Example 1:

The wave comes from a cable with wave impedance Z_{v1} = 40 Ω through an overhead line with wave impedance Z_{v2} = 400 Ω to a transformer with wave impedance Z_{v3} = 4000 Ω. The voltage wave has sharp edge with voltage U = 100 kV. Configuration is shown in figure 1-1. Calculate the penetration voltage wave in transformer.

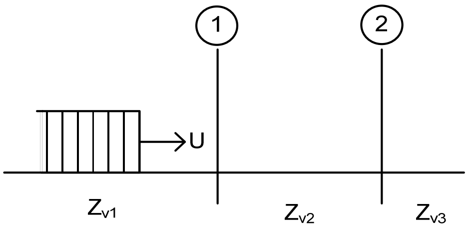

Fig. 1-1

Solution:

The penetration voltage wave from the first boundary “1” to the second environment:

$$u_{p2} = \frac{2 \cdot Z_{v2}}{Z_{v1} + Z_{v2}} \cdot u_{p1} = \frac{2 \cdot 400}{40 + 400} \cdot 100 = 182\ kV$$

The penetration voltage wave from the second boundary “1” to the third environment:

$$u_{p3} = \frac{2 \cdot Z_{v3}}{Z_{v2} + Z_{v3}} \cdot u_{p2} = \frac{2 \cdot 4000}{400 + 4000} \cdot 182 = 330\ kV$$

The voltage conditions are shown in Fig. 1-2. (Different wave propagation speeds in different environments are not respected.)

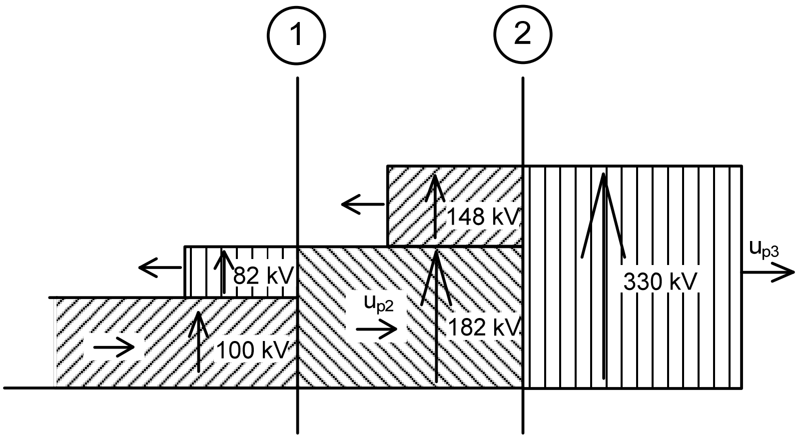

Fig. 1-2

Example 2:

Calculate the impact of surge arrester with resistance R on the progressive wave for the configuration in Fig. 2-1.

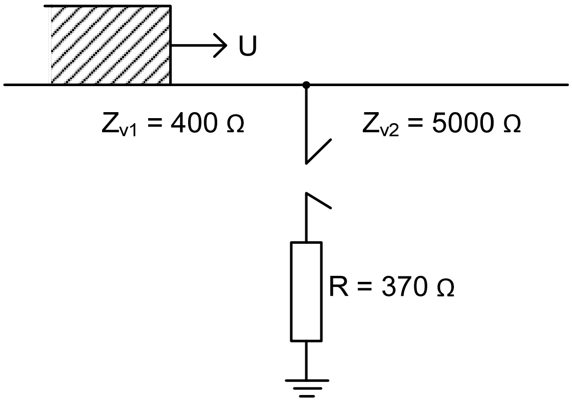

Fig. 2-1

Solution:

We neglect the fact that surge arrester will act with a small delay. For simplicity it is assumed a permanent connection of the resistance to the boundary.

The penetration voltage wave to the second boundary:

$$u_{p2} = \frac{2}{Z_{v1} \cdot (\frac{1}{Z_{v1}} + \frac{1}{Z_{v2}} + \frac{1}{R})} \cdot u_{p1} = \frac{2}{400 \cdot \left(\frac{1}{400} + \frac{1}{5000} + \frac{1}{370}\right)} \cdot U = 0{,}925 \cdot U$$

If there is no resistance connected (R → ∞), the penetration voltage wave to the second boundary is:

$$u_{p2}^{*} = \frac{2 \cdot Z_{v2}}{Z_{v1} + Z_{v2}} \cdot u_{p1} = \frac{2 \cdot 5000}{400 + 5000} \cdot U = 1{,}85 \cdot U$$

Then the ratio $\frac{u_{p2}}{u_{p2}^{*}} = \frac{0{,}925}{1{,}85} = 0{,}5$ determines the positive influence of connected resistance on the penetration voltage wave: $u_{p2} = 0{,}5 \cdot u_{p2}^{*}$

Example 3:

The overhead line is connected to the transformer through a capacitor bushing with capacity C = 0,01 μF. Find out the capacity efficient time impact on the voltage wave with a sharp edge and voltage U = 200 kV. The length of the wave is 2 km (Fig. 3-1). Calculate the maximal value of the wave penetrated to the transformer.

