

## Výpočty nesouměrných soustav

### Metoda souměrných složkových soustav

- vychází ze superpozice nesouměrnosti jako součet 3 souměrných 3f elektrických soustav (sousedné, zpětné a netočivé)
- jako každá superpozice vyžaduje linearitu problému
- využívá možnosti „propojit“ výsledná složková schémata, což je důsledkem výjimečného matematického řešení pro specifické poruchy (pouze při výjimečném postavení fáze A jsou výsledky jednoduché)
- aktivní nemusí být pouze sousledná síť, ale při nesouměrnosti zdroje i zpětná a netočivá souměrná soustava
- Transformační matice:

$$\bar{F} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix} \quad \bar{F}^{-1} = \frac{1}{3} \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix}$$

- Příklad transformace

Nesouměrná 3f soustava:

$$X_A = 7.17 \sin(t + 0.27)$$

$$X_B = 4.71 \sin(t - 2.44)$$

$$X_C = 3.79 \sin(t + 2.41)$$



Po transformaci:

$$X_A^{(1)} = 5 \cdot \sin(t + 0.1)$$

$$X_A^{(2)} = 2 \cdot \sin(t + 0.5)$$

$$X_B^{(1)} = 5 \cdot \sin\left(t + 0.1 - \frac{2\pi}{3}\right)$$

$$X_B^{(2)} = 2 \cdot \sin\left(t + 0.5 + \frac{2\pi}{3}\right)$$

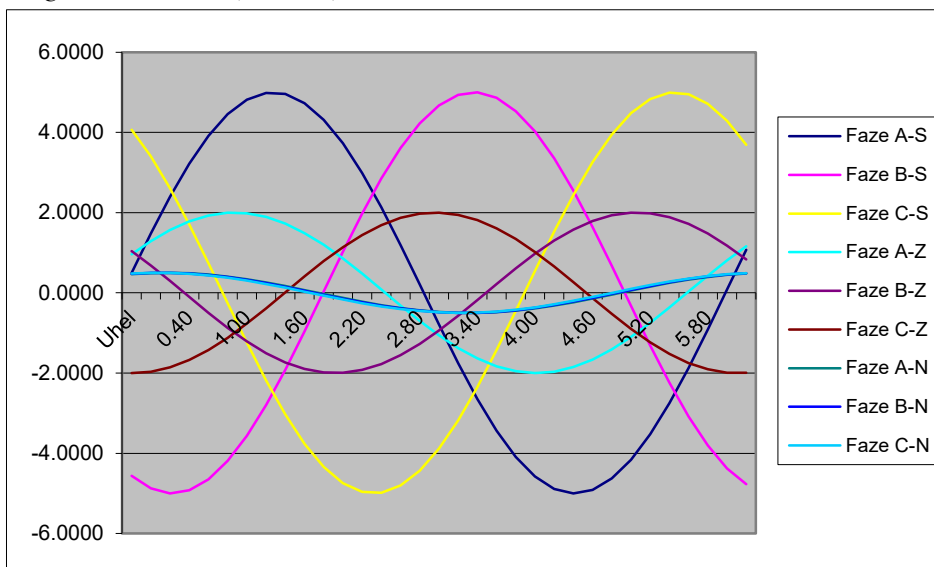
$$X_C^{(1)} = 5 \cdot \sin\left(t + 0.1 + \frac{2\pi}{3}\right)$$

$$X_C^{(2)} = 2 \cdot \sin\left(t + 0.5 - \frac{2\pi}{3}\right)$$

$$X_A^{(0)} = 0.5 \cdot \sin(t + 1.2)$$

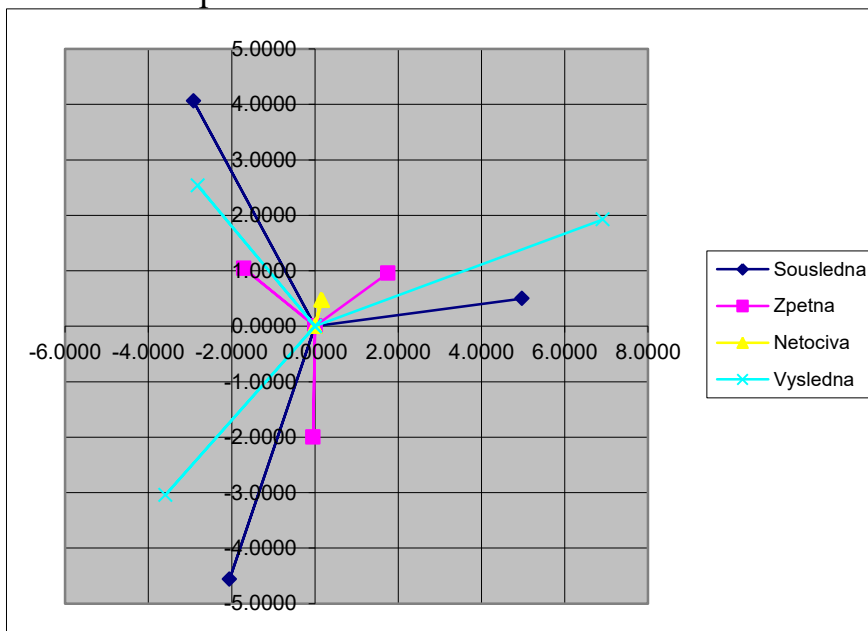
$$X_B^{(0)} = 0.5 \cdot \sin(t + 1.2)$$

$$X_C^{(0)} = 0.5 \cdot \sin(t + 1.2)$$



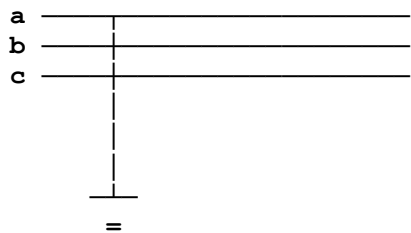
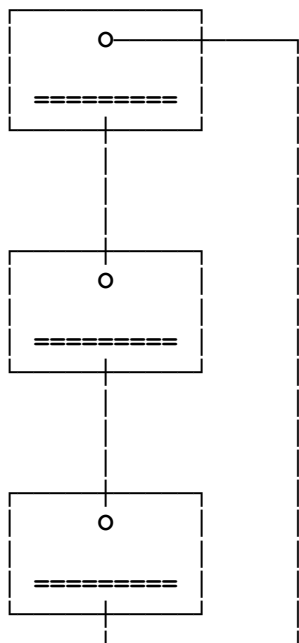
(zobrazeno jako (1)-S-sousledná, (2)-Z-zpětná, (0)-N-netočivá)

Ve fázorové podobě:

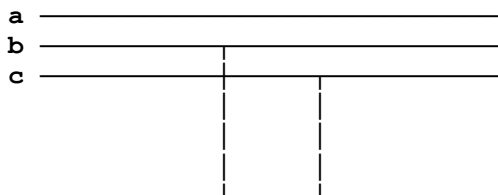
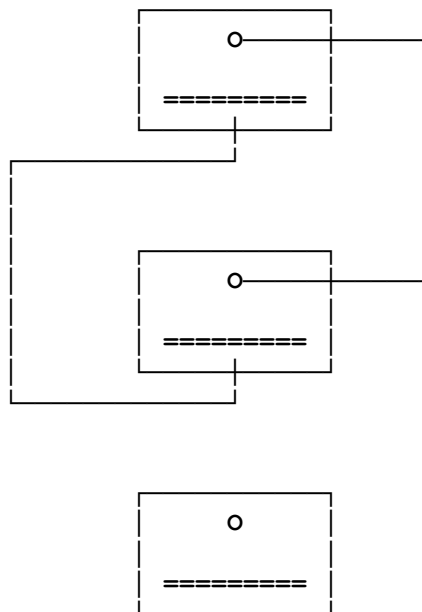


