1. Industrial plant consumes the active power $P = 1280\,\mathrm{kW}$ with power factor $cos\,\varphi = 0{,}76$. Calculate consumed apparent power and find out how the power factor is changed if we add a capacitor bank with the size $Q_c = 550\,\mathrm{kvar}$ (reactive power).

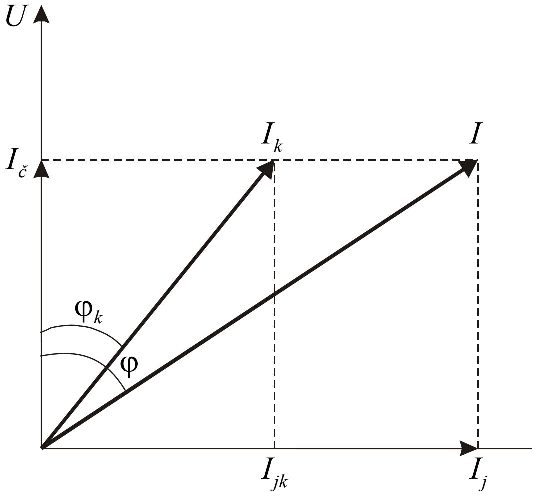

Fig. 1 – Phasor diagram (by compensation)

Calculation of apparent power:

$$S = \frac{P}{cos\,\varphi} = \frac{1280}{0{,}76} = 1684\,\mathrm{kVA}\,. \tag{1.1}$$

The power factor $cos\,\varphi = 0{,}76$ corresponds to $sin\,\varphi = 0{,}65$

The reactive power:

$$\mathrm{Q} = \mathrm{S}\cdot\sin\varphi = 1684\cdot 0{,}65 \doteq 1095\ \mathrm{kVAr} \tag{1.2}$$

Adding the capacitor bank (see Fig. 1) compensates the reactive power Q partially to the value:

$$\mathrm{Q_k} = \mathrm{Q} - \mathrm{Q_c} = 1095 - 550 = 545\ \mathrm{kVAr}\,. \tag{1.3}$$

Before compensation:

$$\mathrm{tg}\varphi = \frac{\mathrm{Q}}{\mathrm{P}} = \frac{1095}{1280} \doteq 0{,}86\,, \tag{1.4}$$

The phase angle is $\varphi \doteq 40{,}7^\circ$.

After compensation:

$$\mathrm{tg}\varphi_\mathrm{k} = \frac{\mathrm{Q_k}}{\mathrm{P}} = \frac{545}{1280} \doteq 0{,}43\,, \tag{1.5}$$

This corresponds to the phase angle $\varphi_\mathrm{k} \doteq 23^\circ$. The power factor after compensation will be $cos\,\varphi_k = 0{,}92$.

2. Industrial plant is supplied from $22/0{,}4\,\text{kV}$ transformer with nominal apparent power $S_n = 800\,\text{kVA}$. Mean consumed active power is $P = 460\,\text{kW}$ with power factor $cos\,\varphi = 0{,}79$. Calculate the needed reactive power for compensation to the power factor $cos\,\varphi_k = 0{,}95$ for the mean consumed active power. Further calculate the reserve of active power which can be added to the transformer.

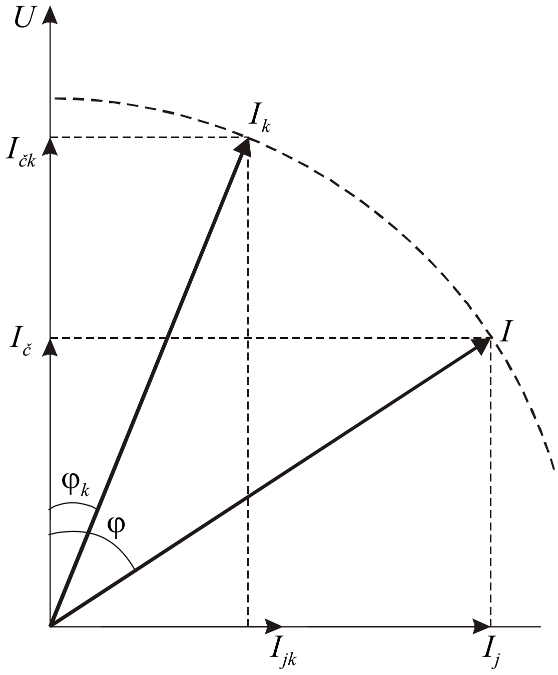

Fig. 2 – The proportion before and after compensation (while the same size of apparent power)

The power factor before compensation $cos\,\varphi = 0{,}79$ corresponds to $\text{tg}\varphi \doteq 0{,}78$. After compensation power factor is $cos\,\varphi_k = 0{,}95$ and this corresponds to $tg\varphi_k = 0{,}33$.

