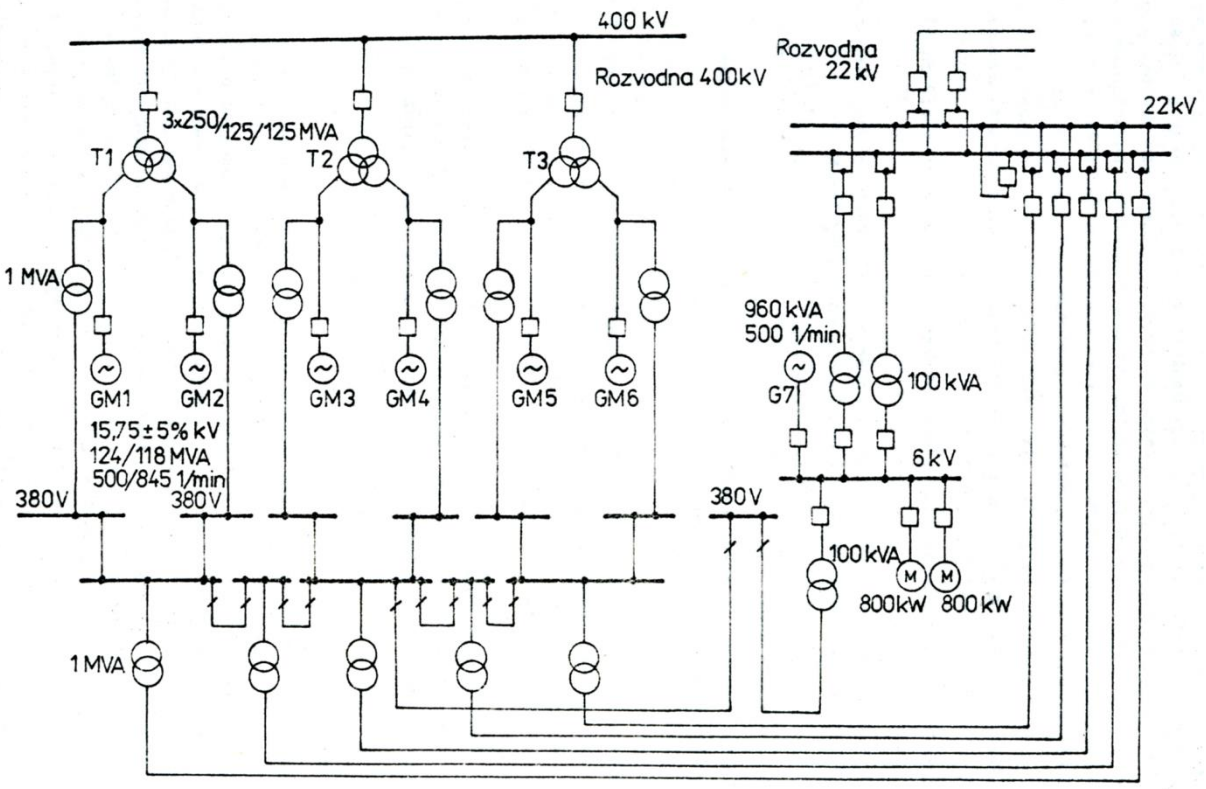
6. Examples of hydropower self-consumption schemes

Example of a schematic diagram of a Czechoslovak hydroelectric pumped storage power plant 4x 105 MW (Dalešice) in a two-machine vertical design (motor-generators and reverse Francis turbines). The two units operate into a common block transformer consisting of three single-phase units and a double 400 kV line. In addition to the working source (transformers Ts1 to Ts4), a small nearby run-of-river hydroelectric power plant (Mohelno) and transformers Ts5 to Ts6 from the 22 kV distribution network are used as the run-on and run-down source.

The asynchronous starting of the motor-generator is current limited by the reactors. The short-circuited stator is used in the recharging of the machine.



