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Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

THEORY OF TRANSMISSION AND DISTRIBUTION OF ELECTRIC ENERGY

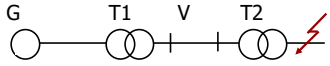
11th lecture - examples

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Calculation of the shock short-circuit current – example 1

- **Task**

Determine the shock surge short-circuit current (3f) after the transformer T2 flowing in the following network:



$S_{nG} = 20$ MVA
$U_{nG} = 6{,}3$ kV
$x''_d = 0{,}12$

$X = 0{,}37\ \Omega/\text{km}$
$l = 4{,}5$ km

$S_{nT1} = 30$ MVA
$p_{T1} = 6{,}3 / 35$ kV
$u_{kT1} = 0{,}11$

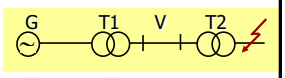
$S_{nT2} = 40$ MVA
$p_{T2} = 35 / 110$ kV
$u_{kT2} = 0{,}11$

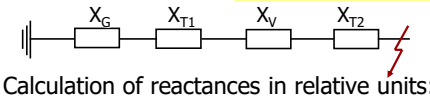
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Calculation of the shock short-circuit current – example 1

- **Solution**

1/ Replacement scheme:





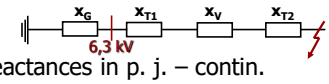
2/ Calculation of reactances in relative units:

- We choose:
  - S_v = 100 MVA (in general)
  - U_v = 110 kV (the rated voltage at the short-circuit point)
- conversion to Sv and to the place of short circuit

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Calculation of the shock short-circuit current – example 1

- **Solution**



2/ Calculation of reactances in p. j. – contin.

- **G:**

$$x_G = x''_d \cdot \frac{U_{nG}^2}{S_{nG}} \cdot \frac{1}{p_{T1}^2} \cdot \frac{1}{p_{T2}^2} \cdot \frac{S_v}{U_v^2} = 0{,}12 \cdot \frac{6{,}3^2}{20} \cdot \frac{35^2}{6{,}3^2} \cdot \frac{110^2}{35^2} \cdot \frac{100}{110^2} =$$

$$= 0{,}12 \cdot \frac{100}{20} = 0{,}6$$

U_n primary T1 -> 2 transfers

- **T1:**

$$x_{T1} = u_{kT1} \cdot \frac{U_{nT1}^2}{S_{nT}} \cdot \frac{1}{p_{T1}^2} \cdot \frac{1}{p_{T2}^2} \cdot \frac{S_v}{U_v^2} = 0{,}11 \cdot \frac{6{,}3^2}{30} \cdot \frac{35^2}{6{,}3^2} \cdot \frac{110^2}{35^2} \cdot \frac{100}{110^2} =$$

$$= 0{,}367$$

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Calculation of the shock short-circuit current – example 1

- **Řešení**



2/ Calculation of reactances in p. j. – contin.

- **V:**

$$x_V = X \cdot l \cdot \frac{1}{p_{T2}^2} \cdot \frac{S_v}{U_v^2} = 0{,}37 \cdot 4{,}5 \cdot \frac{110^2}{35^2} \cdot \frac{100}{110^2} = 0{,}136$$

- **T2:**

U_n secondary T2 -> no transfer

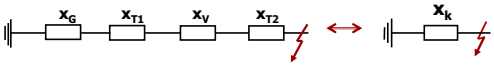
$$x_{T2} = u_{kT2} \cdot \frac{U_{nT2}^2}{S_{nT2}} \cdot \frac{S_v}{U_v^2} = 0{,}11 \cdot \frac{110^2}{40} \cdot \frac{100}{110^2} = 0{,}275$$

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Calculation of the shock short-circuit current – example 1

- **Solution**

3/ Calculation of overall reactance x_k



$$x_k = x_G + x_{T1} + x_V + x_{T2} = 0,6 + 0,367 + 0,136 + 0,275 = 1,378$$

$$X_k = x_k \frac{U_v^2}{S_v} = 1,378 \cdot \frac{110^2}{100} = 166,74\ \Omega$$

4/ Calculation voltage

$$U_{výp} = \frac{c \cdot U_n}{\sqrt{3}} = \frac{1,1 \cdot 110}{\sqrt{3}} = 69,86\text{kV}$$

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Calculation of the shock short-circuit current – example 1

- **Solution**

5/ Initial short-circuit current

$$I_k'' = \frac{U_{výp}}{X_k} = \frac{69,86}{166,74} = 0,419\ \text{kA}$$

or:

$$I_k'' = c \cdot \frac{S_v}{x_k \cdot \sqrt{3} \cdot U_v} = 1,1 \cdot \frac{100}{1,378 \cdot \sqrt{3} \cdot 110} = 0,419\ \text{kA}$$

(I_v)