Consumed reactive power before compensation:

$$\text{Q} = \text{P}\cdot\text{tg}\varphi = 460\cdot 0{,}78 \doteq 359\ \text{kVAr}. \tag{2.1}$$

Reactive power after compensation:

$$\text{Q}_\text{k} = \text{P}\cdot\text{tg}\varphi_\text{k} = 460\cdot 0{,}33 \doteq 152\ \text{kVAr}. \tag{2.2}$$

Reactive power of capacitor bank:

$$\text{Q}_\text{c} = \text{Q} - \text{Q}_\text{k} = 359 - 152 = 207\ \text{kVAr}. \tag{2.3}$$

Before compensation the reserve active power P_{rez} can be calculated from the relation:

$$S_n = \sqrt{\left(P + P_{rez}\right)^2 + Q^2}\ , \tag{2.4}$$

Hence

$$\mathrm{P_{rez}} = \sqrt{\mathrm{S_n^2 - Q^2}} - \mathrm{P} = \sqrt{800^2 - 359^2} - 460 \doteq 255\ \mathrm{kW}\,. \tag{2.5}$$

After compensation the reserve active power P_{rez} is higher:

$$\mathrm{P_{k\ rez}} = \sqrt{\mathrm{S_n^2 - Q_k^2}} - \mathrm{P} = \sqrt{800^2 - 152^2} - 460 \doteq 325\ \mathrm{kW}\,. \tag{2.6}$$

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3. The asynchronous motor $1600\mathrm{kW}$ is working in discontinuous operation. It is working with nominal power with current 350 A for three minutes and in no-load mode with active power 100 kW and current 150 A for two minutes. The nominal voltage is $U_n = 3\mathrm{kV}$.

Design the capacitor bank so that the power factor is $cos\,\varphi_k = 0{,}96$ for nominal power loading. Check up the power factor in no-load mode.

The motor nominal apparent power:

$$\mathrm{S_n} = \sqrt{3} \cdot \mathrm{U_n} \cdot \mathrm{I_n} = \sqrt{3} \cdot 3 \cdot 10^3 \cdot 350 \doteq 1{,}82\ \mathrm{MVA}\,. \tag{3.1}$$

The power factor without compensation:

$$cos\,\varphi = \frac{P_n}{S_n} = \frac{1600.10^3}{1{,}82.10^6} = 0{,}879\,. \tag{3.2}$$

The apparent power in no-load mode:

$$\mathrm{S_0} = \sqrt{3} \cdot \mathrm{U_n} \cdot \mathrm{I_0} = \sqrt{3} \cdot 3 \cdot 10^3 \cdot 150 \doteq 779\ \mathrm{kVA}\,, \tag{3.3}$$

and corresponding power factor

$$cos\,\varphi_0 = \frac{P_0}{S_0} = \frac{100}{779} = 0{,}128\,. \tag{3.4}$$

The reactive power without compensation:

$$\mathrm{Q} = \mathrm{P} \cdot \mathrm{tg}\varphi = 1600 \cdot 10^3 \cdot 0{,}543 \doteq 869\ \mathrm{kVAr}\,. \tag{3.5}$$

The reactive power when power factor is $cos\,\varphi_k = 0{,}96$:

$$\mathrm{Q_k} = \mathrm{P} \cdot \mathrm{tg}\varphi_\mathrm{k} = 1600 \cdot 10^3 \cdot 0{,}292 \doteq 467\ \mathrm{kVAr}\,. \tag{3.6}$$

The power of capacitor bank (for assigned power factor $cos\,\varphi_k = 0{,}96$)

$$\mathrm{Q_c} = \mathrm{Q} - \mathrm{Q_k} = 869 - 467 = 402\ \mathrm{kVAr}\,. \tag{3.7}$$

The reactive power in no-load mode before compensation:

$$\mathrm{Q_0} = \mathrm{P_0} \cdot \mathrm{tg}\varphi_0 = 100 \cdot 10^3 \cdot 7{,}75 \doteq 775\ \mathrm{kVAr}\,. \tag{3.8}$$

Capacitor banks after compensation contribute $402\ \mathrm{kVAr}$ of the reactive power. The consumed reactive power from power grid in no-load mode after compensation will be:

$$\mathrm{Q}_{0\mathrm{k}} = \mathrm{Q}_0 - \mathrm{Q}_\mathrm{c} = 775 - 402 = 373\ \mathrm{kVAr}\,. \tag{3.9}$$

This value is equal to power factor after compensation in no-load mode with this equation:

$$Q_{0k} = P_0 \cdot tg\varphi_{0k}\,, \tag{3.10}$$

Hence:

$$tg\varphi_{0k} = \frac{Q_{0k}}{P_0} = \frac{373}{100} = 3{,}73\,. \tag{3.11}$$

Power factor in no-load mode after compensation: $\cos\varphi_{0\mathrm{k}} \doteq 0{,}26$.

The capacitor bank is constructed from three capacitors connected to the triangle (delta). Each capacitor supplies reactive power:

$$\mathrm{Q}_{\mathrm{c}1} = \frac{\mathrm{Q}_\mathrm{c}}{3} = 134\ \mathrm{kVAr} \tag{3.12}$$

Capacity of each capacitor:

$$\mathrm{C}_1 = \frac{\mathrm{Q}_{\mathrm{c}1}}{\omega \cdot \mathrm{U}^2} = \frac{134 \cdot 10^3}{100 \cdot \pi \cdot 3000^2} \doteq 47{,}4\ \mu\mathrm{F} \tag{3.13}$$