Exercise on the dimensioning of a medium-voltage line

For the medium-voltage line shown in the figure, determine:

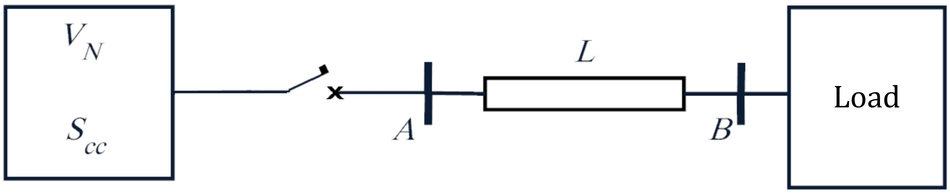

Figure 1: diagram of the study network

1) The cross-section of the line conductor, assuming that we consider EPR-insulated cables with unipolar conductors (data provided), and
2) The peak short-circuit current at points A and B.
3) Choose the necessary circuit breaker for short-circuit protection and propose a tuning of the protection time-current characteristic. Compute and verify the Joule integral assuming an intervention time the short circuit protection of 100 ms.

Data

The short circuit power is S_{CC}=350 MVA ;

The nominal voltage is V_N= 15 kV ;

The ratio R_{CC}/X_{CC} =0.1

The active power of the load is P=3.5MW (power factor 0.87 lagging).

Length of the line L = 5km.

Medium-voltage conductor characteristics (20kV) with EPR insulation 

Cross-section (mm^2)	Per-unit length resistance (Ω/km)	Per-unit length reactance (Ω/km)	Per-unit length capacitance $(\mu F/km)$	Ampacity limit (A)
25	0.929	0.15	0.18	157
35	0.670	0.14	0.17	190
50	0.495	0.13	0.19	228
70	0.344	0.13	0.21	284
95	0.248	0.12	0.23	346
120	0.198	0.12	0.25	399

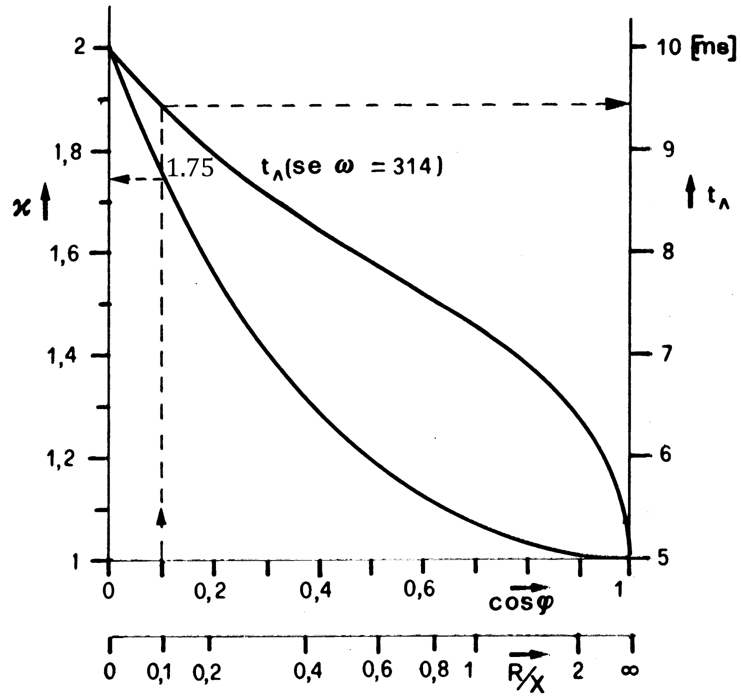

Figure 2: characteristic of the factor χ

Question 1

To determine the conductor cross-section, we first need to determine the current that flows through the line.

The active power can be used to compute the nominal current:

$$P = \sqrt{3} V_N I_N \cos\varphi$$

$$I_N = \frac{P}{\sqrt{3} V_N \cos\varphi} = \frac{3.5 \cdot 10^6}{\sqrt{3} \cdot 15 \cdot 10^3 \cos\varphi} = 155A$$

From the table, we will initially choose a conductor cross-section of 25mm^2 which has a maximum admissible current equal to 157 A.