Example of a schematic of a Czechoslovak hydroelectric pumped storage plant 6x 111 MW (Dlouhé Stráně) in a three-machine vertical design (motor-generators, turbines and pumps). A small G7 alternator and a 22 kV distribution network are again used as the starting and running source.



7. Sources of self-consumption of electricity

The reliability of the V.S. provision is determined not only by the scheme used, but also by the correct choice of partial sources, which are divided according to their purpose into:

- Incoming resources
- Work resources
- Backup (Reserve) power supplies
- Period sources

The power supplies must provide power to the V.S. at startup from idle, full rated operation, power plant run-up to full idle from normal, fault or emergency condition.

Period sources

For power supply of electrical protection, control, backup pumps of lubricating oil of turbo machines, emergency lighting, ...). For smaller units realized by accumulator batteries. For larger block outputs and for NPPs, combinations of these solutions are used:

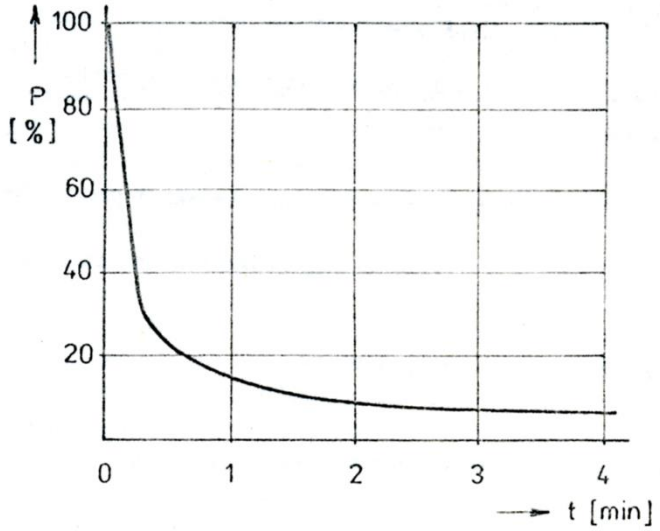
- Alternator plus diesel engine or combustion turbine
- Rechargeable batteries with rotary converters or inverters

Inverters have better efficiency and reliability, but are more responsive to power changes than rotary inverters. Gas-fired units are a new feature of backup power supplies, but are rarely installed due to their high cost and are used as peak power supplies in the EC during frequency drops.

In the NPP, in addition to the increased reliability, the requirements for emergency sources in the conventional part are similar to those of conventional thermal power plants; in addition, there is a need to provide the reactor part, especially emergency reactor aftercooling,

emergency cooling of the primary circuit, emergency feed pumps, ventilation systems, control drives, primary circuit shower systems, protection and safety detectors.

Time course of residual heat in the reactor during emergency aftercooling:



8. Calculation of the size of self-consumption sources

The output of the working and backup power supplies is determined on the basis of the total output of all appliances:

$$\sum S_P = \frac{\sum P_{BI}}{\cos\varphi} \cdot \beta \qquad \beta = \frac{k_S \cdot k_V}{\eta_m \cdot \eta_S}$$

Where:

$\sum P_{BI}$ -Sum of the nominal installed capacities of all appliances

$k_S = \frac{\sum P_{BN}}{\sum P_{BI}}$ -Coefficient of present (contemporaneity)

$\sum P_{BN}$ -Sum of the rated outputs of the appliances that are running at the same time

$k_V = \frac{\sum P_B}{\sum P_{BN}}$ -Utilization coefficient

$\sum P_B$ -Summing the actual power consumption of all appliances

η_m -Mean efficiency of appliances at a given usage

η_S -Efficiency of the power supply system from the V.S.

$\cos\varphi$ -Medium power factor of appliances

$\beta = \frac{k_S \cdot k_V}{\eta_m \cdot \eta_S}$ -Consumption factor

Then the power supply must meet: $S_Z \geq \sum S_P$

Afterwards, it is necessary to verify the design for the start of the largest drive and for the start of the self-propelled group of drives. The voltage should not fall below 0.85 U_N , but must not fall below 0.8 U_N . For self-propulsion, the limiting value for the bus voltage is 0.65 U_N .