## Propojení složkových soustav pro jednotlivé druhy poruch

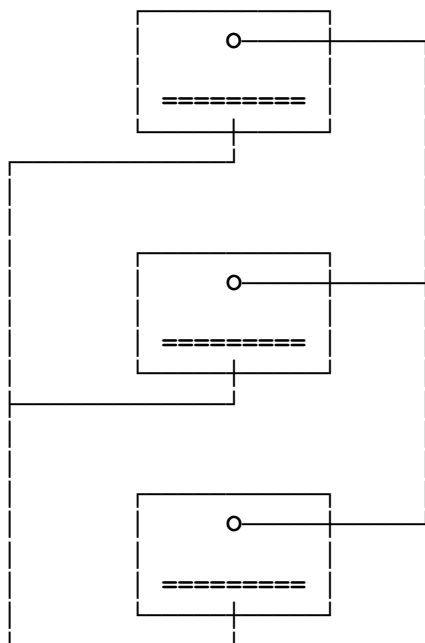
**Jednofázový zkrat:**



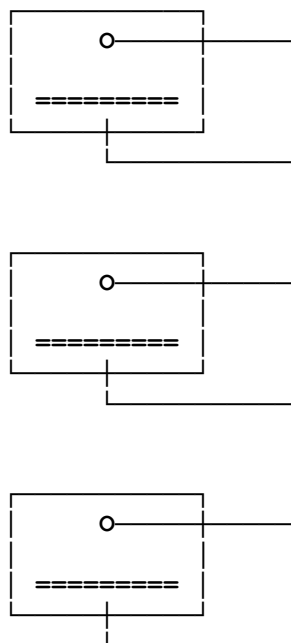
**Dvoufázový zkrat:**

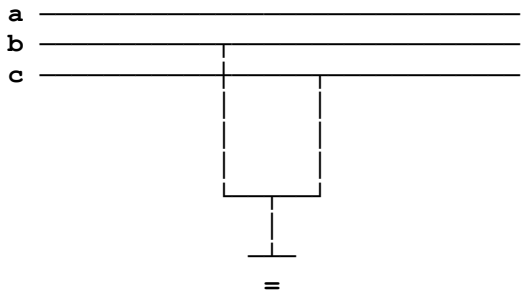


**Dvoufázový zemní zkrat:**

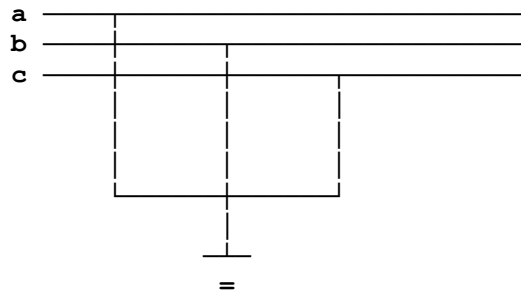
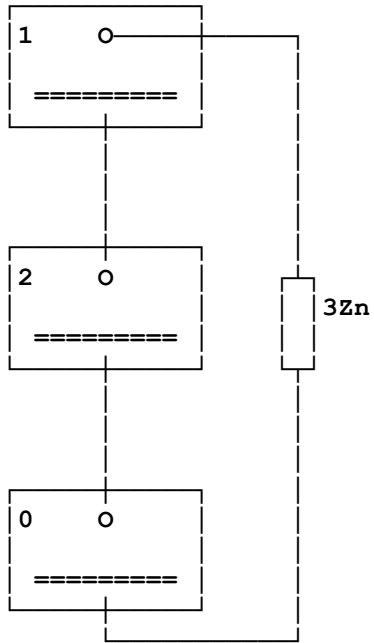


**Trojfázový zkrat:**

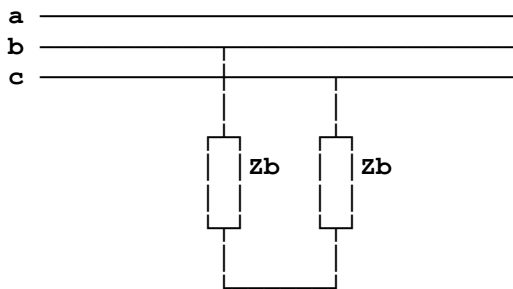
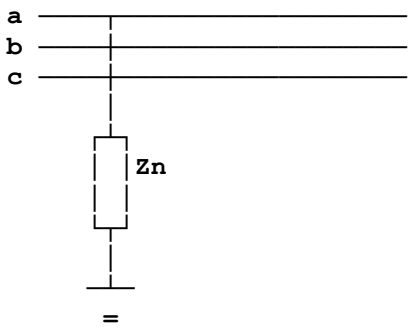
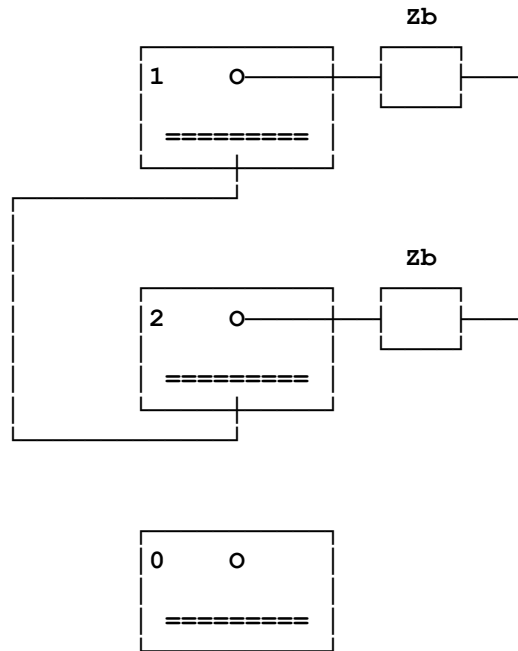




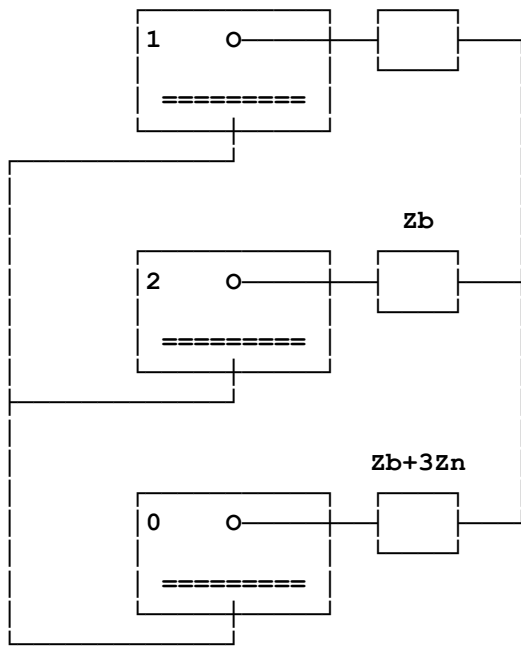
Jednofázová porucha:



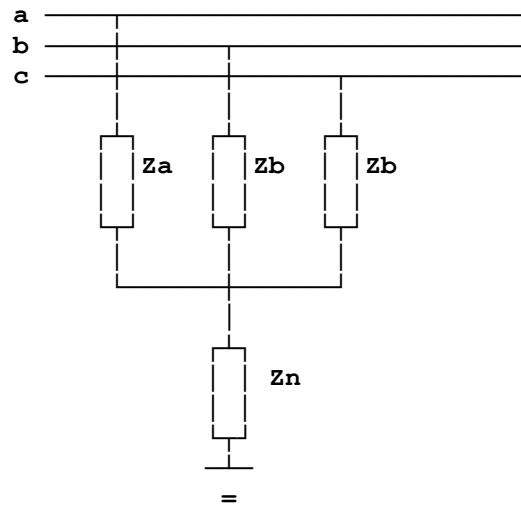
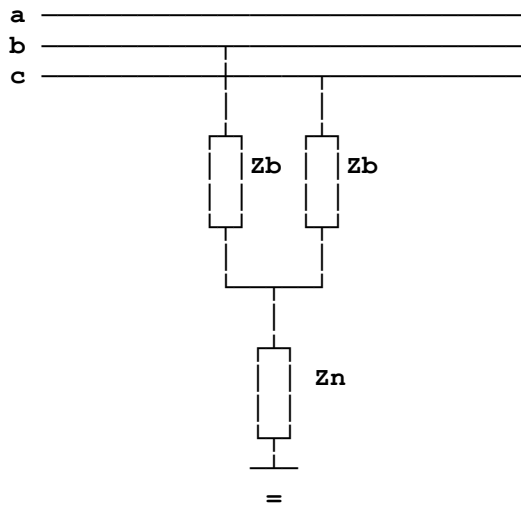
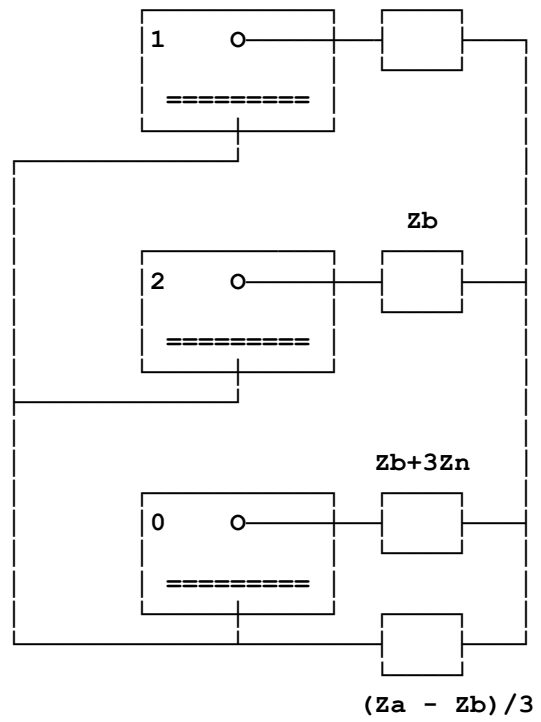
Dvoufázová poruchy:



Dvoufázová zemní porucha:  
Zb

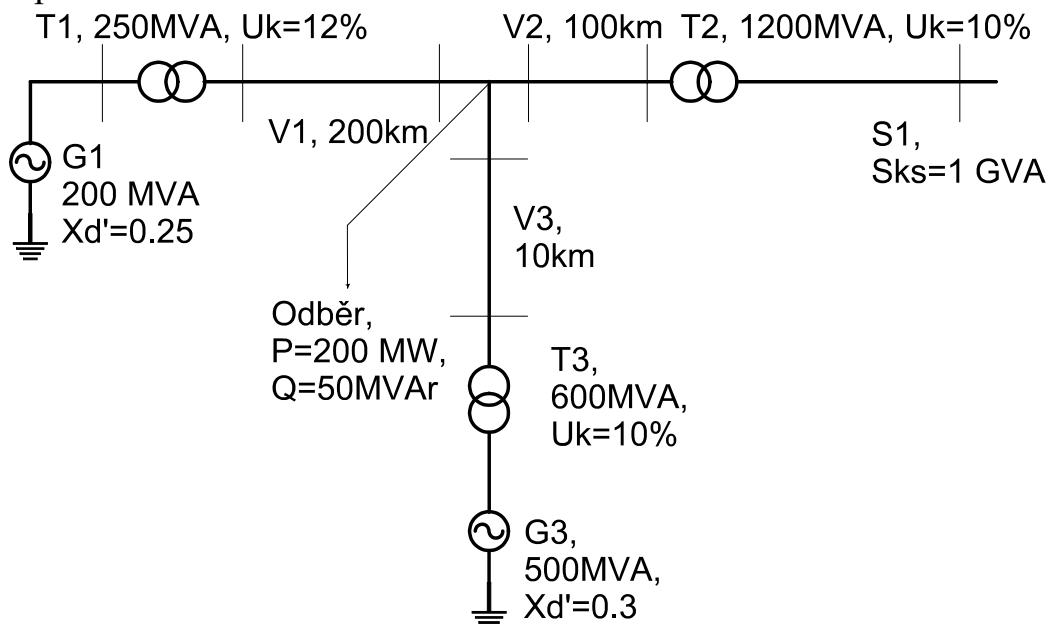


Třífázová porucha:  
Zb



## Komplexní příklad na metodu souměrných složkových soustav

Zadání příkladu dle obrázku:



Dodatečné hodnoty:

- impedance vedení  $x_V=0.3 \Omega/km$
- vztažné napětí  $U_V=220kV$
- vztažný výkon  $S_V=250MVA$
- zapojení transformátorů:
  - T1:  $Y_n Y_n$
  - T2:  $Y_n Y_n$
  - T3:  $Y_N d$

Vypočtené reálné ohmické hodnoty přepočtené na hladinu  $U_V$ :

$$X_{d1}' = 0.25 * (10^2/200) * (220^2/10^2) \Omega = 60.5 \Omega$$

$$X_{d3}' = 0.3 * (15^2/500) * (220^2/15^2) \Omega = 29.04 \Omega$$

$$X_{T1} = j (12/100) * (220^2/250) \Omega = j 23.23 \Omega$$

$$X_{T2} = j (10/100) * (220^2/1200) \Omega = j 4.03 \Omega$$

$$X_{T3} = j (10/100) * (220^2/600) \Omega = j 8.07 \Omega$$

$$X_{V1} = j 0.3 * 200 \Omega = j 60 \Omega$$

$$X_{V2} = j 0.3 * 100 \Omega = j 30 \Omega$$

$$X_{V3} = j 0.3 * 10 \Omega = j 3 \Omega$$

$$X_S = j (400^2/1000) * (220^2/400^2) \Omega = j 48.4 \Omega$$

$$Z_P = U_V^2 / S_P = 220^2 / (200 + j50) \Omega = 220^2 / (200 + j50) * (200 - j50) / (200 - j50) \Omega = 227.76 - j 56.94 \Omega$$

Sestavené náhradní schéma:

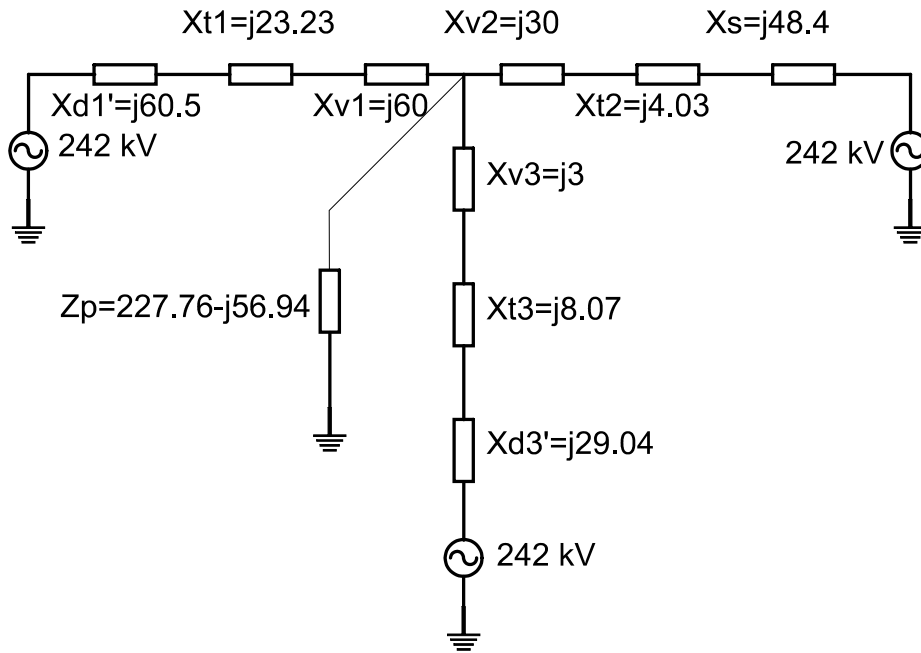
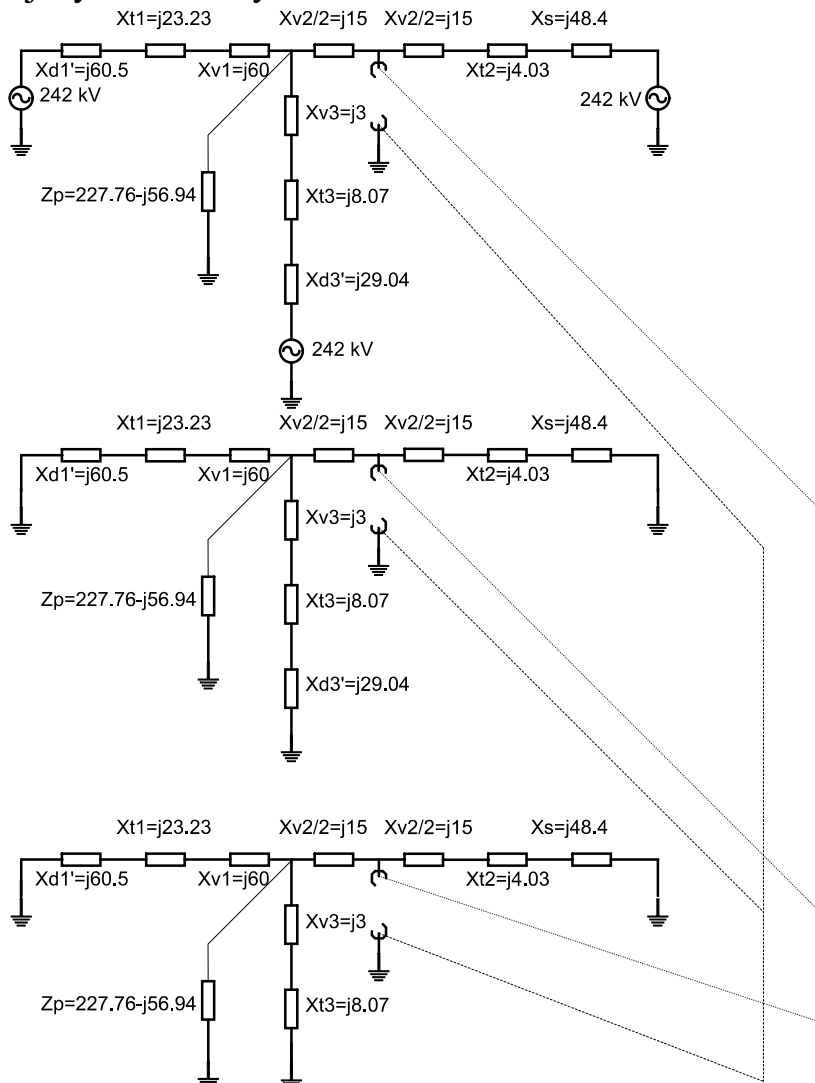