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Decomposition of asymmetric system into symmetrical components by Fortescue method - example 2

- Decompose into symmetrical components (numerically and graphically) the system:

$$\bar{I}_a = 0\ ' \ \bar{I}_b = 150\text{A}\ ' \ \bar{I}_c = \bar{a} \cdot 100\text{A}$$

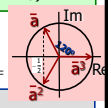
$$\bar{I}_1 = \frac{1}{3}(\bar{I}_a + \bar{a} \cdot \bar{I}_b + \bar{a}^2 \bar{I}_c)$$
$$\bar{I}_2 = \frac{1}{3}(\bar{I}_a + \bar{a}^2 \bar{I}_b + \bar{a} \cdot \bar{I}_c)$$
$$\bar{I}_0 = \frac{1}{3}(\bar{I}_a + \bar{I}_b + \bar{I}_c)$$

$$\bar{I}_1 = \frac{1}{3}(0 + \bar{a} \cdot 150 + \bar{a}^3 100) = \frac{1}{3}(150\bar{a} + 100) =$$

$$= \frac{1}{3}[150(-\frac{1}{2} + j\frac{\sqrt{3}}{2}) + 100] = \frac{1}{3}(-75 + j\sqrt{3} \cdot 75 + 100) =$$

$$= \frac{1}{3}(25 + j\sqrt{3} \cdot 75) = \frac{25}{3} + j\sqrt{3} \cdot 25$$

$$\bar{I}_1 = 8,3 + j43,3 = 44,1 \cdot e^{j79}$$



$$\bar{a} = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$
$$\bar{a}^2 = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$
$$\bar{a}^3 = \left(-\frac{1}{2}\right)^2 - \left(j\frac{\sqrt{3}}{2}\right)^2 = \frac{1}{4} + \frac{3}{4} = 1$$

$j^2 = -1$

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Decomposition of asymmetric system into symmetrical components by Fortescue method - example 2

- Decompose into symmetrical components (numerically and graphically) the system:

$\bar{I}_a = 0\ ' \ \bar{I}_b = 150A\ ' \ \bar{I}_c = \bar{a} \cdot 100A$

$$\bar{I}_1 = \frac{1}{3}(\bar{I}_a + \bar{a} \cdot \bar{I}_b + \bar{a}^2 \bar{I}_c)$$
$$\bar{I}_2 = \frac{1}{3}(\bar{I}_a + \bar{a}^2 \bar{I}_b + \bar{a} \cdot \bar{I}_c)$$
$$\bar{I}_0 = \frac{1}{3}(\bar{I}_a + \bar{I}_b + \bar{I}_c)$$

$$\bar{I}_2 = \frac{1}{3}(0 + \bar{a}^2 150 + \bar{a}^2 100) = \frac{1}{3} \cdot 250(-\frac{1}{2} - j\frac{\sqrt{3}}{2}) =$$

$$= -\frac{125}{3} - j\frac{\sqrt{3} \cdot 125}{3}$$

$$\bar{I}_2 = -41{,}7 - j72{,}2 = 83{,}4 \cdot e^{j240}$$

$$\bar{a} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \qquad j^2 = -1$$
$$\bar{a}^2 = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$
$$\bar{a}^3 = \left(-\frac{1}{2}\right)^2 - \left(j\frac{\sqrt{3}}{2}\right)^2 = \frac{1}{4} + \frac{3}{4} = 1$$

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Decomposition of asymmetric system into symmetrical components by Fortescue method - example 2

- Decompose into symmetrical components (numerically and graphically) the system:

$\bar{I}_a = 0\ ' \ \bar{I}_b = 150A\ ' \ \bar{I}_c = \bar{a} \cdot 100A$

$$\bar{I}_1 = \frac{1}{3}(\bar{I}_a + \bar{a} \cdot \bar{I}_b + \bar{a}^2 \bar{I}_c)$$
$$\bar{I}_2 = \frac{1}{3}(\bar{I}_a + \bar{a}^2 \bar{I}_b + \bar{a} \cdot \bar{I}_c)$$
$$\bar{I}_0 = \frac{1}{3}(\bar{I}_a + \bar{I}_b + \bar{I}_c)$$

$$\bar{I}_0 = \frac{1}{3}(0 + 150 + \bar{a} \cdot 100) = \frac{1}{3}[150 + 100(-\frac{1}{2} + j\frac{\sqrt{3}}{2})] =$$

$$= \frac{100}{3} + j\frac{\sqrt{3} \cdot 50}{3}$$

$$\bar{I}_0 = 33{,}3 + j28{,}9 = 44{,}1 \cdot e^{j41}$$

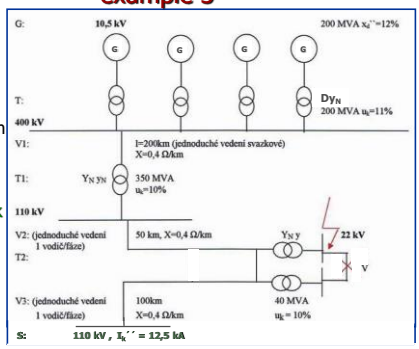
Perform the graphical decomposition according to the instructions in pic. ☺

$$\bar{a} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \qquad j^2 = -1$$
$$\bar{a}^2 = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$
$$\bar{a}^3 = \left(-\frac{1}{2}\right)^2 - \left(j\frac{\sqrt{3}}{2}\right)^2 = \frac{1}{4} + \frac{3}{4} = 1$$