The backup power supply is usually the same as the working power supply, if more than one working power supply is backing up, the power is selected according to the largest of them. In addition, it is required to provide power to the next idle unit (important for run time) and 50% of the total power consumption of the plant in addition to the normal operation of the unit. For NPPs, the back-up power supply must ensure the emergency shutdown of one reactor unit in addition to the normal working operation of the unit.

One back-up power supply is installed for two power units, and two back-up power supplies are installed for more units.

Particularly for NPPs, it is necessary to clearly specify the schedule for running appliances during shutdown.

9. Source size control in V.S.

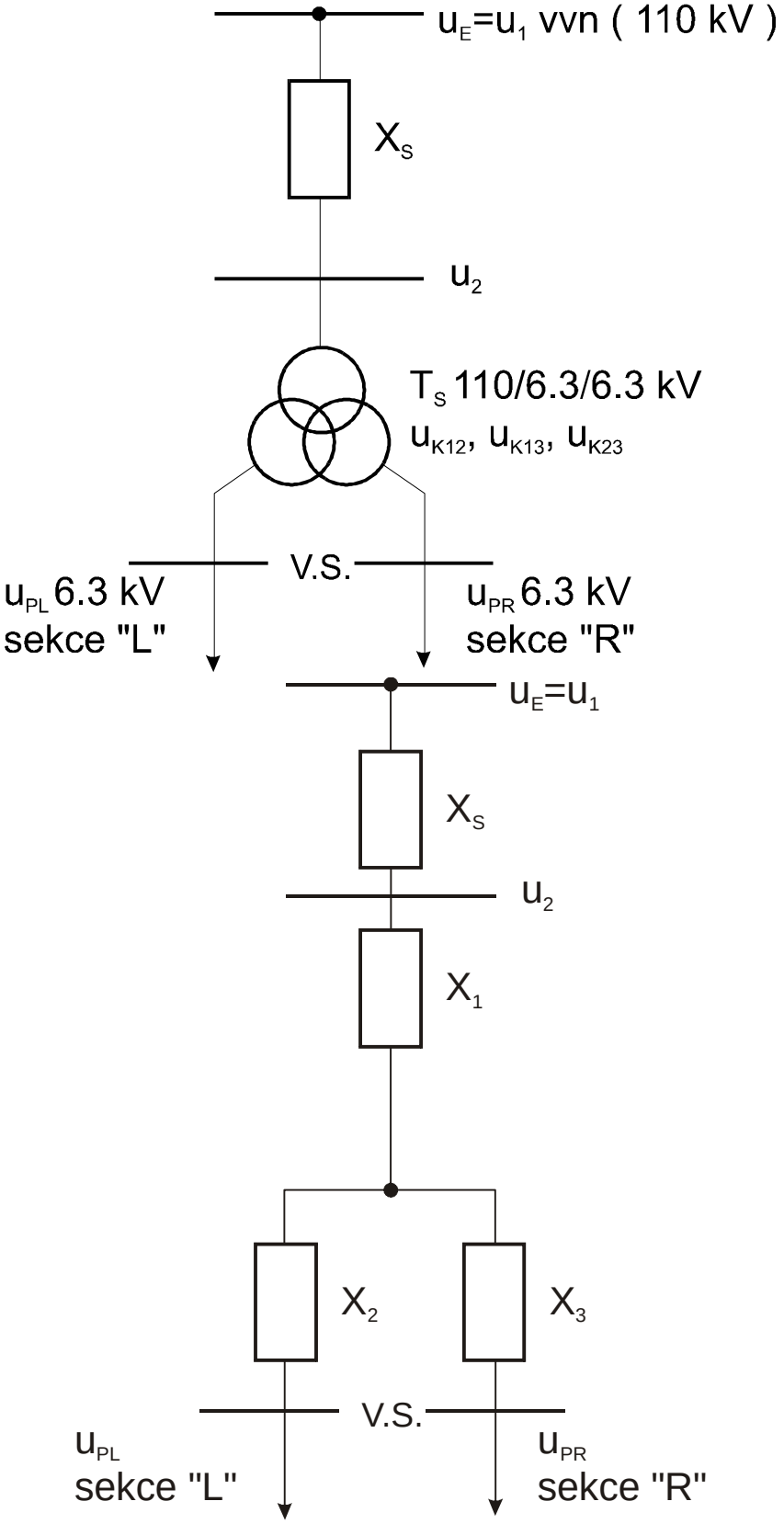
Necessary check for individual drives or self-propulsion of groups. Voltage ratios are checked with possible selection of gear ratio. At the same time, it is necessary to check the setting of the protections for extraordinary operating conditions (heavy and prolonged motor start-ups, self-starting).

