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THEORY OF TRANSMISSION AND DISTRIBUTION OF ELECTRIC ENERGY

4th lectures - examples

Creation of substitute schema - examples 1 (1)

Task:

Create the equivalent substitute schema of network shown in the Fig. 4.1 with recalculation of impedance (reactance) to voltage level of 6 kV:

1) in physical values
2) in relative values

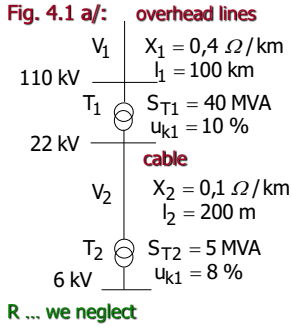
Perform the calculation:

a) with nominal conversions
b) with fictitious conversions

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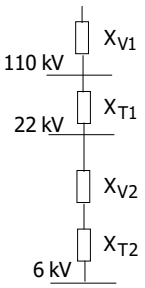
Creation of substitute schema - example 1 (2)

Fig. 4.1 a/: overhead lines



R ... we neglect

substitute schema



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Creation of substitute schema - example 1 (3)

Solution: ad 1 / Calculation in [Ω]

a) with nominal conversions

- X_{V1} = 0,4.100.(23/110)².(6,3/22)² = 0,143 Ω
- X_{T1} = 10/100.110²/40.(23/110)².(6,3/22)² = 0,108 Ω
- X_{V2} = 0,1.0,2.(6,3/22)² = 0,0016 Ω
- X_{T2} = 8/100.22²/5.(6,3/22)² = 0,635 Ω

b) with fictitious conversions

- X_{V1} = 40.(22/110)².(6/22)² = 0,119 Ω
- X_{T1} = 10/100.110²/40.(22/110)².(6/22)² = 0,09 Ω
- X_{V2} = 0,02.(6/22)² = 0,0015 Ω
- X_{T2} = 8/100.22²/5.(6/22)² = 0,576 Ω

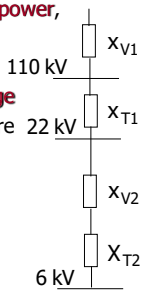
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Creation of substitute schema - example 1 (4)

ad 2) Calculation in relative values

- We choose the reference apparent power, e.g. S_v = 40 MVA (the most common in the solved circuit)
- Then we select the reference voltage U_v = 6 kV (i.e. U_n in the place, where we solve the network)

Fic. 4.1 b/: Substitute schema in relative units



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Creation of substitute scheme – example 1 (5)

ad a) **Calculation with nominal conversions**

- x_{V1} = 0,4.100.(23/110)^2.(6,3/22)^2.40/6^2 = 0,159
- x_{T1} = 10/100.110^2/40.(23/110)^2.(6,3/22)^2.40/6^2 = 0,0018
- x_{V2} = 0,1.0,2.(6,3/22)^2.40/6^2 = 0,12
- x_{T2} = 8/100.22^2/5.(6,3/22)^2.40/6^2 = 0,71

ad b) **Calculation with fictitious conversions**

- x_{V1} = 40.(22/110)^2.(6/22)^2.40/6^2 = 0,132
- x_{T1} = 10/100.110^2/40.(22/110)^2.(6/22)^2.40/6^2 = 0,132
- x_{V2} = 0,02.(6/22)^2.40/6^2 = 0,1
- x_{T2} = 8/100.22^2/5.(6/22)^2.40/6^2 = 0,64

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Creating a substitute schema for a multi-node network - example 2 (1)

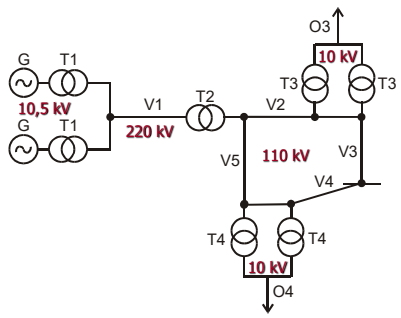
Task:

- Compile a substitute schema (with description) of the network shown in the Fig. 4.2 and calculate the longitudinal reactances of the individual elements and the power consumption in relative units related to the voltage level of the generators G.
  (Choose S_v = 135 MVA).
- Next, recalculate the detected reactances from relative units to ohmic and to the point between V3 a V4 lines.

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Creating a substitute schema for a multi-node network - example 2 (2)

Fig. 4.2:



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Creating a substitute schema for a multi-node network - example 2 (3)

Numerical task:

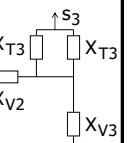
- G: P_n = 45 MW U_n = 10,5 kV cos φ = 0,85
- x_d = 113 % x_q = 70,8 % x_d' = 30,3 % x_d'' = 12 %
- T1: S_n = 120 MVA u_k = 12 % p = 10,5/242 + 5 % kV
- T2: S_n = 180 MVA u_k = 15 % p = 220/121 kV
- T3: S_n = 60 MVA u_k = 10,5 % p = 110/11 kV
- T4: S_n = 31,5 MVA u_k = 10,5 % p = 110/11 kV
- V1: U_n = 220 kV X_v = 0,421 Ω/km l = 250 km
- V2: U_n = 110 kV X_v = 0,379 Ω/km l = 65 km
- V3: U_n = 110 kV X_v = 0,408 Ω/km l = 65 km
- V4: U_n = 110 kV X_v = 0,294 Ω/km l = 60 km
- V5: U_n = 110 kV X_v = 0,400 Ω/km l = 30 km
- O3: P_n = 55 MW U_n = 10 kV cos φ = 0,95
- O4 : P_n = 25 MW U_n = 10 kV cos φ = 0,95