Schéma propojených složkových soustav:



Výpočet náhradní impedance zpětné složkové soustavy:

$$Z_A = j(60.5 + 23.23 + 60) \Omega = j143.73 \Omega \quad Z_B = j(29.04 + 8.07 + 3) \Omega = j40.11 \Omega$$

$$Z_C = j(15 + 4.03 + 48.4) \Omega = j67.43 \Omega \quad Z_D = 227.76 - j57.94 \Omega$$

$$\frac{1}{Z_{pom}} = \frac{1}{Z_A} + \frac{1}{Z_B} + \frac{1}{Z_D} \Rightarrow Z_{pom} = 4.26 + j31.8 \Omega$$

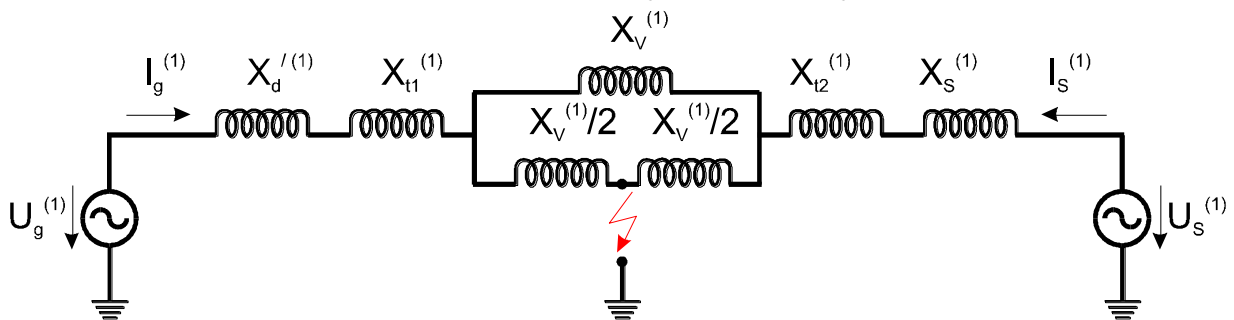
$$\frac{1}{Z^{(2)}} = \frac{1}{Z_{pom} + j15} + \frac{1}{Z_C} \Rightarrow Z^{(2)} = 1.48 + j27.7 \Omega$$

$$\frac{1}{Z_{pom2}} = \frac{1}{Z_A} + \frac{1}{j(8.07 + 3)} + \frac{1}{Z_D} \Rightarrow Z_{pom2} = 0.445 + j10.4 \Omega$$

$$\frac{1}{Z^{(0)}} = \frac{1}{Z_{pom2} + j15} + \frac{1}{Z_C} \Rightarrow Z^{(0)} = 0.235 + j18.5 \Omega$$

$$\frac{1}{Z_{ekv}} = \frac{1}{Z^{(2)}} + \frac{1}{Z^{(0)}} \Rightarrow Z_{ekv} = 0.322 + j11.1 \Omega$$

### Komplexní příklad na metodu souměrných složkových soustav 2



$$i = \sqrt{-1}$$

$$a = e^{j\frac{2\pi}{3}} = \frac{1}{2} + j\frac{\sqrt{3}}{2}$$

$$\bar{F} = \begin{bmatrix} 1 & 1 & 1 \\ a^2 & a & 1 \\ a & a^2 & 1 \end{bmatrix}$$

$$U_N = 110 \text{ kV}$$

$$x_d' = 0.5 \quad \cos \varphi = 0.98$$

$$P_N = 20 \text{ MW}$$

$$u_{K1} = 10\% \quad S_{NT1} = 35 \text{ MVA}$$

$$u_{K2} = 10\% \quad S_{NT2} = 50 \text{ MVA}$$

$$x_V = 0.3 \Omega / \text{km} \quad l = 20 \text{ km}$$

$$S_{KS} = 1000 \text{ MVA}$$

```
% Axiomy
i=sqrt(-1)
A=-0.5+sqrt(3)/2*i
F=[ 1  1  1
    A*A A  1
    A  A*A 1 ]
pause

% Vstupni udaje
% Alternator
Xdc=0.5*(0.98/20)*110^2*i
% Transformator 1
Xt1=10/100*110^2/35*i
% Transformator 2
Xt2=10/100*110^2/50*i
% Vedeni
Xv=20*0.3*i
% Sit'
Xs=110^2/1000*i
```