<u>Question 2</u>

The equivalent circuit for the calculation of the short-circuit current at point A is as follows:

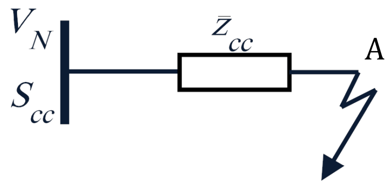

Figure 3: equivalent circuit for short-circuit at point A

The impedance of the short circuit is:

$$Z_{CC}^{A} = Z_{CC} = \frac{V_N^2}{S_{CC}} = \frac{15^2 \cdot 10^6 V}{350 \cdot 10^6 MVA} = 0.642\Omega$$

$$\left(Z_{CC}^{A}\right)^2 = \left(R_{CC}^{A}\right)^2 + \left(X_{CC}^{A}\right)^2 = 1.01\ X_{CC}^2$$

And by substitution:

$$X_{CC}^{A} = \sqrt{\left(Z_{CC}^{A}\right)^2 / 1.01} = 0.639\ \Omega$$

$$R_{CC}^{A} = 0.1 \cdot X_{CC}^{A} = 0.063\ \Omega$$

$$\overline{Z}_{CC}^{A} = R_{CC}^{A} + jX_{CC}^{A} = 0.063 + j0.639$$

The short-circuit current at point A is:

$$I_{CCA} = \frac{V_N}{\sqrt{3} Z_{CC}^{A}} = \frac{15 \cdot 10^3 V}{\sqrt{3} \cdot 0.642\Omega} = 13.5\ kA$$

The peak value of the short-circuit current is as follows. Note that the value of χ_A, equal to 1.75, depends on the ratio $R_{CC}^{A} / X_{CC}^{A} = 0.1$ (see Figure 2).

$$I_P^{A} = \sqrt{2} \cdot I_{CC}^{A} \cdot \chi_A = \sqrt{2} \cdot 13.5 \cdot 1.75\ kA = 33.3\ kA$$

The equivalent circuit for the calculation of the short-circuit current at point B is as follows:

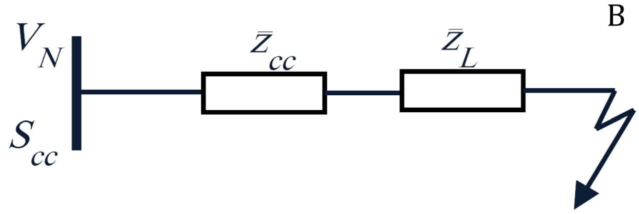

Figure 4: equivalent circuit for short-circuit at point B

The short-circuit current at point B is:

$$I_{CC}^{B} = \frac{V_N}{\sqrt{3}\left|\overline{Z}_{CC} + \overline{Z}_L\right|}$$

Using the table, we can calculate the line impedance as follows:

$$\overline{Z}_L = L \cdot (r + jx) = 5 \cdot (0.929 + j0.15)\Omega = 4.65 + j0.75\Omega$$

The total impedance $\overline{Z}_{CC}^{B} = \overline{Z}_{CC} + \overline{Z}_L$ is therefore:

$$\overline{Z}_{CC} + \overline{Z}_L = 0.063 + j0.639 + 4.65 + j0.75\Omega = 4.71 + j1.389\Omega = 4.91 \cdot e^{j16.44°}\Omega$$

The short-circuit current at point B is therefore:

$$I_{CC}^{B} = \frac{V_N}{\sqrt{3}\left|\overline{Z}_{CC}^{B}\right|} = \frac{15 \cdot 10^3 V}{\sqrt{3} \cdot 4.91\Omega} = 1.76\ \ kA$$

The peak value of the short-circuit current is as follows. Note that the value of χ_A, equal to 1, depends on the ratio $R_{CC}^{B} / X_{CC}^{B} = 3.41$ (see Figure 2).

$$I_P^B = \sqrt{2} \cdot I_{CC}^{B} \cdot \chi_B = \sqrt{2} \cdot 1.76 \cdot 1\ \ kA = 2.48\ \ kA$$

Question 3

The Joule integral should be verified at the beginning of the line, where the short-circuit current is highest.

The chosen circuit breaker has a breaking capacity of 15 kA and the interruption time which corresponds to I_{CCA} is equal to 100 ms. The computation of the Joule integral is as follows:

We start with: $\left(I_{CC}^{A}\right)^2 t < K^2 S^2$

If we substitute the selected cross-section S=25 mm^2 and the value of K corresponding to a cable with EPR insulation (K=143):

$$\left(13.5 \cdot 10^3\right)^2 0.1 < 143^2 25^2$$
$$18.2250 \cdot 10^6 < 12.78 \cdot 10^6$$

Therefore, the Joule integral is not verified.