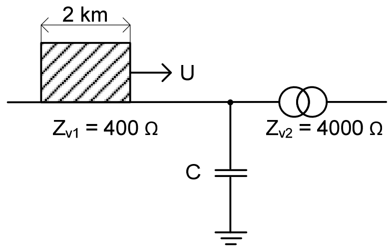

Fig. 3-1

Solution:

The circuit time constant:

$$T_c = \frac{C \cdot Z_{v1} \cdot Z_{v2}}{Z_{v1} + Z_{v2}} = \frac{0{,}01 \cdot 10^{-6} \cdot 400 \cdot 4000}{400 + 4000} = 3{,}64 \cdot 10^{-6}\ s = 3{,}64\ \mu s$$

The capacity efficient time in the circuit:

$$t_c = 3 \cdot T_c = 3 \cdot 3{,}64 = 10{,}92\ \mu s$$

The voltage wave duration time for its length 2 km:

$$t = \frac{l}{c} = \frac{2}{300\ 000} = 6{,}7 \cdot 10^{-6}\ s = 6{,}7\ \mu s$$

Based on calculation and Fig. 3_2, the capacitor has a longer effect in the circuit than the voltage wave duration. Therefore the maximal penetration wave size into transformer is set for the time t = 6,7 μs.

$$u_{p2max} = \frac{2 \cdot Z_{v2}}{Z_{v1} + Z_{v2}} \cdot U \cdot \left(1 - e^{-\frac{t}{T_c}}\right) = \frac{2 \cdot 4000}{400 + 4000} \cdot 200 \cdot \left(1 - e^{-\frac{6{,}67}{3{,}64}}\right) = 306\ kV$$

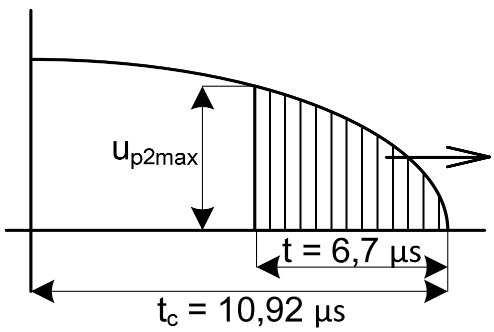

Fig. 3-2

If there is no capacitor, the penetration wave in the transformer would be u_{p2} = 364 kV and the voltage wave would have moreover the sharp edge.

Example 4:

The overhead line is connected to the transformer through a capacitor bushing with capacity C = 0,005 μF. Find out the capacity efficient time impact on the voltage wave with a sharp edge and voltage U = 200 kV. The length of the wave is 2 km (Fig. 3-1). Calculate the maximal value of the wave penetrated to the transformer.

Solution:

The circuit time constant:

$$T_c = \frac{C \cdot Z_{v1} \cdot Z_{v2}}{Z_{v1} + Z_{v2}} = \frac{0{,}005 \cdot 10^{-6} \cdot 400 \cdot 4000}{400 + 4000} = 1{,}82 \cdot 10^{-6}\ s = 1{,}82\ \mu s$$

The capacity efficient time in the circuit:

$$t_c = 3 \cdot T_c = 3 \cdot 1{,}82 = 5{,}46\ \mu s$$

The voltage wave duration time for its length 2 km:

$$t = \frac{l}{c} = \frac{2}{300\ 000} = 6{,}7 \cdot 10^{-6}\ s = 6{,}7\ \mu s$$

We can see the voltage wave duration time is longer than the capacity efficient time in the circuit as shown in Fig. 4-1. Therefore the penetration wave size into transformer will be:

$$u_{p2max} = \frac{2 \cdot Z_{v2}}{Z_{v1} + Z_{v2}} \cdot U = \frac{2 \cdot 4000}{400 + 4000} \cdot 200 = 364\ kV$$

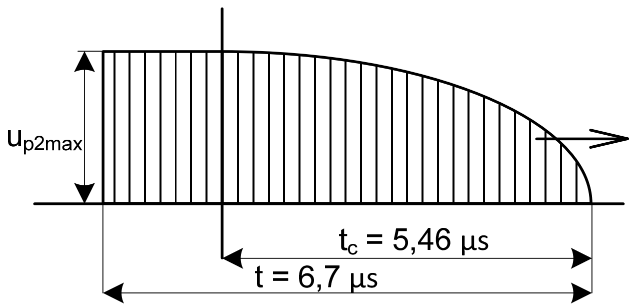

Fig. 4-1

The penetration voltage wave has the same size as for the configuration without the capacity but it doesn't have the sharp edge due to the capacity.