$$i = 0 + 1i$$

$$A = -0.50000 + 0.86603i$$

F =

$$1.00000 + 0.00000i \quad 1.00000 + 0.00000i \quad 1.00000 + 0.00000i$$

$$-0.50000 - 0.86603i \quad -0.50000 + 0.86603i \quad 1.00000 + 0.00000i$$

$$-0.50000 + 0.86603i \quad -0.50000 - 0.86603i \quad 1.00000 + 0.00000i$$

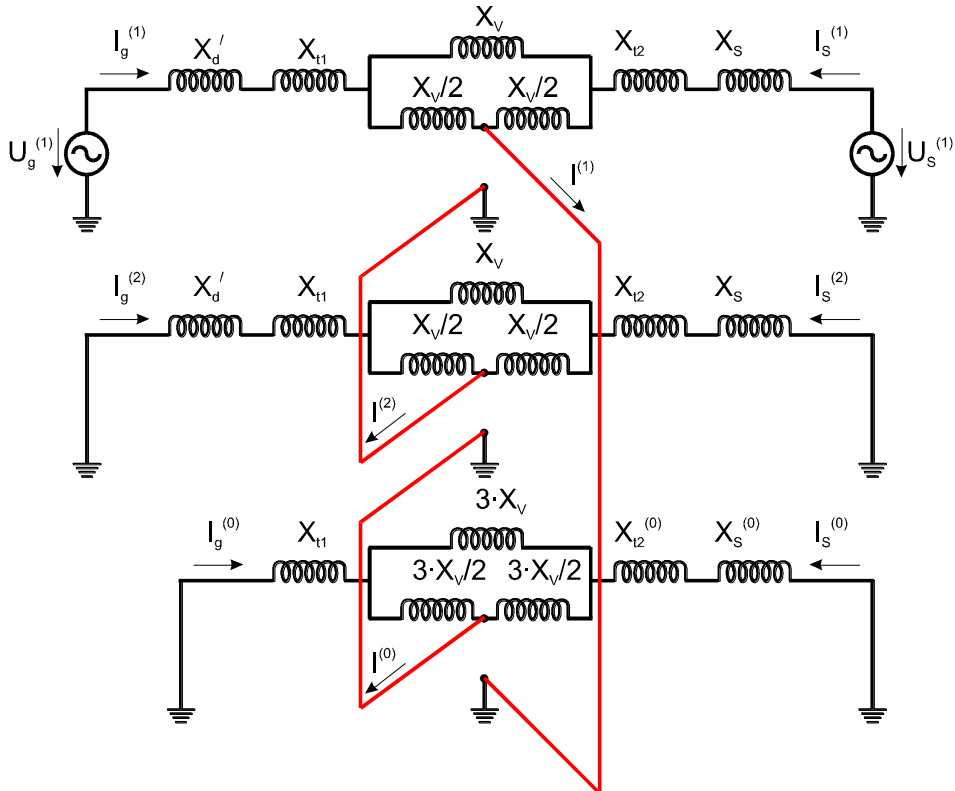
$$X_{dc} = 0.00000 + 296.45000i$$

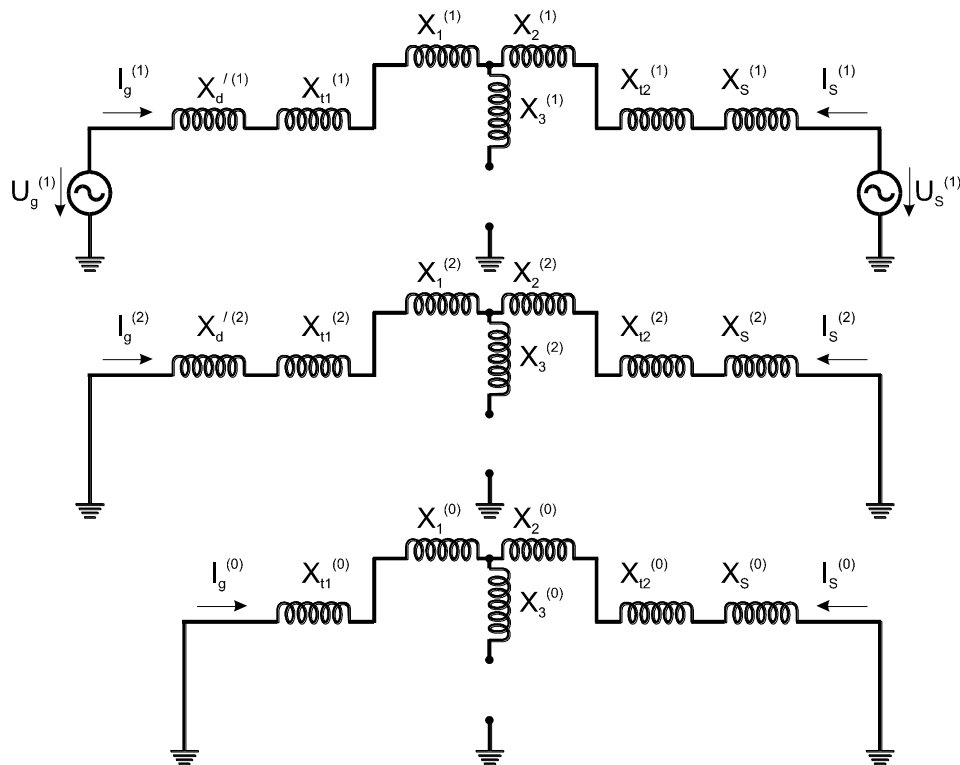
$$X_v = 0 + 6i$$

$$X_{t1} = 0.00000 + 34.57143i$$

$$X_s = 0.00000 + 12.10000i$$

$$X_{t2} = 0.00000 + 24.20000i$$





Přepočít trojúhelník hvězda

$$X_{11} = X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{21} = X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{31} = (X_v/2) * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{12} = X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{22} = X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{32} = (X_v/2) * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{10} = 3 * X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{20} = 3 * X_v * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{30} = 3 * (X_v/2) * (X_v/2) / (X_v + X_v/2 + X_v/2)$$

$$X_{11} = 0.00000 + 1.50000i$$

$$X_{21} = 0.00000 + 1.50000i$$

$$X_{31} = 0.00000 + 0.75000i$$

$$X_{12} = 0.00000 + 1.50000i$$

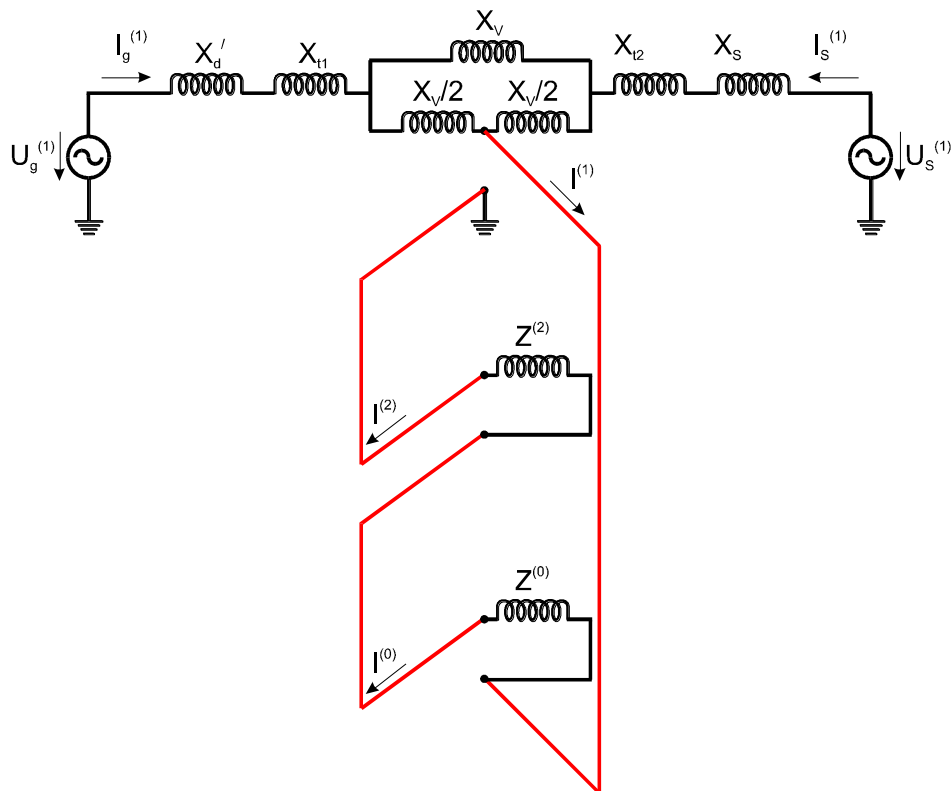
$$X_{22} = 0.00000 + 1.50000i$$

$$X_{32} = 0.00000 + 0.75000i$$

$$X_{10} = 0.00000 + 4.50000i$$

$$X_{20} = 0.00000 + 4.50000i$$

$$X_{30} = 0.00000 + 2.25000i$$



Zpětná, netočivavá a ekvivalentní impedance

$$Z_2 = X_{l2} + (X_{d'c} + X_{t1} + X_{l2}) * (X_{l2} + X_{t2} + X_s) / ((X_{d'c} + X_{t1} + X_{l2}) + (X_{l2} + X_{t2} + X_s))$$

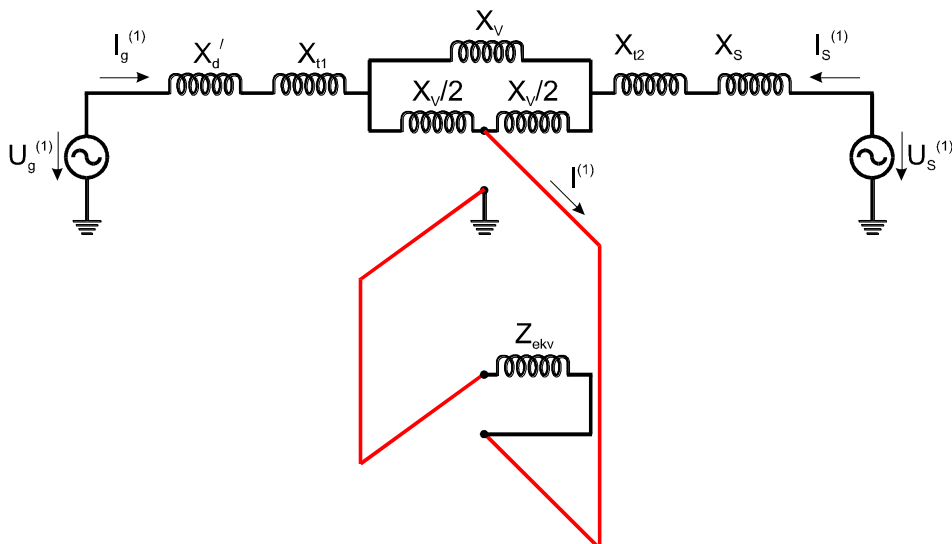
$$Z_0 = X_{l0} + (X_{t1} + X_{l0}) * (X_{l0} + X_{t2} + X_s) / ((X_{t1} + X_{l0}) + (X_{l0} + X_{t2} + X_s))$$

$$Z_{ekv} = Z_2 + Z_0$$

$$Z_2 = 0.00000 + 34.69162i$$

$$Z_0 = 0.00000 + 22.20850i$$

$$Z_{ekv} = 0.00000 + 56.90013i$$



Sousledná impedance

$$Z1 = X31 + (X_{dc} + X_{t1} + X_{11}) * (X_{21} + X_{t2} + X_s) / ((X_{dc} + X_{t1} + X_{11}) + (X_{21} + X_{t2} + X_s)) +$$