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Calculation of short-circuit currents - example 3

- **Task:**
  - Determine the short-circuit conditions in the marked part of EA (see pic.) – specific task below



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Calculation of short-circuit currents - example 3

- **Task:**
  - Calculation:
    1) **3f short-circuit current in case, that:**
       a/ switch V is open
       b/ V is pinned
    2) **2f short-circuit current without ground**
    3) **the current flowing from the connection of one phase to the ground**
       (1f short-circuit **X** 1f ground connection **???**)
  - Solve:
    - in relative units => choose S_v, U_v and calculate I_v
    - with fictional transfers
    - substitute scheme for consecutive, backward and zero components

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Calculation of short-circuit currents - example 3

- **Method:**

1) according to wiring diagram (for worst case) => replacement scheme, i.e.:
   - all elements are replaced by passive parameters (longitudinal only) - generally Z, resp.
     - R => 0, if it is R < 0,3. X ; for vn, vvn =>just X (R - neglect)
     - X => 0, if it is X < 0,3. R ; for nn => just R (X - neglect)
   - we don't consider consumption
   - in place of resources (alternators, system) ground
   - at the place of the short-circuit we are considering the source of voltage U_{vjp} (phase) => the short-circuit current flows from the fault point only in the branches to short-circuit current sources (alternator, system)
2) From the substitution scheme we determine the total impedance of the short circuit (short-circuit impedance) between the short-circuit point and the ground =>Z_k (Z_c)
3) vypočteme příslušný zkratový proud

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Calculation of short-circuit currents - example 3

- **Method – contin.:**
  - When solving a short circuit, we create a substitute diagram - generally for a sequential, reverse and zero soustavu, ie we determine the values of impedances of individual ES elements:
    - CONSECUTIVE (see earlier, resp. contrary. u **(*)** – next p.)
    - BACKWARED $Z_k^{(2)} = Z_k^{(1)}$ ... for most network elements

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Calculation of short-circuit currents - example 3

(*) Repetition of relations for determination of reactances of individual EC elements:

	[fyz. j.]	[p. j.]
line	$X_v = X_{[\Omega/km]} \cdot l \cdot \frac{1}{p^2}$	$x_v = X_v \cdot \frac{S_v}{U_v^2}$
transformer	$X_t = \frac{u_k\%}{100} \cdot \frac{U_{nt}^2}{S_{nt}} \cdot \frac{1}{p^2}$	$x_t = X_t \cdot \frac{S_v}{U_v^2}$
alternator	$X_g = \frac{x_d''\%}{100} \cdot \frac{U_{ng}^2}{S_{ng}} \cdot \frac{1}{p^2}$	$x_g = X_g \cdot \frac{S_v}{U_v^2}$
system (network)	$X_s = \frac{c \cdot U_{ns}}{\sqrt{3} \cdot I_{ks}''} \cdot \frac{1}{p^2}$	$x_s = X_s \cdot \frac{S_v}{U_v^2}$

from the formula $I_k'' = \frac{U_{výp}}{X_k} = \frac{c \cdot U_n}{\sqrt{3} \cdot X_k} \Rightarrow X_s = \frac{c \cdot U_n}{\sqrt{3} \cdot I_{ks}''} \cdot \frac{1}{p^2}$, where

I_k'' ... Initial short-circuit current (= 3f symmetrical)

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Calculation of short-circuit currents - example 3

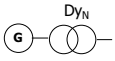
- Method – contin.:
  - ZERO $Z_k^{(0)}$ ... it depends on what elements are in the network
    - line: R same, $X_v^{(0)} = k.X_v^{(1)}$ (k - viz tab. 3 eg to calculate passive parameters of management – lect. 2)

K výpočtu nulové složky indukčnosti:

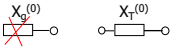
$L_0 = k.L$	k	
	Jednoduché ved.	Dvojité vedení
AlFe, 1 vodič na fázi	1,9	3,0
Cu svazek	2,4	3,5
Fe 1 vodič na fázi	2,7	4,8
svazek	3,2	5,5

Tab. č. 3

    - system: $X_s^{(0)} = 3.X_s^{(1)}$
    - alternator: if the block transformer is connected Dy_N