Finding a suitable transformer conversion

u_E	-Source voltage
u_2	-Voltage at the primary terminals of the transformer
S_{KS}	-Short circuit power of the power system
S_{NT}	-Nominal transformer power
u_{Kij}	-Transformer short-circuit voltage
u_{PL} , u_{PR}	- Voltage at busbars of sections "L" and "R"

$$x_1 = \frac{x_{12} + x_{13} - x_{23}}{2} \qquad x_2 = \frac{x_{12} + x_{23} - x_{13}}{2} \qquad x_3 = \frac{x_{13} + x_{23} - x_{12}}{2}$$

Spare network reactance: $$X_S = \frac{U_E}{\sqrt{3} I_{KS}} = \frac{{U_E}^2}{S_{KS}}$$



Proportional value based on converted reference values: $x_S = \frac{X_S}{X_V'} = X_S \frac{S_V}{(U_V')^2} = X_S \frac{S_V}{(p \cdot U_V)^2}$

Relative value of the voltage related again to the converted reference voltage:

$$u_E = \frac{U_E}{U_V^{/}} = \frac{U_E}{p \cdot U_V}$$

We assume the main contribution to the voltage drop at the transformer is due to the flow of the reactive component of the current $R \cdot I \cos\varphi < X \cdot I \sin\varphi \quad => \quad R \cdot I_{č} < X \cdot I_j$.

This is valid without any residue when checking at LV level, for LV the active resistance has to be considered.

Reactive component of the current in section "L" :

$$i_{jL} = \frac{I_{jL}}{I_V} = \frac{Q_L}{\sqrt{3} \cdot U_P} \cdot \frac{\sqrt{3} \cdot U_V}{S_V} = \frac{Q_L}{S_V \cdot u_P} = \frac{q_L}{u_P}$$

If the voltages in the sections will be the same: $u_{PL} = u_{PR} = u_P$, then:

$$i_j = i_{jL} + i_{jR} = \frac{q_L + q_R}{u_P}$$

and the voltage of the power supply: $u_E = (x_S + x_1) i_j + i_{jL} x_2 + u_P$

the equation for the conversion: $$\frac{U_E}{p \cdot U_V} - X_S \frac{S_V}{p^2 {U_V}^2} i_j - x_1 i_j - x_2 i_{jL} = u_P$$

$$(x_1 i_j + x_2 i_{jL} + u_P) p^2 - \frac{U_E}{U_V} p + X_S \frac{S_V}{{U_V}^2} i_j = 0$$

$$a \cdot p^2 + b \cdot p + c = 0$$

Example:

$u_{K12} = 10\%$ $u_{K23} = 11\%$ $u_{K31} = 12\%$

$x_1 = \frac{10 + 12 - 11}{200} = 0.0550$ $x_2 = 0.0450$ $x_3 = 0.0650$

$U_E = 110\,kV$ $S_{KS} = 100\,MVA$ $X_S = \frac{110^2}{100} = 121\,\Omega$

$U_V = 6.3\,kV$ $S_V = 10\,MVA$ $u_P = 1$

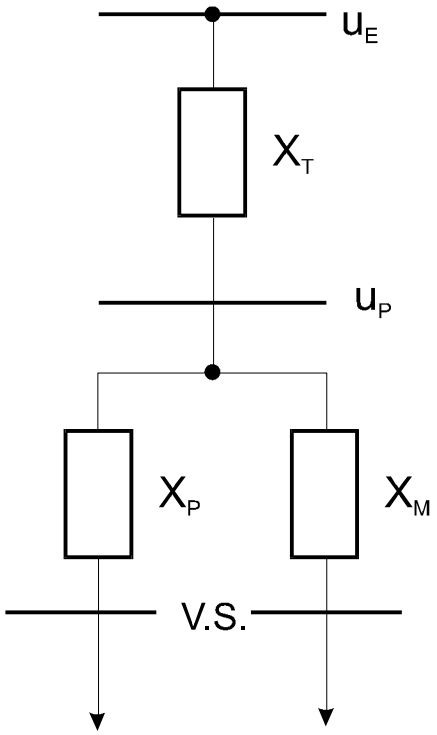
$Q_L = Q_R = 3\,MVAr$ $i_{jL} = \frac{3}{10 \cdot 1} = 0.3$ $i_j = 0.6$

$a \cdot p^2 + b \cdot p + c = 0$ $a = 0.055 \cdot 0.6 + 0.045 \cdot 0.3 + 1 = 1.0465$

$b = -\frac{110}{6.3} = -17.4603$ $c = 121 \frac{10}{6.3^2} 0.6 = 18.2918$

$p = \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2a} = 15.5613$ $u_E = \frac{U_E}{U_V^{/}} = \frac{110}{15.5613 \cdot 6.3} = 1.1220$

Starting the largest drive



x_M -replacement reactance of the motor at start-up
x_P -replacement preload reactance

$$\Delta u_T = u_E - u_P = i_T x_T \qquad i_T = \frac{u_E - u_P}{x_T} = \frac{u_P}{x_Z}$$

$$x_Z = \frac{x_P \cdot x_M}{x_P + x_M} \qquad x_P = \frac{1}{i_{jP}} = \frac{1}{q_P} = \frac{1}{\frac{Q_P}{S_T}} = \frac{1}{\sin\varphi_P} \cdot \frac{S_T}{S_P}$$

$$x_M = \frac{1}{i_K} \cdot \frac{1}{i_{NM}} = \frac{1}{i_K} \cdot \frac{1}{s_{NM}} = \frac{1}{i_K} \cdot \frac{S_T}{S_M}$$

i_K - times the rated current at start-up
$cos\varphi_P$ -mean power factor of the previous load

$$i_T = \frac{u_P}{x_Z} = u_P \left(\frac{S_P \sin\varphi_P}{S_T} + i_K \frac{S_M}{S_T} \right)$$

$$s_{KM} = \frac{S_{KM}}{S_T} = i_{KM} = \frac{u_E}{x_T} = \frac{u_E}{u_E - u_P} i_T = \frac{u_E \cdot u_P}{u_E - u_P} \left(\frac{S_P \sin\varphi_P}{S_T} + i_K \frac{S_M}{S_T} \right)$$

The actual short-circuit power on the busbars must be:

$$S_K \geq S_{KM} = s_{KM} \cdot S_T = \frac{u_E \cdot u_P}{u_E - u_P} \left(S_P \sin\varphi_P + i_K \cdot S_M \right)$$