Zekv

$$I1 = 1.1 * 110000 / (\sqrt{3} * Z1)$$

$$I2 = I1$$

$$I0 = I1$$

$$Z1 = 0.00000 + 91.59175i$$

$$I1 = 0.00000 - 762.72572i$$

$$I2 = 0.00000 - 762.72572i$$

$$I0 = 0.00000 - 762.72572i$$

Proudy generátoru a sítě

$$I^{(1)}(Z_1 - Z_{ekv} - X_3^{(1)}) = I_g^{(1)}(X_d' + X_{t1} + X_1^{(1)}) = I_S^{(1)}(X_S + X_{t2} + X_2^{(1)}) \Rightarrow$$

$$I_{g1} = I1 * (Z1 - Zekv - X31) / (Xdc + Xt1 + X11)$$

$$I_{s1} = I1 * (Z1 - Zekv - X31) / (Xs + Xt2 + X21)$$

$$I_{g1} = 0.00000 - 77.85407i$$

$$I_{s1} = 0.00000 - 684.87164i$$

$$I^{(2)}(X^{(2)} - X_3^{(2)}) = I_g^{(2)}(X_d' + X_{t1} + X_1^{(2)}) = I_S^{(2)}(X_S + X_{t2} + X_2^{(2)}) \Rightarrow$$

$$I_{g2} = I2 * (X2 - X32) / (Xdc + Xt1 + X12)$$

$$I_{s2} = I2 * (X2 - X32) / (Xs + Xt2 + X22)$$

$$I_{g2} = 0.00000 - 77.85407i$$

$$I_{s2} = 0.00000 - 684.87164i$$

$$I^{(0)}(X^{(0)} - X_3^{(0)}) = I_g^{(0)}(X_{t1} + X_1^{(0)}) = I_S^{(0)}(X_S + X_{t2} + X_2^{(0)}) \Rightarrow$$

$$I_{g0} = I0 * (X0 - X30) / (Xt1 + X10)$$

$$I_{s0} = I0 * (X0 - X30) / (Xs + Xt2 + X20)$$

$$I_{g0} = 0.00000 - 389.61629i$$

$$I_{s0} = 0.00000 - 373.10943i$$

Napětí v místě poruchy

$$U^{(1)} = I^{(1)} Z_{ekv} = c \frac{U_n}{\sqrt{3}} - I^{(1)}(Z^{(1)} - Z_{ekv})$$

$$U^{(2)} = -I^{(2)} Z^{(2)} \quad U^{(0)} = -I^{(0)} Z^{(0)}$$

$$U1 = I1 * Zekv$$

$$U1 = 1.1 * 110000 / \sqrt{3} - I1 * (Z1 - Zekv)$$

$$U2 = -I2 * Z2$$

$$U0 = -I0 * Z0$$

$$U1 = 4.3399e+04$$

$$U2 = -2.6460e+04$$

$$U0 = -1.6939e+04$$

Napětí v místě vlastní spotřeby

$$U_Z^{(1)} = c \frac{U_n}{\sqrt{3}} - I_g^{(1)} (X_{d'} + X_{t1})$$

$$U_Z^{(2)} = -I_g^{(2)} (X_{d'} + X_{t1}) \quad U_Z^{(0)} = -I_g^{(0)} X_{t1}$$

$$U_{z1} = 1.1 * 110000 / \sqrt{3} - I_{g1} * (X_{dc} + X_{t1})$$

$$U_{z2} = -I_{g2} * (X_{dc} + X_{t1})$$

$$U_{z0} = -I_{g0} * X_{t1}$$

$$U_{z1} = 4.4088e+04$$

$$U_{z2} = -2.5771e+04$$

$$U_{z0} = -1.3470e+04$$

Jmenovitá soustava napětí

$$U_N^{(1)} = c \frac{U_n}{\sqrt{3}} \quad U_N^{(2)} = 0 \quad U_N^{(0)} = 0$$

$$U_{n1} = 1.1 * 110000 / \sqrt{3}$$

$$U_{n2} = 0$$

$$U_{n0} = 0$$

Přepočítání na fázové hodnoty

$$U_{por} = F * [U_1 \ U_2 \ U_0]'$$

$$U_{por} =$$

$$1.0e+04 *$$

$$0.00000 + 0.00000i$$

$$-2.54085 - 6.05000i$$

$$-2.54085 + 6.05000i$$

$$[U_{por}] = \begin{bmatrix} U_{por a} \\ U_{por b} \\ U_{por c} \end{bmatrix} = [F] \cdot \begin{bmatrix} U^{(1)} \\ U^{(2)} \\ U^{(0)} \end{bmatrix}$$

$$U_z = F * [U_{z1} \ U_{z2} \ U_{z0}]'$$

$$U_z =$$

$$1.0e+04 *$$

$$0.48471 + 0.00000i$$

$$-2.26279 - 6.05000i$$

$$-2.26279 + 6.05000i$$

$$[U_z] = \begin{bmatrix} U_{z a} \\ U_{z b} \\ U_{z c} \end{bmatrix} = [F] \cdot \begin{bmatrix} U_z^{(1)} \\ U_z^{(2)} \\ U_z^{(0)} \end{bmatrix}$$

$$U_n = F * [U_{n1} \ U_{n2} \ U_{n0}]'$$

$$U_n =$$

$$1.0e+04 *$$

$$6.98594 + 0.00000i$$

$$-3.49297 - 6.05000i$$

$$-3.49297 + 6.05000i$$

$$[U_n] = \begin{bmatrix} U_{n a} \\ U_{n b} \\ U_{n c} \end{bmatrix} = [F] \cdot \begin{bmatrix} U_n^{(1)} \\ U_n^{(2)} \\ U_n^{(0)} \end{bmatrix}$$

$I_{por} = F * [I1 \ I2 \ I0].'$

$I_{por} =$   
 $1.0e+03 *$   
 $0.00000 - 2.28818i$   
 $-0.00000 - 0.00000i$   
 $0.00000 - 0.00000i$

$$[I_{por}] = \begin{bmatrix} I_{por\ a} \\ I_{por\ b} \\ I_{por\ c} \end{bmatrix} = [F] \cdot \begin{bmatrix} I^{(1)} \\ I^{(2)} \\ I^{(0)} \end{bmatrix}$$

$I_g = F * [I_g1 \ I_g2 \ I_g0].'$

$I_g =$   
 $1.0e+02 *$   
 $0.00000 - 5.45324i$   
 $-0.00000 - 3.11762i$   
 $0.00000 - 3.11762i$

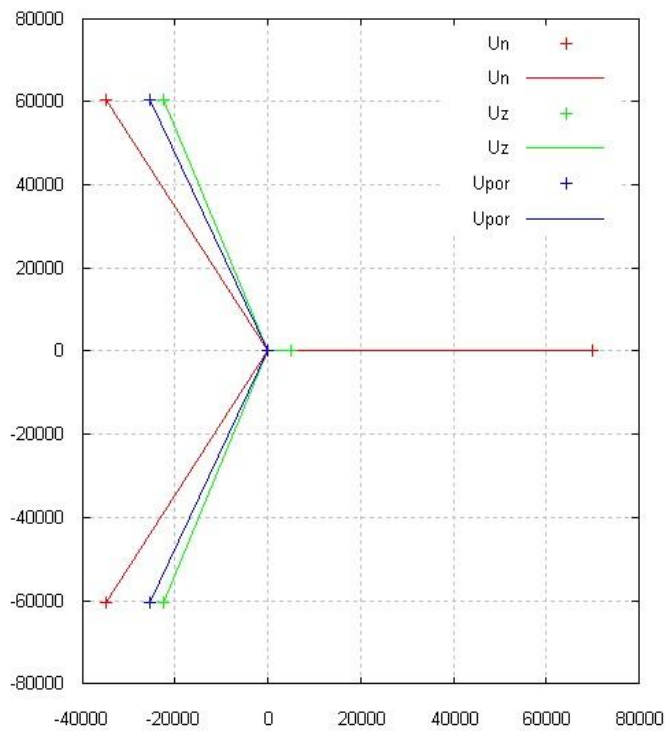
$$[I_g] = \begin{bmatrix} I_{g\ a} \\ I_{g\ b} \\ I_{g\ c} \end{bmatrix} = [F] \cdot \begin{bmatrix} I_g^{(1)} \\ I_g^{(2)} \\ I_g^{(0)} \end{bmatrix}$$