=> $X_g^{(0)}$ falls out of the scheme



    - trafo: $X_T^{(0)} = X_T^{(1)}$ when connected $y_N y_N$ (vvn/vvn)
      $X_T^{(0)} = \infty$ when connected $y_N y$ (vvn/vn)

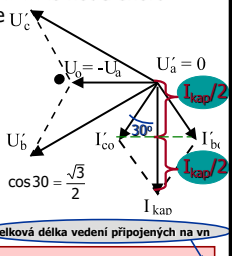
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Calculation of short-circuit currents - example 3

- Method – contin.: (viz 1. lect.)
  - It is an isolated system => 1f fault is not a short circuit, ale ground fault, where
    - size of capacitive current is determined from the phasor diagram
      - we assume symmetrical passive line parameters, then $C_{b0} = C_{c0} = C_0$

$$|I'_{b0}| = |I'_{c0}| = U_{sdr} \cdot B_0$$

$$\frac{I_{kap}}{2} = |I'_{c0}| \cos 30$$



$$I_{kap} = 2 \cdot |I'_{c0}| \cos 30 = 2 \cdot |I'_{c0}| \cdot \frac{\sqrt{3}}{2} = \sqrt{3} \cdot U_{sdr} \cdot B_0 = \sqrt{3} \cdot U_{sdr} \cdot \omega \cdot C_0 \cdot l$$

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Calculation of short-circuit currents - example 3

- Method – contin.:
  - Specific calculations of short-circuit currents for MV and MV networks (sizes only):
    - 3 phase short-circuit

$$I_{k3f} = \frac{U_{výp}}{X_k^{(1)}} = \frac{c \cdot U_n}{\sqrt{3} \cdot X_k^{(1)}}$$

short-circuit voltage

$$I_{k3f} = \frac{c \cdot U_n}{\sqrt{3} \cdot x_k^{(1)} \frac{U_v^2}{S_v}} = \frac{c \cdot S_v}{\sqrt{3} \cdot x_k^{(1)} \cdot U_v} = \frac{c \cdot I_v}{x_k^{(1)}} \quad (U_v = U_n)$$

where: U_n ... short-circuit voltage
$X_k^{(1)}$ ... short-circuit reactance of sequential component in Ω
$x_k^{(1)}$ ... short-circuit reactance of sequential component in p.j.
I_v ... relative current

$$I_v = \frac{S_v}{\sqrt{3} \cdot U_v}$$

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Calculation of short-circuit currents - example 3

- Method – contin.:
  - 2 phase short-circuit

$$I_{k2f} = \frac{\sqrt{3} \cdot U_{výp}}{X_k^{(1)} + X_k^{(2)}} = \frac{\sqrt{3} \cdot c \cdot U_n}{\sqrt{3} \cdot 2 \cdot X_k^{(1)}} = c \cdot \frac{U_n}{2 \cdot X_k^{(1)}}$$

$$I_{k2f} = \frac{\sqrt{3} \cdot c \cdot U_n}{\sqrt{3} \cdot 2 \cdot x_k^{(1)} \frac{U_v^2}{S_v}} = \frac{\sqrt{3} \cdot c \cdot S_v}{2 \cdot x_k^{(1)} \cdot \sqrt{3} \cdot U_v} = \frac{\sqrt{3} \cdot c \cdot I_v}{2 \cdot x_k^{(1)}}$$

I_v

where: $X_k^{(2)}$ ... short-circuit reactance of the backward component in Ω

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Calculation of short-circuit currents - example 3

- Method – contin.:
  - 1 phase short-circuit

$$I_{k1f} = \frac{3 \cdot U_{výp}}{X_k^{(1)} + X_k^{(2)} + X_k^{(0)}} = \frac{3 \cdot c \cdot U_n}{\sqrt{3} \cdot (2 \cdot X_k^{(1)} + X_k^{(0)})} = \frac{\sqrt{3} \cdot c \cdot U_n}{2X_k^{(1)} + X_k^{(0)}}$$

$$I_{k1f} = \frac{3 \cdot c \cdot U_n}{\sqrt{3} \cdot (2 \cdot x_k^{(1)} + x_k^{(0)}) \frac{U_v^2}{S_v}} = \frac{3 \cdot c \cdot I_v}{2 \cdot x_k^{(1)} + x_k^{(0)}}$$

where: $X_k^{(0)}$ ... short-circuit reactance of zero component in Ω

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Calculation of short-circuit currents - example 3

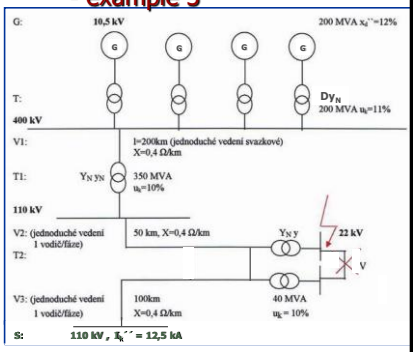
- Diagram of the solved network:
  - Here again to clarify the replacement of the upstream and downstream components

For calculation
- we choose :

S_v = 40 MVA

U_v = 22 kV
- we count:

$$I_V = \frac{S_V}{\sqrt{3} \cdot U_V}$$

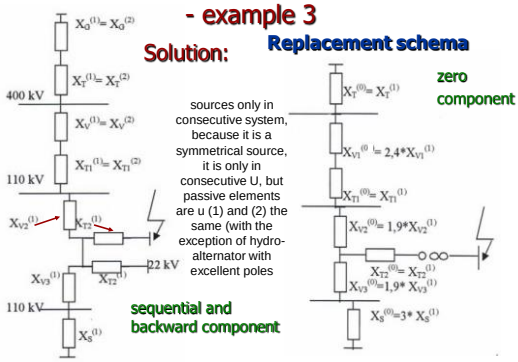


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Calculation of short-circuit currents - example 3

Solution:

Replacement schema



sources only in consecutive system, because it is a symmetrical source, it is only in consecutive U, but passive elements are u (1) and (2) the same (with the exception of hydro-alternator with excellent poles

zero component

sequential and backward component

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Calculation of short-circuit currents - example 3

- Here agaun to clarify the replacement of the zero component:
  - $Z_k^{(0)}$ ... it depends on what elements are in the network
    - line: R same, $X_v^{(0)} = k.X_v^{(1)}$

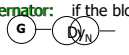
(k - viz tab. 3 eg to calculate passive parameters of management – lect. 2)

K výpočtu nulové složky indukčnosti:

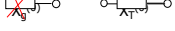
$L_0 = k.L$		k	
		Jednoduché ved.	Dvojité vedení
$AlFe_6$	1 vodič na fázi	1,9	3,0
CN	svazek	2,4	3,5
Fe	1 vodič na fázi	2,7	4,8
	svazek	3,2	5,5

Tab. č. 3

- system: $X_s^{(0)} = 3.X_s^{(1)}$
- alternator: if the block transformer is connected Dy_N



=> $X_g^{(0)}$ falls out of the scheme



- trafo: $X_T^{(0)} = X_T^{(1)}$ when connected $y_N y_N$ (vvn/vvn)

$X_T^{(0)} = \infty$ when connected $y_N y$ (vvn/vn)

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Calculation of short-circuit currents - example 3

Solution: Calculate the replacement reactance of the consecutive component

v Ω

$$X_G^{(1)} = \frac{1}{4}\cdot\frac{x_d''}{100}\frac{U_{nG}^2}{S_{nG}}\frac{1}{p^2} = \frac{0{,}12}{4}\cdot\frac{10{,}5^2}{200}\left(\frac{22}{110}\right)^2\left(\frac{110}{400}\right)^2\left(\frac{400}{10{,}5}\right)^2 = 0{,}073\ \Omega$$

$$x_G^{(1)} = X_G^{(1)}\cdot\frac{S_v}{U_v^2} = \frac{0{,}12}{4}\cdot\frac{22^2}{200}\cdot\frac{40}{22^2} = \frac{0{,}024}{4} = 0{,}006$$

v p.j.

$$X_T^{(1)} = \frac{1}{4}\cdot\frac{u_k}{100}\frac{U_{nT}^2}{S_{nT}}\frac{1}{p^2} = \frac{0{,}11}{4}\cdot\frac{400^2}{200}\left(\frac{22}{110}\right)^2\left(\frac{110}{400}\right)^2 = 0{,}067\ \Omega$$

$$x_T^{(1)} = X_T^{(1)}\cdot\frac{S_v}{U_v^2} = \frac{0{,}11}{4}\cdot\frac{22^2}{200}\cdot\frac{40}{22^2} = \frac{0{,}024}{4} = 0{,}0055$$

$$X_{V1}^{(1)} = X\cdot l\cdot\frac{1}{p^2} = 0{,}4\cdot 200\cdot\left(\frac{22}{110}\right)^2\left(\frac{110}{400}\right)^2 = 0{,}242\ \Omega$$

$$x_{V1}^{(1)} = X_{V1}^{(1)}\cdot\frac{S_v}{U_v^2} = 0{,}242\frac{40}{22^2} = 0{,}02$$

We choose:
S_v = 40 MVA
U_v = 22 kV
Calculate:
I_v = 1,05 kA

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Calculation of short-circuit currents - example 3