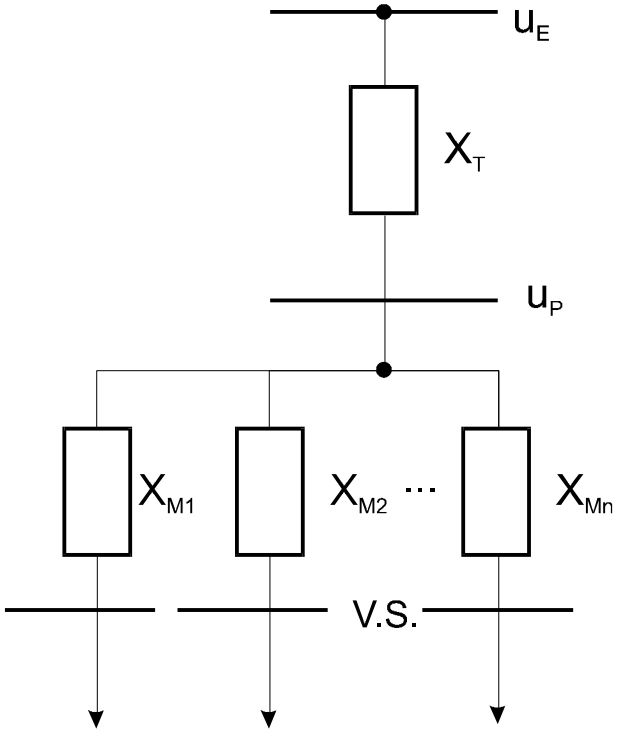
Check for transformer overload during start-up:

$$i_T = \frac{u_E}{x_C} = \frac{u_E}{x_T + x_Z}$$

Check for the magnitude of voltage drop:

$$\Delta u_T = i_T \cdot x_T = \frac{u_E}{x_T + x_Z} x_T \leq 0.2 \qquad u_P = i_T \cdot x_Z = \frac{u_E}{x_T + x_Z} x_Z \geq 0.8$$

Self-propulsion of the drive group



$$x_Z = \left(\frac{1}{x_{M1}} + \frac{1}{x_{M2}} + \cdots + \frac{1}{x_{Mn}} \right)^{-1} \qquad x_Z = \frac{S_T}{\sum_{l=1}^{n} i_{Kl} \cdot S_{Ml}}$$

i_{Kl} - times the rated current at start-up of *the l-th* drive

$$i_T = \frac{u_P}{x_Z} = \frac{u_E}{x_T + x_Z} \qquad \Delta u_T = i_T \cdot x_T = \frac{u_E}{x_T + x_Z} x_T$$

$$x_Z = \frac{x_T (u_E - \Delta u_T)}{\Delta u_T}$$

$$s_{KM} = i_{KM} = \frac{u_E}{x_T} = \frac{u_E}{u_E - u_P} i_T = \frac{u_E}{u_E - u_P} \cdot \frac{u_P}{x_Z} = \frac{u_E \cdot u_P}{u_E - u_P} \cdot \frac{1}{S_T} \sum_{l=1}^{n} i_{Kl} \cdot S_{Ml}$$

The actual short-circuit power on the busbars must be:

$$S_K \geq S_{KM} = \frac{u_E \cdot u_P}{u_E - u_P} \sum_{l=1}^{n} i_{Kl} \cdot S_{Ml}$$

Check for transformer overload during start-up:

$$i_T = \frac{u_E}{x_C} = \frac{u_E}{x_T + x_Z}$$

Check for the magnitude of voltage drop:

$$\Delta u_T = i_T \cdot x_T = \frac{u_E}{x_T + x_Z} x_T < 35\ \%$$

If we consider the average value of the current of the starting drive group:

$i_{CK} = (i_{K1} + i_{K2} + \ldots + i_{Kn})\frac{1}{n}$, and the overall apparent performance of the group:

$S_{CM} = S_{M1} + S_{M2} + \ldots + S_{Mn}$ then: $x_Z = \frac{1}{i_{CK}} \cdot \frac{S_T}{S_{CM}}$

Because $x_Z = \frac{x_T(u_E - \Delta u_T)}{\Delta u_T}$, is the maximum total power of the group:

$$S_{CM} \leq S_T \frac{\Delta u_T}{u_E - \Delta u_T} \cdot \frac{1}{i_{CK} \cdot x_T}$$

If the actual power of the group is greater than S_{CM} , then it is necessary to split the group (i.e., remove some drives from the self-propulsion), or reduce x_T by reducing u_K , or increasing S_T .