$I_s = F * [I_s1 \ I_s2 \ I_s0].'$

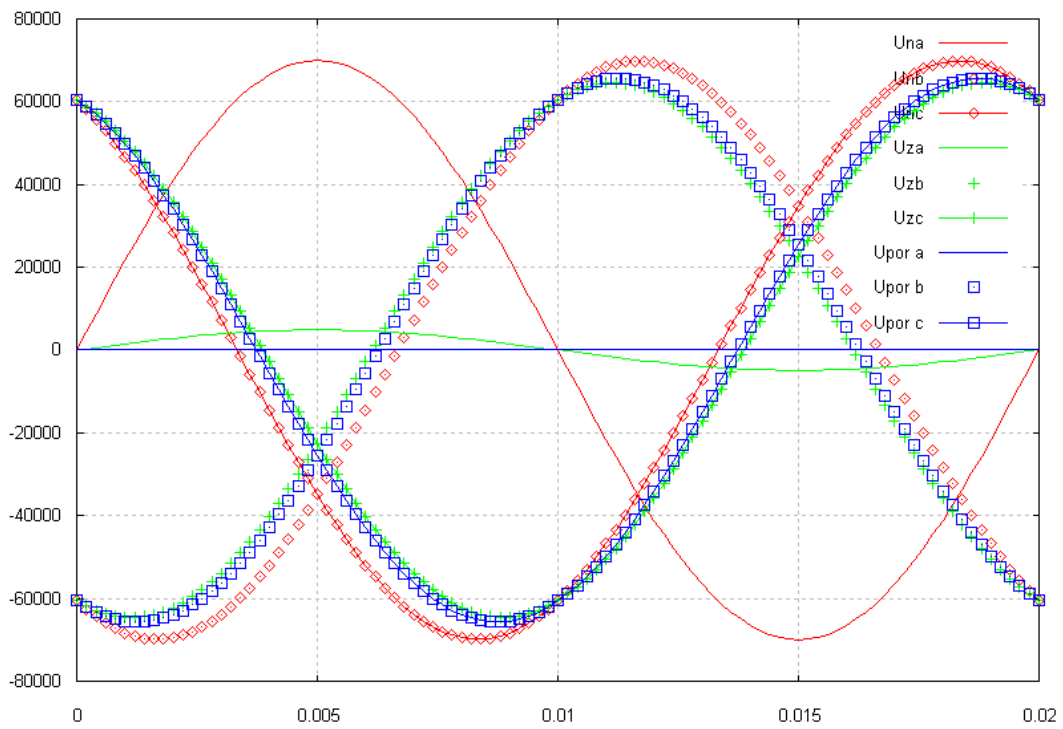
$I_s =$   
 $1.0e+03 *$   
 $0.00000 - 1.74285i$   
 $0.00000 + 0.31176i$   
 $-0.00000 + 0.31176i$

$$[I_s] = \begin{bmatrix} I_{s\ a} \\ I_{s\ b} \\ I_{s\ c} \end{bmatrix} = [F] \cdot \begin{bmatrix} I_s^{(1)} \\ I_s^{(2)} \\ I_s^{(0)} \end{bmatrix}$$

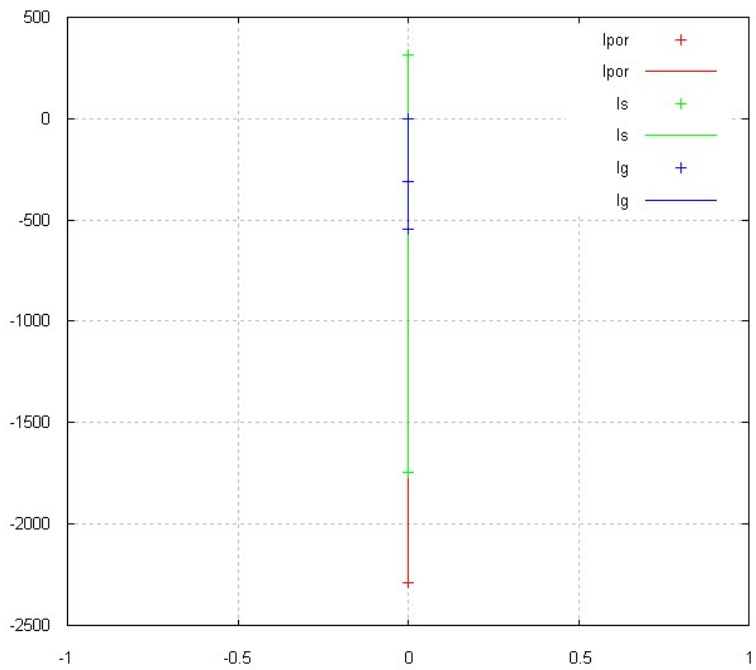
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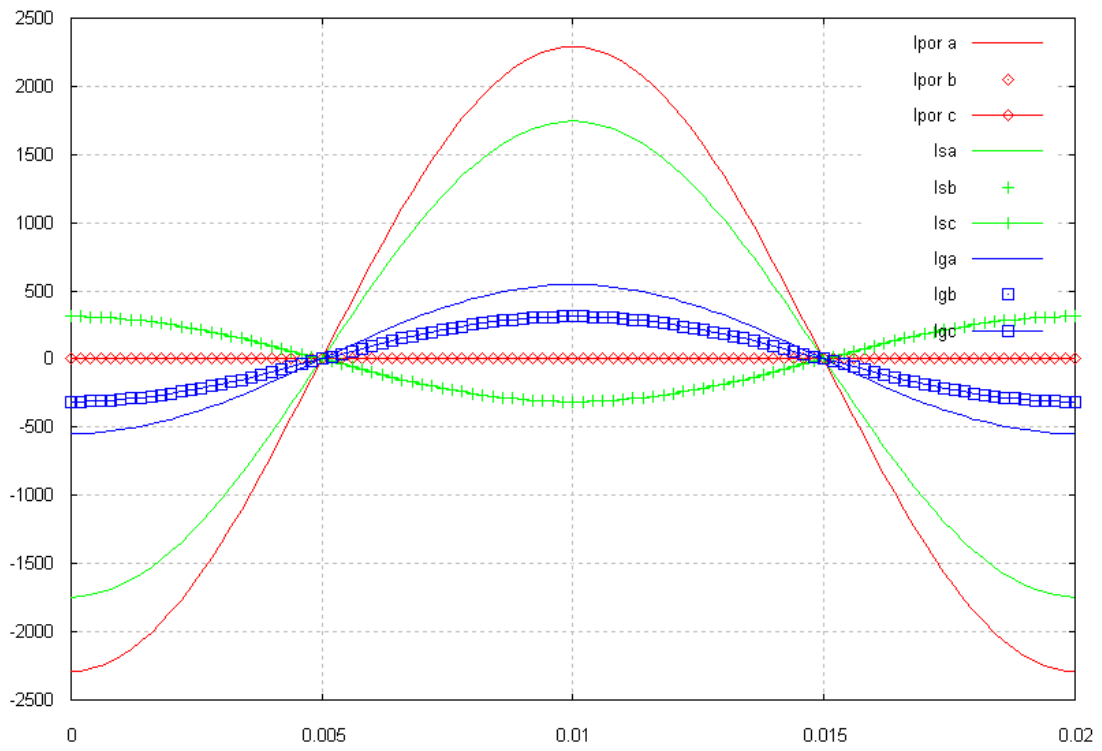
Napeti Un, Uz a Upor



Proudy Ipor, Is a Ig



Proudy lpor, ls a lg





## Řešení pomocí programu PORUCHA

### Vstupní data programu:

Zkusební příklad Cvicení zimní semestr 2005

POCET UZLU

5

PODELNE IMPEDANCE

( zadavani <I-ty uzel> <J-ty uzel> <hodnota impedance mezi uzly I a J> )

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Uzel I	Uzel J	Impedance Zij
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Sousledna soustava

1	2	331.02
2	3	6
3	4	36.3
2	5	3
3	5	3
0	0	0

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Zpetna soustava ( pouze zmeny oproti sousledne soustave )

0	0	0
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Netociva soustava ( pouze zmeny oproti sousledne soustave )

1	2	34.57
2	3	18
2	5	9
3	5	9
0	0	0

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Pricne IMPEDANCE

( zadavani <I-ty uzel> <hodnota impedance proti zemi v uzlu I> )

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Uzel I	Impedance Zi
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Sousledna soustava

0	0
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Zpetna soustava ( pouze zmeny oproti sousledne soustave )

0	0
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Netociva soustava ( pouze zmeny oproti sousledne soustave )

0	0
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ZDROJE NAPETI

1	69859
4	69859
0	0

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DRUH PORUCHY (1-jednofazovy, 2-dvoufazovy, 3-dvoufazovy zemni, 4-trifazovaá)

1

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CISLO UZLU PORUCHY

5

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IMPEDANCE PORUCHY

Zn

0

Za

0

Zb

0

### Výstupní data programu:

Výstup programu PORUCHA (c) 1991, 1994 Foot-Software

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Byla řešena porucha : Jednofázový zkrat