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Creating a substitute schema for a multi-node network - example 2 (4)

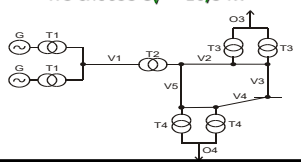
Solution:

- Substitute network schema



For recalculation to G:

- we choose U_v = 10,5 kV



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Creating a substitute schema for a multi-node network - example 2 (5)

Solution:

- Calculation of substitute schema elements (conversion to G):
  - **GENERATOR**
    - Longitudinal synchronous reactance

$$x_d = \frac{x_d[\%]}{100} \cdot \frac{U_{ng}^2}{S_{ng}} \cdot \frac{S_v}{U_v^2} = \frac{113}{100} \cdot \frac{10{,}5^2}{\left(\frac{45}{0{,}85}\right)} \cdot \frac{135}{10{,}5^2} = 2{,}882$$

    - Transverse synchronous reactance

$$x_q = \frac{x_q[\%]}{100} \cdot \frac{U_{ng}^2}{S_{ng}} \cdot \frac{S_v}{U_v^2} = \frac{70{,}8}{100} \cdot \frac{10{,}5^2}{\left(\frac{45}{0{,}85}\right)} \cdot \frac{135}{10{,}5^2} = 1{,}805$$

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Creating a substitute schema for a multi-node network - example 2 (6)

Solution:

- Calculation of substitute schema elements (conversion to G):
  - **GENERATOR**
    - Longitudinal transient reactance

$$x'_d = \frac{x'_d[\%]}{100} \cdot \frac{U_{ng}^2}{S_{ng}} \cdot \frac{S_v}{U_v^2} = \frac{30,3}{100} \frac{10,5^2}{\left(\frac{45}{0,85}\right)} \frac{135}{10,5^2} = 0,773$$

    - Transverse shock reactance

$$x''_d = \frac{x''_d[\%]}{100} \cdot \frac{U_{ng}^2}{S_{ng}} \cdot \frac{S_v}{U_v^2} = \frac{12}{100} \frac{10,5^2}{\left(\frac{45}{0,85}\right)} \frac{135}{10,5^2} = 0,306$$

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Creating a substitute scheme for a multi-node network - example 2 (7)

Solution:

- Calculation of substitute scheme elements (conversion to G):
  - **TRANSFORMER T1**

$$x_{T1} = \frac{u_k[\%]}{100} \frac{U_{nt}^2}{S_{nt}} \frac{1}{p^2} \frac{S_v}{U_v^2} = \frac{12}{100} \frac{242^2}{120} \left(\frac{10,5}{254,1}\right)^2 \frac{135}{10,5^2} = 0,123$$

  - **LINE V1**

$$x_{V1} = x_V \frac{1}{p^2} \frac{S_v}{U_v^2} = 0,421 \cdot 250 \left(\frac{10,5}{254,1}\right)^2 \frac{135}{10,5^2} = 0,220$$

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Creating a substitute schema for a multi-node network - example 2 (8)

Solution:

- Calculation of substitute schema elements (conversion to G):
  - **TRANSFORMER T2**

$$x_{T2} = \frac{u_k[\%]}{100} \frac{U_{nt}^2}{S_{nt}} \frac{1}{p^2} \frac{S_v}{U_v^2} = \frac{15}{100} \frac{121^2}{180} \left(\frac{10,5}{254,1}\right)^2 \left(\frac{220}{121}\right)^2 \frac{135}{10,5^2} = 0,084$$

  - **LINE V2**

$$x_{V2} = x_V \frac{1}{p^2} \frac{S_v}{U_v^2} = 0,379 \cdot 65 \left(\frac{10,5}{254,1}\right)^2 \left(\frac{220}{121}\right)^2 \frac{135}{10,5^2} = 0,170$$

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Creating a substitute schema for a multi-node network - example 2 (9)

Solution:

- Calculation of substitute schema elements (conversion to G):
  - LINE V3

$$x_{V3} = X_V \frac{1}{p^2}\frac{S_V}{U_V^2} = 0{,}408 \cdot 65\left(\frac{10{,}5}{254{,}1}\right)^2\left(\frac{220}{121}\right)^2 \frac{135}{10{,}5^2} = 0{,}183$$

  - LINE V4

$$x_{V4} = X_V \frac{1}{p^2}\frac{S_V}{U_V^2} = 0{,}294 \cdot 60\left(\frac{10{,}5}{254{,}1}\right)^2\left(\frac{220}{121}\right)^2 \frac{135}{10{,}5^2} = 0{,}122$$