Solution: Calculate the replacement reactance of the consecutive component

v Ω

$$X_{T1}^{(1)} = \frac{u_k}{100}\cdot\frac{U_{nT1}^2}{S_{nT1}}\frac{1}{p^2} = 0{,}1\cdot\frac{110^2}{350}\cdot\left(\frac{22}{110}\right)^2 = 0{,}138\ \Omega$$

$$x_{T1}^{(1)} = X_{T1}^{(1)}\cdot\frac{S_v}{U_v^2} = 0{,}138\cdot\frac{40}{22^2} = 0{,}0114$$

$$X_{V2}^{(1)} = X\cdot l\cdot\frac{1}{p^2} = 0{,}4\cdot 50\cdot\left(\frac{22}{110}\right)^2 = 0{,}8\ \Omega$$

v p.j.

$$x_{V2}^{(1)} = X_{V2}^{(1)}\cdot\frac{S_v}{U_v^2} = 0{,}8\cdot\frac{40}{22^2} = 0{,}0661$$

$$X_{T2}^{(1)} = \frac{u_k}{100}\cdot\frac{U_{nT2}^2}{S_{nT2}} = 0{,}1\cdot\frac{22^2}{40} = 1{,}21\ \Omega$$

$$x_{T2}^{(1)} = X_{T2}^{(1)}\cdot\frac{S_v}{U_v^2} = 0{,}1$$

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Calculation of short-circuit currents - example 3

Solution: Calculate the replacement reactance of the consecutive component

v Ω

$$X_{V3}^{(1)} = X\cdot l\cdot\frac{1}{p^2} = 0{,}4\cdot 100\cdot\left(\frac{22}{110}\right)^2 = 1{,}6\ \Omega$$

$$x_{V3}^{(1)} = X_{V3}^{(1)}\cdot\frac{S_v}{U_v^2} = 1{,}6\cdot\frac{40}{22^2} = 0{,}1322$$

v p.j.

$$X_S^{(1)} = \frac{c\cdot U_{nS}}{\sqrt{3}\cdot I_k''}\cdot\frac{1}{p^2} = \frac{1{,}1\cdot 110}{\sqrt{3}\cdot 12{,}5}\cdot\left(\frac{22}{110}\right)^2 = 0{,}224\ \Omega$$

$$x_S^{(1)} = X_S^{(1)}\cdot\frac{S_v}{U_v^2} = 0{,}224\cdot\frac{40}{22^2} = 0{,}0185$$

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Calculation of short-circuit currents - example 3

Solution: Calculation of substitute zero reactants ($X^{(0)}$ in Ω whose $x^{(0)}$ in p.j.)

$X_T^{(0)} = X_T^{(1)} = 0{,}067\ \Omega$ $\quad X_{V1}^{(0)} = 2{,}4 \cdot X_{V1}^{(1)} = 2{,}4 \cdot 0{,}242 = 0{,}581\ \Omega$

$x_T^{(0)} = x_T^{(1)} = 0{,}0055$ $\quad x_{V1}^{(0)} = 2{,}4 \cdot x_{V1}^{(1)} = 2{,}4 \cdot 0{,}02 = 0{,}048$

$X_{T1}^{(0)} = 0{,}138\ \Omega$ $\quad X_{V2}^{(0)} = 1{,}9 \cdot X_{V2}^{(1)} = 1{,}9 \cdot 0{,}8 = 1{,}52\ \Omega$

$x_{T1}^{(0)} = 0{,}0114$ $\quad x_{V2}^{(0)} = 1{,}9 \cdot 0{,}0661 = 0{,}1256$

$X_{T2}^{(0)} = 1{,}21\ \Omega$ $\quad X_{V3}^{(0)} = 1{,}9 \cdot X_{V3}^{(1)} = 1{,}9 \cdot 1{,}6 = 3{,}04\ \Omega$

$x_{T2}^{(0)} = 0{,}1$ $\quad x_{V3}^{(0)} = 1{,}9 \cdot 0{,}1322 = 0{,}2512$

$X_S^{(0)} = 3 \cdot X_S^{(1)} = 3 \cdot 0{,}224 = 0{,}672\ \Omega$

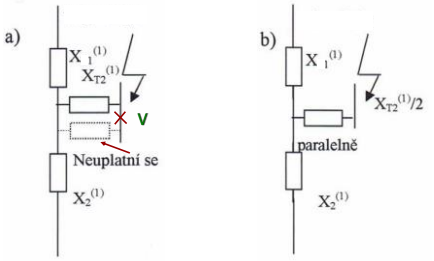
$x_S^{(0)} = 3 \cdot x_S^{(1)} = 3 \cdot 0{,}0185 = 0{,}0555$

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Calculation of short-circuit currents - example 3

Solution: Modify replacement scheme

- switch V disconnected
- switch V closed



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Calculation of short-circuit currents - example 3