Náhradní impedance zpětné a netočivé složkové soustavy = 56.903690

PORUCHOVÉ PROUDY ( v místě poruchy [ 5 ] )

	ProudS	ProudZ	ProudN			
	-762.696	-762.696	-762.696			
	ProudA-R	ProudA-I	ProudB-R	ProudB-I	ProudC-R	ProudC-I
	-2288.088	0.000	-0.000	-0.000	-0.000	0.000
	ProudA-A	ProudB-A	ProudC-A			
	2288.088	0.000	0.000			

NAPĚTÍ V UZLECH SÍTĚ

Uzel	US	UZ	UN
[ 1 ]	69859.356	-0.234	-1.169
[ 2 ]	44089.009	-25772.208	-13469.896
[ 3 ]	44999.499	-24861.733	-13544.231
[ 4 ]	69859.356	-2.055	-1.119
[ 5 ]	43400.210	-26461.015	-16939.195

Uzel	UA-R	UA-I	UB-R	UB-I	UC-R	UC-I
[ 1 ]	69857.954	0.000	-34930.730	-60500.179	-34930.730	60500.179
[ 2 ]	4846.904	0.000	-22628.297	-60501.589	-22628.297	60501.589
[ 3 ]	6593.534	0.000	-23613.114	-60501.602	-23613.114	60501.602
[ 4 ]	69856.182	0.000	-34929.770	-60501.756	-34929.770	60501.756
[ 5 ]	0.000	0.000	-25408.793	-60501.595	-25408.793	60501.595

Uzel	UA-A	UB-A	UC-A
[ 1 ]	69857.954	69860.057	69860.057
[ 2 ]	4846.904	64594.753	64594.753
[ 3 ]	6593.534	64946.309	64946.309
[ 4 ]	69856.182	69860.943	69860.943
[ 5 ]	0.000	65620.498	65620.498

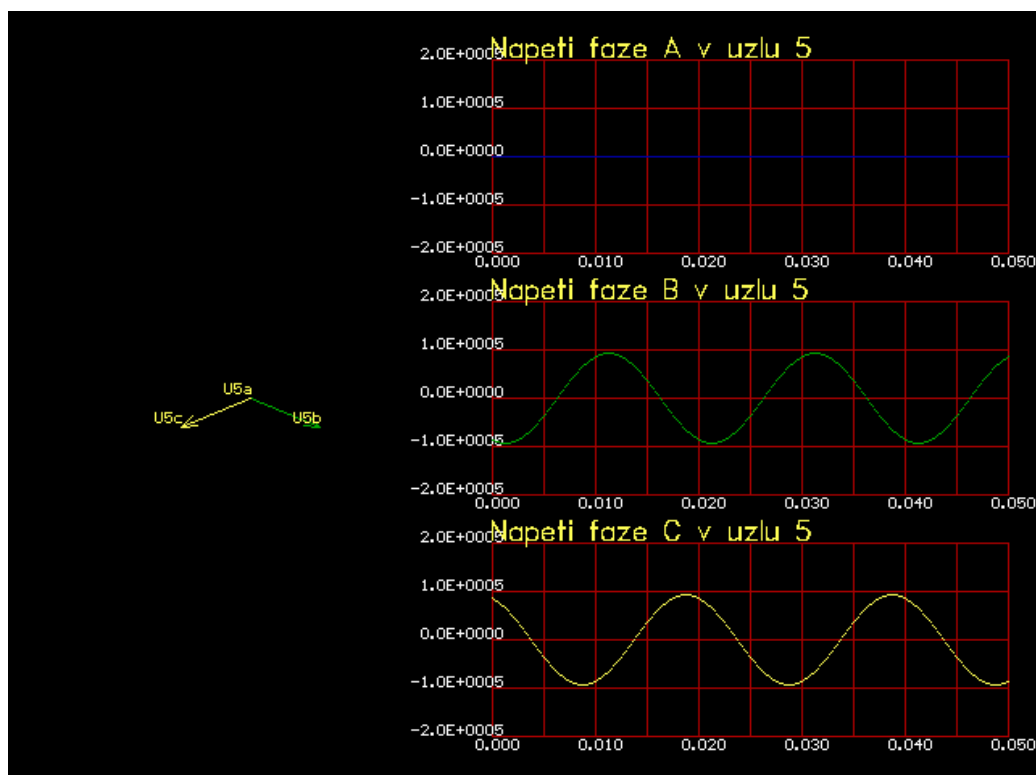
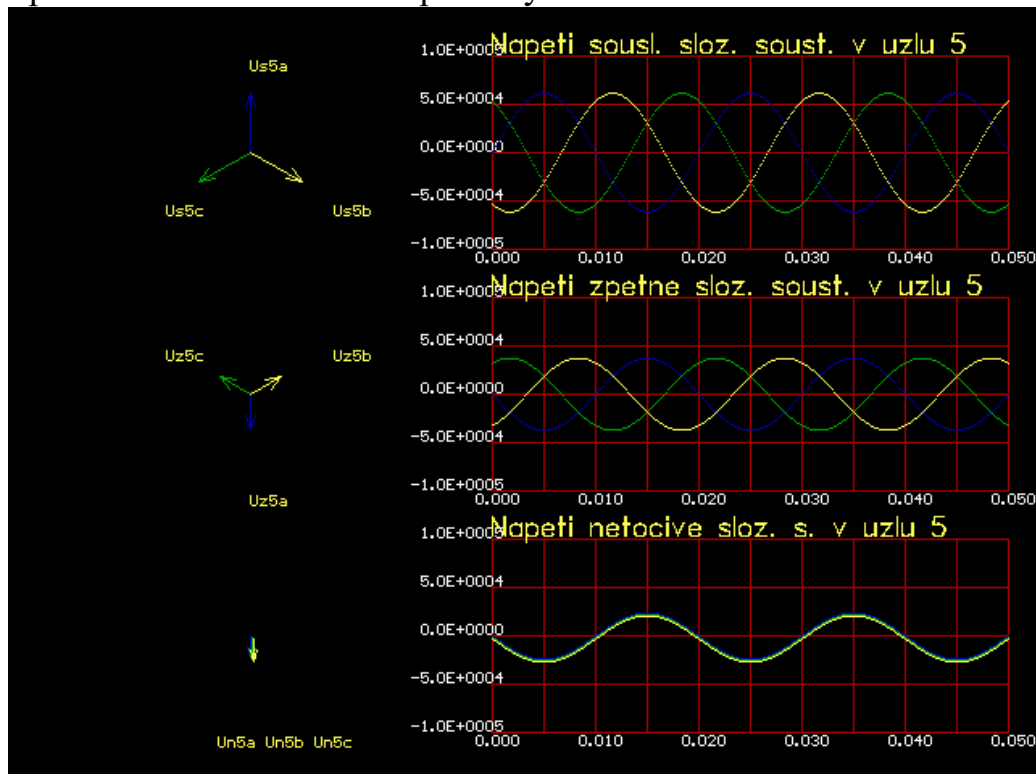
PROUDY MEZI UZLY SÍTĚ

Od u. K u.	ProudS	ProudZ	ProudN			
[ 1, 2 ]	77.851	77.856	389.607			
[ 2, 3 ]	-151.748	-151.746	4.130			
[ 2, 5 ]	229.600	229.602	385.478			
[ 3, 4 ]	-684.845	-684.840	-373.088			
[ 3, 5 ]	533.096	533.094	377.218			
Od u. K u.	ProudA-R	ProudA-I	ProudB-R	ProudB-I	ProudC-R	ProudC-I
[ 1, 2 ]	545.315	0.000	311.754	0.004	311.754	-0.004
[ 2, 3 ]	-299.364	0.000	155.877	0.002	155.877	-0.002
[ 2, 5 ]	844.679	0.000	155.877	0.002	155.877	-0.002
[ 3, 4 ]	-1742.773	0.000	311.754	0.004	311.754	-0.004
[ 3, 5 ]	1443.408	0.000	-155.877	-0.002	-155.877	0.002

Od u. K u.	ProudA-A	ProudB-A	ProudC-A

[ 1, 2 ]	545.315	311.754	311.754
[ 2, 3 ]	299.364	155.877	155.877
[ 2, 5 ]	844.679	155.877	155.877
[ 3, 4 ]	1742.773	311.754	311.754
[ 3, 5 ]	1443.408	155.877	155.877

Napětí proti zemi v místě vzniku poruchy:



Proudy dodávané do poruchy ze strany generátoru:

