

System is in fig. 1 with load $P = 100$ MW with $\cos \varphi = 1$ to large power grid. Calculate the transmission angle and check the ability of system. Neglect resistances and shunt admittances of elements in the system.

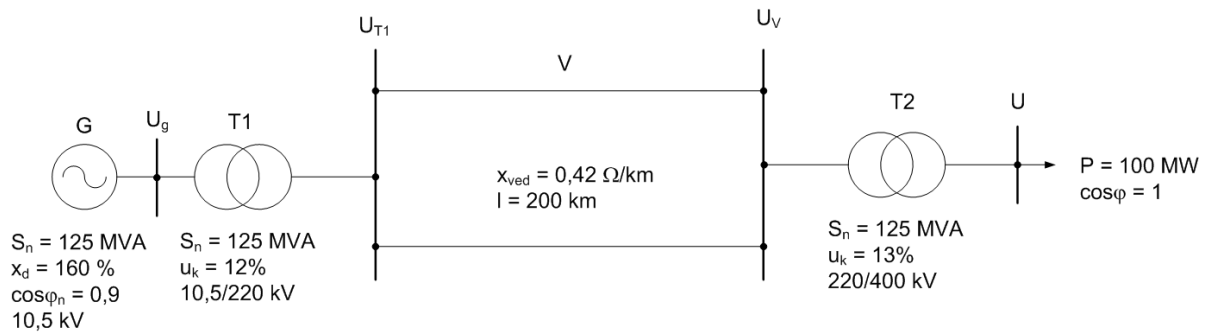


Fig. 1: Circuit diagram

Reference values:

- reference power $S_v = 100$ MVA
- reference voltage $U_v = 220$ kV (after T2)

Calculate relative values:

- generator

$$x_g = \frac{x_d}{100} \cdot \frac{S_v}{S_g} \cdot \left(\frac{U_g}{U_v} \right)^2 \cdot \left(\frac{220}{10,5} \right)^2 = \frac{160}{100} \cdot \frac{100}{125} \cdot \left(\frac{10,5}{220} \right)^2 \cdot \left(\frac{220}{10,5} \right)^2 = 1,28$$

- transformer T1

$$x_{T1} = \frac{u_k}{100} \cdot \frac{S_v}{S_{T1}} \cdot \left(\frac{U_{T1}}{U_v} \right)^2 \cdot \left(\frac{220}{10,5} \right)^2 = \frac{12}{100} \cdot \frac{100}{125} \cdot \left(\frac{10,5}{220} \right)^2 \cdot \left(\frac{220}{10,5} \right)^2 = 0,096$$

- transformer T2

$$x_{T2} = \frac{u_k}{100} \cdot \frac{S_v}{S_{T2}} \cdot \left(\frac{U_{T2}}{U_v} \right)^2 \cdot \left(\frac{220}{400} \right)^2 = \frac{13}{100} \cdot \frac{100}{125} \cdot \left(\frac{400}{220} \right)^2 \cdot \left(\frac{220}{400} \right)^2 = 0,104$$

- line

$$x_v = x_{ved} \cdot l \cdot \frac{1}{2} \cdot \frac{S_v}{U_v^2} = \frac{1}{2} \cdot 0,42 \cdot 200 \cdot \frac{100 \cdot 10^6}{(220 \cdot 10^3)^2} = 0,087$$

total reactance:

$$x_c = x_g + x_{T1} + x_v + x_{T2} = 1,567$$

Next we use the phasor diagram in fig. 2, where is load $P = 100 \text{ MW}$ with $\cos \varphi = 1$ ($\rightarrow P = S_V$). Phasor of voltage and current ($i = 1$, not entirely accurate) are in the end of transmission in the same phase.