Solution: Calculation of the total short-circuit reactance $X_k^{(1)}$ of the consecutive component in Ω

$$X_1^{(1)} = X_G^{(1)} + X_T^{(1)} + X_{V1}^{(1)} + X_{T1}^{(1)} + X_{V2}^{(1)} = 0{,}073 + 0{,}067 + 0{,}242 + 0{,}138 + 0{,}8 = 1{,}32\ \Omega$$

$$X_2^{(1)} = X_S^{(1)} + X_{V3}^{(1)} = 0{,}224 + 1{,}6 = 1{,}824\ \Omega$$

Ad a/ switch V disconnected

$$X_k^{(1)} = \frac{X_1^{(1)} \cdot X_2^{(1)}}{X_1^{(1)} + X_2^{(1)}} + X_{T2}^{(1)} = \left(\frac{1{,}32 \cdot 1{,}824}{1{,}32 + 1{,}824}\right) + 1{,}21 = 1{,}976\ \Omega$$

Ad b/ switch V closed

$$X_k^{(1)} = \frac{X_1^{(1)} \cdot X_2^{(1)}}{X_1^{(1)} + X_2^{(1)}} + \frac{X_{T2}^{(1)}}{2} = 0{,}766 + \frac{1{,}21}{2} = 1{,}371\ \Omega$$

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Calculation of short-circuit currents - example 3

Solution: Calculation of the total short-circuit reactance $x_k^{(1)}$ sequential components in p.j.

$$x_1^{(1)} = x_G^{(1)} + x_T^{(1)} + x_{V1}^{(1)} + x_{T1}^{(1)} + x_{V2}^{(1)} = \\ = 0{,}006 + 0{,}0055 + 0{,}02 + 0{,}0114 + 0{,}0661 = 0{,}109$$

$$x_2^{(1)} = x_S^{(1)} + x_{V3}^{(1)} = 0{,}0185 + 0{,}1322 = 0{,}151$$

Ad a) switch V disconnected

$$x_k^{(1)} = \frac{x_1^{(1)} \cdot x_2^{(1)}}{x_1^{(1)} + x_2^{(1)}} + x_{T2}^{(1)} = \frac{0{,}109 \cdot 0{,}151}{0{,}109 + 0{,}151} + 0{,}1 = 0{,}163$$

Ad b) switch V closed

$$x_k^{(1)} = \frac{x_1^{(1)} \cdot x_2^{(1)}}{x_1^{(1)} + x_2^{(1)}} + \frac{x_{T2}^{(1)}}{2} = 0{,}063 + \frac{0{,}1}{2} = 0{,}113$$

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Calculation of short-circuit currents - example 3

Solution: Calculation of 3f short circuit current

1/

$$I_{k(3f)} = \frac{U_{výp}}{X_k^{(1)}} = \frac{c \cdot U_n}{\sqrt{3} \cdot X_k^{(1)}}$$

from frequency v Ω

a) $\frac{1{,}1 \cdot 22}{\sqrt{3} \cdot 1{,}976} = 7{,}071$ kA

b) $\frac{1{,}1 \cdot 22}{\sqrt{3} \cdot 1{,}371} = 10{,}191$ kA

$$I_{k(3f)} = \frac{c \cdot U_n}{\sqrt{3} \cdot x_k^{(1)} \frac{U_v^2}{S_v}} = \frac{c \cdot S_v}{\sqrt{3} \cdot x_k^{(1)} \cdot U_v} = \frac{c \cdot I_v}{x_k^{(1)}} =$$

from reactance v p.j. ($U_v = U_n$)

a) $= \frac{1{,}1 \cdot 1{,}05}{0{,}163} = 7{,}086$ kA

b) $= \frac{1{,}1 \cdot 1{,}05}{0{,}113} = 10{,}221$ kA

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Calculation of short-circuit currents - example 3

Solution: Calculation of 2f short circuit current

2/ a)

$$I_{k(2f)} = \frac{\sqrt{3} \cdot U_{výp}}{2 \cdot X_k^{(1)}} = \frac{\sqrt{3} \cdot c \cdot U_n}{\sqrt{3} \cdot 2 \cdot X_k^{(1)}} = \frac{1{,}1 \cdot 22}{2 \cdot 1{,}976} = 6{,}123 \text{ kA}$$

from frequency in Ω

$$I_{k(2f)} = \frac{c \cdot U_n}{2 \cdot x_k^{(1)} \frac{U_v^2}{S_v}} = \frac{\sqrt{3} \cdot c \cdot S_v}{2 \cdot x_k^{(1)} \sqrt{3} \cdot U_v} = \frac{\sqrt{3} \cdot c \cdot I_v}{2 \cdot x_k^{(1)}} =$$

(I_v)

from reactance in p.j.

$$= \frac{\sqrt{3} \cdot 1{,}1 \cdot 1{,}05}{2 \cdot 0{,}163} = 6{,}137 \text{ kA} \quad (8{,}85 \text{ kA})$$

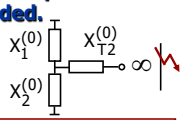
b)

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Calculation of short-circuit currents - example 3

Solution: Calculation of the total short-circuit reactance $X_k^{(0)}$ or $x_k^{(0)}$ of the zero component in Ω and in p.j. if 1f short circuit is needed.