The conductor cross-section should be re-chosen according to the following relation:

$$S^2 > \frac{\left(I_{CC}^{A}\right)^2 t}{K^2} > 29.85 \ mm^2$$

Therefore, we must choose the larger cross-section shown in Table 1, which is 35 mm^2.

Now, we need to re-calculate the short-circuit current at point B.

The impedance of the line becomes:

$$\overline{Z}_{L"} = L \cdot (r + jx) = 5 \cdot (0.670 + j0.14) = 3.35 + j0.7 \ \Omega$$

The total impedance $\overline{Z}_{CC}^{B"} = \overline{Z}_{CC} + \overline{Z}_{L"}$ is:

$$\overline{Z}_{CC} + \overline{Z}_{L"} = 0.063 + j0.639 + 3.35 + j0.7 = 3.41 + j1.339\Omega = 3.66 \cdot e^{j21.45°}\Omega$$

The new short-circuit current at B is as follows:

$$I_{CC}^{B"} = \frac{V_N}{\sqrt{3}\left|\overline{Z}_{CC} + \overline{Z}_{L"}\right|} = \frac{15 \cdot 10^3 V}{\sqrt{3} \cdot 3.66\Omega} = 2.36 \ kA$$

The peak value of the short-circuit current becomes:

$$I_P^{B"} = \sqrt{2} I_{CC}^{B"} \cdot \chi_{B"} = \sqrt{2} \cdot 2.36 \cdot 10^3 \cdot 1 = 3.32 \ kA$$

Note that the value of $\chi_{B''}$ is equal to 1, which depends on the ratio $R_{CC}^{B''} / X_{CC}^{B''} = 2.54$ (see Figure 2).

In the following figure, the verification of the Joule integral is shown for different conductor cross-sections:

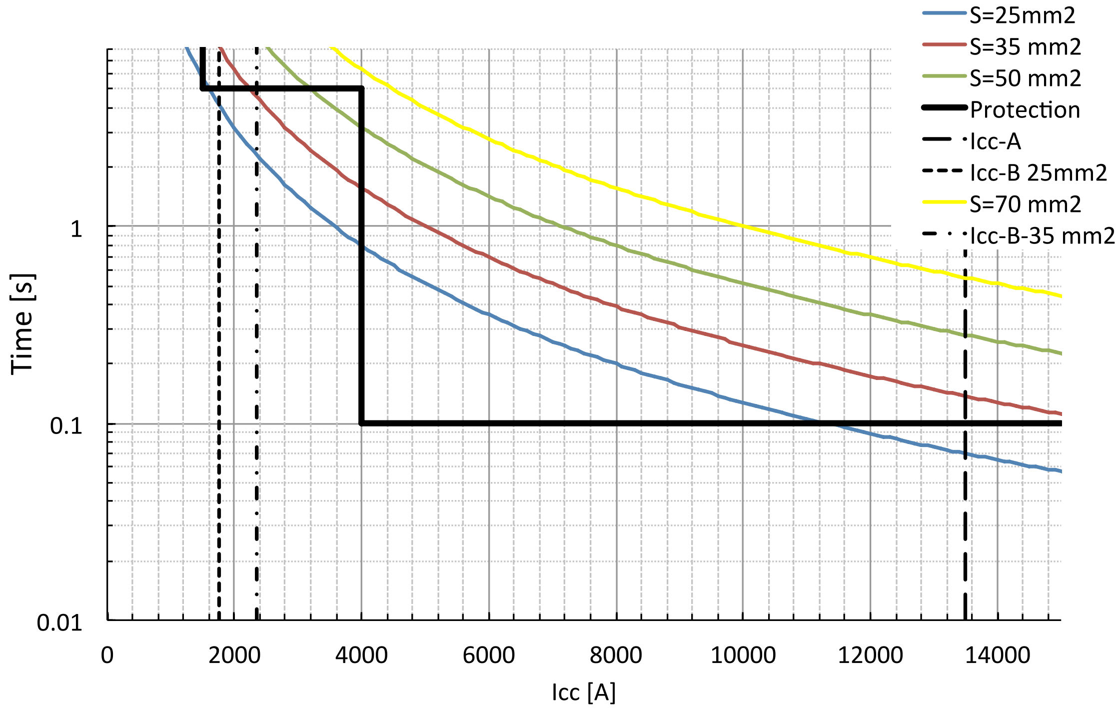

Figure 5: Joule integral verification for different conductor cross-sections