  - LINE V5

$$x_{V5} = X_V \frac{1}{p^2}\frac{S_V}{U_V^2} = 0{,}400 \cdot 30\left(\frac{10{,}5}{254{,}1}\right)^2\left(\frac{220}{121}\right)^2 \frac{135}{10{,}5^2} = 0{,}083$$

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Creating a substitute scheme for a multi-node network - example 2 (10)

Solution:

- Calculation of substitute scheme elements (conversion to G):
  - TRANSFORMER T3

$$x_{T3} = \frac{u_k[\%]}{100}\frac{U_{nt}^2}{S_{nt}}\frac{1}{p^2}\frac{S_V}{U_V^2} = \frac{10{,}5}{100}\frac{11^2}{60}\left(\frac{10{,}5}{254{,}1}\right)^2\left(\frac{220}{121}\right)^2\left(\frac{110}{11}\right)^2\frac{135}{10{,}5^2} = 0{,}146$$

  - TRANSFORMER T4

$$x_{T4} = \frac{u_k[\%]}{100}\frac{U_{nt}^2}{S_{nt}}\frac{1}{p^2}\frac{S_V}{U_V^2} = \frac{10{,}5}{100}\frac{11^2}{31{,}5}\left(\frac{10{,}5}{254{,}1}\right)^2\left(\frac{220}{121}\right)^2\left(\frac{110}{11}\right)^2\frac{135}{10{,}5^2} = 0{,}279$$

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Creating a substitute scheme for a multi-node network - example 2 (11)

Solution:

- Calculation of substitute scheme elements (conversion to G):

Consumption power output

  - CONSUMPTION C3

$$s_3 = \frac{S_{o3}}{S_V} = \frac{P_n + jQ_n}{S_V} = \frac{P_n + jP_n tg\varphi}{S_V} = \frac{55 + j55 \cdot 0{,}329}{135} = 0{,}407 + j0{,}134$$

  - CONSUMPTION C4

$$s_4 = \frac{S_{o4}}{S_V} = \frac{P_n + jQ_n}{S_V} = \frac{P_n + jP_n tg\varphi}{S_V} = \frac{25 + j25 \cdot 0{,}329}{135} = 0{,}185 + j0{,}061$$

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Creating a substitute schema for a multi-node network - example 2 (12)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **GENERATOR**
    - Longitudinal synchronous reactance

$$X_d = x_d \frac{U_V^2}{S_V} \frac{1}{p^2} = 2{,}882 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 416{,}89\ \Omega$$

    - Transverse synchronous reactance

$$X_q = x_q \frac{U_V^2}{S_V} \frac{1}{p^2} = 1{,}8054 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 261{,}20\ \Omega$$

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Creating a substitute schema for a multi-node network - example 2 (13)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **GENERATOR**
    - Longitudinal transient reactance

$$X'_d = x'_d \frac{U_V^2}{S_V} \frac{1}{p^2} = 0{,}773 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 111{,}79\ \Omega$$

    - Transverse shock reactance

$$X''_d = x''_d \frac{U_V^2}{S_V} \frac{1}{p^2} = 0{,}306 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 44{,}27\ \Omega$$

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Creating a substitute schema for a multi-node network - example 2 (14)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **TRANSFORMER T1**

$$X_{T1} = x_{T1} \frac{U_V^2}{S_V} \frac{1}{p^2} = 0{,}123 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 17{,}72\ \Omega$$

  - **LINE V1**

$$X_{V1} = x_{V1} \frac{U_V^2}{S_V} \frac{1}{p^2} = 0{,}220 \frac{10{,}5^2}{135} \left(\frac{121}{220}\right)^2 \left(\frac{254{,}1}{10{,}5}\right)^2 = 31{,}84\ \Omega$$

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Creating a substitute scheme for a multi-node network - example 2 (15)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **TRANSFORMER T2**

$$X_{T2} = x_{T2}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}084\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 12{,}20\ \Omega$$

Ω

  - **LINE V2**

$$X_{V2} = x_{V2}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}170\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 24{,}60\ \Omega$$

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Creating a substitute scheme for a multi-node network - example 2 (16)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **LINE V3**

$$X_{V3} = x_{V3}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}183\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 26{,}52\ \Omega$$

  - **LINE V4**

$$X_{V4} = x_{V4}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}122\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 17{,}64\ \Omega$$

  - **LINE V5**

$$X_{V5} = x_{V5}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}083\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 11{,}98\ \Omega$$

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Creating a substitute scheme for a multi-node network - example 2 (17)

Solution:

- Recalculation of detected reactances from relative units to ohmic and to the point between lines V3 and V4:
  - **TRANSFORMER T3**

$$X_{T3} = x_{T3}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}146\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 21{,}18\ \Omega$$

  - **TRANSFORMER T4**

$$X_{T4} = x_{T4}\frac{U_V^2}{S_V}\frac{1}{p^2} = 0{,}279\frac{10{,}5^2}{135}\left(\frac{121}{220}\right)^2\left(\frac{254{,}1}{10{,}5}\right)^2 = 40{,}35\ \Omega$$

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