This is only a **procedure** applicable in the **case of other transformer wiring.**



Demonstration in case **a)** switch **V** disconnected

$$X_1^{(0)} = X_T^{(0)} + X_{V1}^{(0)} + X_{T1}^{(0)} + X_{V2}^{(0)} = 0{,}067 + 0{,}581 + 0{,}138 + 1{,}52 = 2{,}306\ \Omega$$

$$X_2^{(0)} = X_S^{(0)} + X_{V3}^{(0)} = 3{,}04 + 0{,}672 = 3{,}712\ \Omega$$

Calculation in Ω

$$X_k^{(0)} = \frac{X_1^{(0)} \cdot X_2^{(0)}}{X_1^{(0)} + X_2^{(0)}} + X_{T2}^{(0)} = \frac{2{,}306 \cdot 3{,}712}{2{,}306 + 3{,}712} + 1{,}21 = 2{,}632\ \Omega$$

Here reactance $X_{T2}^{(0)} \to \infty$ => it will be 1f ground fault!

Calculation of short-circuit currents - example 3

Solution: Calculation of the total short-circuit reactance $X_k^{(0)}$ or $x_k^{(0)}$ of the zero component in Ω and in p.j. if 1f short circuit is needed.

This is only a **procedure** applicable in the **case of other transformer wiring.**

Demonstration in case **a)** switch **V** disconnected

$$x_1^{(0)} = x_T^{(0)} + x_{V1}^{(0)} + x_{T1}^{(0)} + x_{V2}^{(0)} = 0{,}0055 + 0{,}048 + 0{,}0114 + 0{,}1256 = 0{,}1905$$

$$x_2^{(0)} = x_S^{(0)} + x_{V3}^{(0)} = 0{,}2512 + 0{,}0555 = 0{,}3067$$

calculation in p. j.

$$x_k^{(0)} = \frac{x_1^{(0)} \cdot x_2^{(0)}}{x_1^{(0)} + x_2^{(0)}} + x_{T2}^{(0)} = \frac{0{,}1905 \cdot 0{,}3067}{0{,}1905 + 0{,}3067} + 0{,}1 = 0{,}2175$$

Here reactance $X_{T2}^{(0)} \to \infty$ => it will be 1f ground fault!

Calculation of short-circuit currents - example 3

Solution: The procedure for calculating the magnitude of 1f short-circuit current – NO in this example!

This is not a short circuit, but a ground fault - see below for the calculation!

$$I_{k1f} = \frac{3 \cdot U_{výp}}{X_k^{(1)} + X_k^{(2)} + X_k^{(0)}} = \frac{3 \cdot c \cdot U_n}{\sqrt{3} \cdot (2 \cdot X_k^{(1)} + X_k^{(0)})} = \frac{\sqrt{3} \cdot c \cdot U_n}{2X_k^{(1)} + X_k^{(0)}}$$

from reactance in p.j.

$$I_{k1f} = \frac{3 \cdot c \cdot U_n}{\sqrt{3}(2x_k^{(1)} + x_k^{(0)}) \frac{U_v}{S_v}} = \frac{3 \cdot c}{2x_k^{(1)} + x_k^{(0)}} \cdot \frac{S_v}{\sqrt{3}U_v} = \frac{3 \cdot c \cdot I_v}{2x_k^{(1)} + x_k^{(0)}}$$

I_v

from reactance in p.j.

Calculation of short-circuit currents - example 3

- If it were different transformer wiring than Y_N y (e.g. Y_N y_N), we could calculate 1f short circuit current:

$$I_{k1f} = \frac{\sqrt{3} \cdot 1{,}1 \cdot 22}{2 \cdot 1{,}976 + 2{,}632} = 6{,}366 \text{ kA}$$

$$I_{k1f} = \frac{3 \cdot 1{,}1 \cdot 1{,}05}{2 \cdot 0{,}163 + 0{,}2175} = 6{,}375 \text{ kA}$$

- In our case it is 1f ground connection

3/ We choose eg. 400 km = length of all lines connected to 22 kV

$$I_{kap} = \sqrt{3} \cdot \underbrace{\omega C_0}_{B_0} \cdot l \cdot U_n = \sqrt{3} \cdot 1{,}2 \cdot 10^{-6} \cdot 400 \cdot 22 \cdot 10^3 \doteq 18{,}3 \text{ A}$$

$$B_0 \doteq 40\% \cdot B = 0{,}4 \cdot 3 \cdot 10^{-6} = 1{,}2 \cdot 10^{-6} \text{ S/km}$$

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