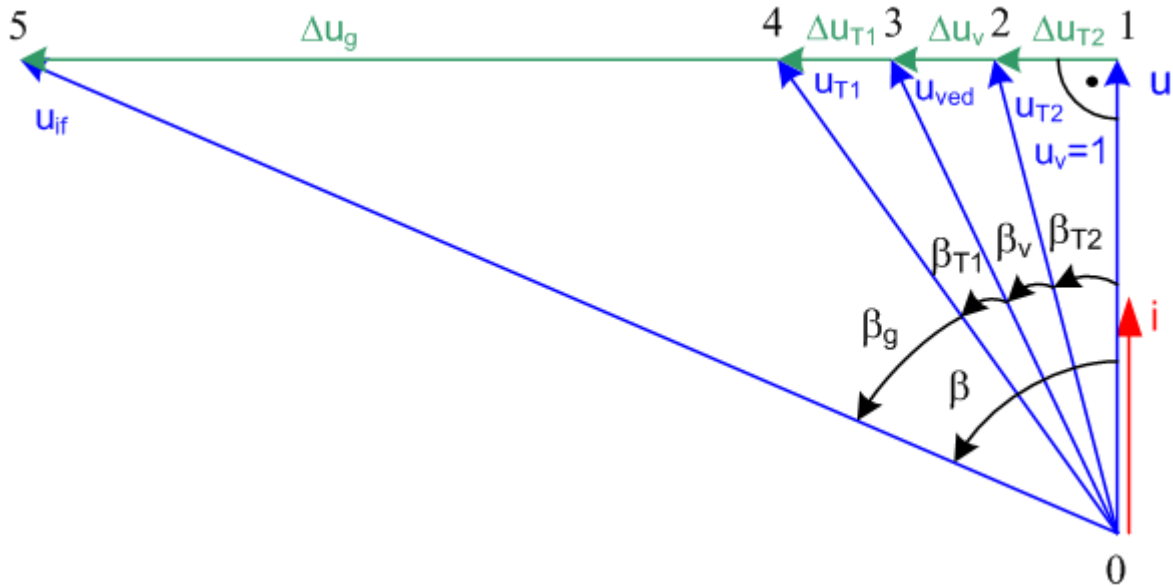


Fig. 2: Phasor diagram

We see, that generator has biggest voltage drop (β_g) in fig. We must calculate first the voltage. From triangle 0,1,2 we calculate voltage u , and β_{T2} , because:

$$\Delta u_{T2} = x_{T2} \cdot i = 0,104$$

Voltage drops on elements:

$$\Delta u_v = x_v \cdot i = 0,087$$

$$\Delta u_{T1} = x_{T1} \cdot i = 0,096$$

$$\Delta u_g = x_g \cdot i = 1,28$$

Next:

$$u = \sqrt{u_v^2 - \Delta u_{T2}^2} = 0,995$$

Individual transmission angles:

$$\sin \beta_{T2} = \frac{\Delta u_{T2}}{u_v} = \frac{0,104}{1} = 0,104$$

$$\rightarrow \beta_{T2} = \underline{5,97^\circ}$$

$$\operatorname{tg}(\beta_{T2} + \beta_v) = \frac{\Delta u_v + \Delta u_{T2}}{u} = \frac{0,087 + 0,104}{0,995} = 0,192$$

$$\rightarrow \beta_{T2} + \beta_v = \underline{10,871^\circ} \quad \rightarrow \beta_v = (\beta_{T2} + \beta_v) - \beta_{T2} = \underline{4,901^\circ}$$

$$\operatorname{tg}(\beta_{T1} + \beta_{T2} + \beta_v) = \frac{\Delta u_{T2} + \Delta u_{ved} + \Delta u_{T1}}{u} = \frac{0,104 + 0,087 + 0,096}{0,995} = 0,287$$

$$\rightarrow \beta_{T1} + \beta_{T2} + \beta_v = \underline{16,096^\circ} \quad \rightarrow \beta_{T1} = (\beta_{T1} + \beta_{T2} + \beta_v) - (\beta_{T2} + \beta_v) = \underline{5,225^\circ}$$

$$\operatorname{tg}(\beta_g + \beta_{T1} + \beta_{T2} + \beta_v) = \frac{\Delta u_g + \Delta u_{T1} + \Delta u_{ved} + \Delta u_{T2}}{u} = \frac{0,104 + 0,087 + 0,096 + 1,28}{0,995} = 1,5755$$

$$\rightarrow \beta_g + \beta_{T1} + \beta_{T2} + \beta_v = \underline{57,597^\circ} \quad \rightarrow \beta_g = (\beta_g + \beta_{T1} + \beta_{T2} + \beta_v) - (\beta_{T1} + \beta_{T2} + \beta_v) = \underline{41,5^\circ}$$

Total transmission angle $\beta = \beta_g + \beta_{T1} + \beta_{T2} + \beta_v = \underline{57,597^\circ}$.

For stable area:

$$\beta < \beta_{\max} = 90^\circ$$

It is correct, the transmission is stable.

Calculate for verification:

$$u_{if} = \frac{u}{\cos \beta} = \frac{0,995}{\cos 57,597^\circ} = \underline{1,857}$$

than

$$p = \frac{u_{if} \cdot u}{x_c} \sin \beta = \frac{1,857 \cdot 0,995}{1,567} \sin 57,597^\circ \approx \underline{1}$$

$$P = p \cdot S_v = 1 \cdot 100 = \underline{100 \text{ MW}} \text{ with } \cos \varphi = 1.$$

For the maximal power is:

$$p_{\max} = \frac{u_{if} \cdot u}{x_c} \sin 90^\circ = \frac{1,857 \cdot 0,995}{1,567} \sin 90^\circ = \underline{1,18}; \quad P_{\max} = p_{\max} \cdot S_v = 1,18 \cdot 100 = \underline{118 \text{ MW}}$$

Nominal active power of generator:

$$P_g = S_g \cdot \cos \varphi_n = 125 \cdot 0,9 = \underline{112,5 \text{ MW}}$$