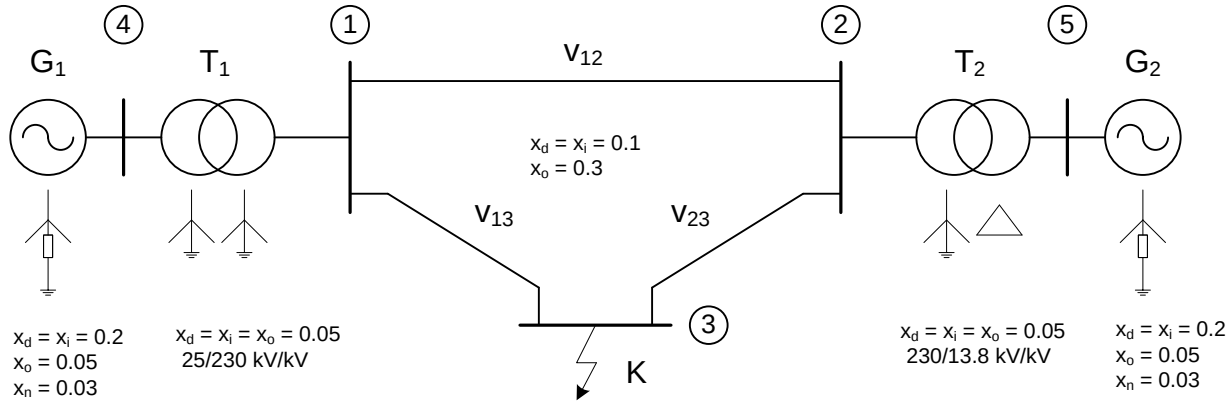
Zadatak 1.

Za elektroenergetski sistem čija je jednopolna šema prikazana na slici ispod:

a) Odrediti bazne struje i impedanse elemenata ako je $S_B = 100\ MVA$, a naponi jednaki nominalnim vrijednostima napona pojedinih naponskih nivoa.
b) Nacrtati ekvivalentne šeme direktnog, inverznog i nultog redosljeda.
c) Proračunati fazne struje i napone u slučaju jednopolnog, dvopolnog, dvopolnog sa zemljom i tropolnog kratkog spoja u čvoru 3.



Rješenje:

a) Bazne vrijednosti napona, struja i impedansi su:

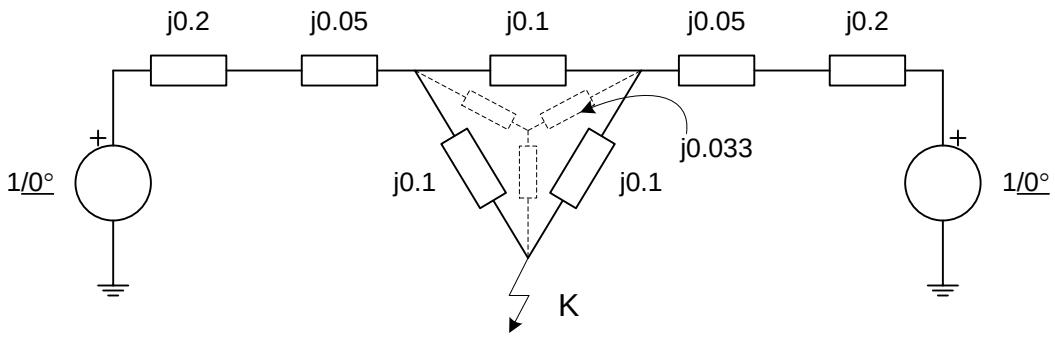
$$U_{B1} = 25\ kV \qquad Z_{B1} = \frac{U_{B1}^2}{S_B} = 6.25\ \Omega \qquad I_{B1} = \frac{S_B}{\sqrt{3}U_{B1}} = 2310\ A$$

$$U_{B2} = 230\ kV \qquad Z_{B2} = \frac{U_{B2}^2}{S_B} = 529\ \Omega \qquad I_{B2} = \frac{S_B}{\sqrt{3}U_{B2}} = 251\ A$$

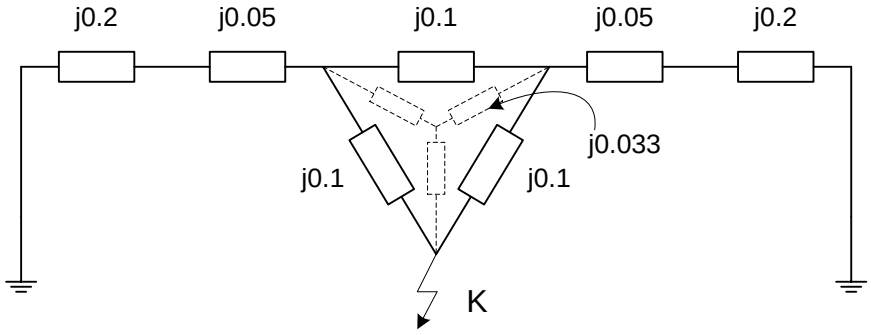
$$U_{B3} = 13.8\ kV \qquad Z_{B3} = \frac{U_{B3}^2}{S_B} = 1.905\ \Omega \qquad I_{B3G} = \frac{S_B}{\sqrt{3}U_{B3}} = 4184\ A$$

$$I_{B3T} = \frac{S_B}{U_{B3}} = 7246\ A$$

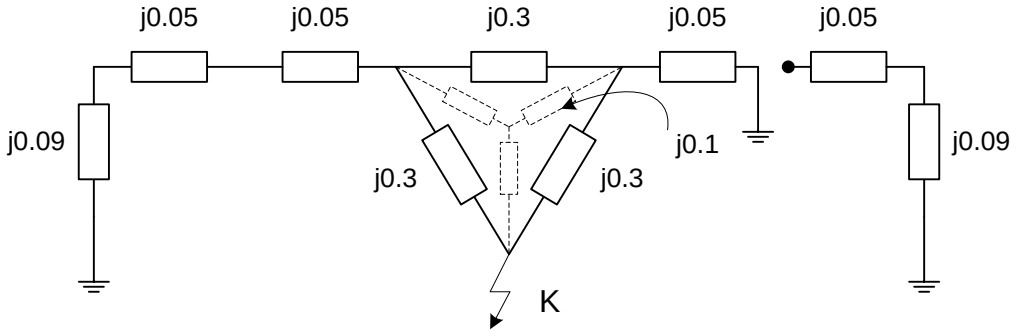
b) Zamjenska šema direktnog redosljeda je:



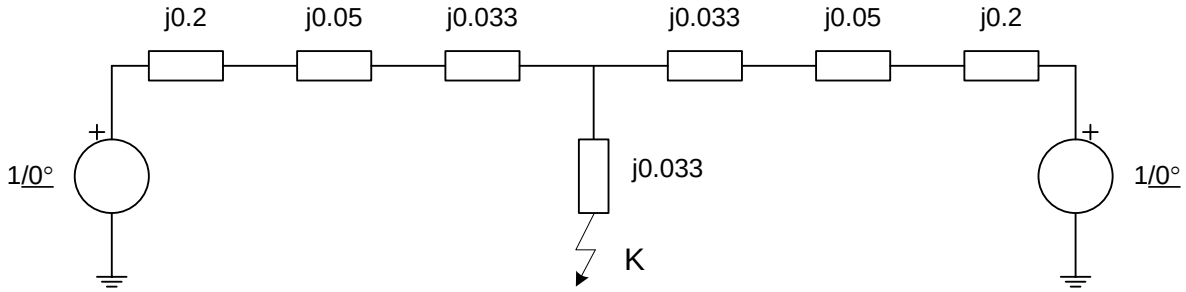
Zamjenska šema inverznog redosljeda je:



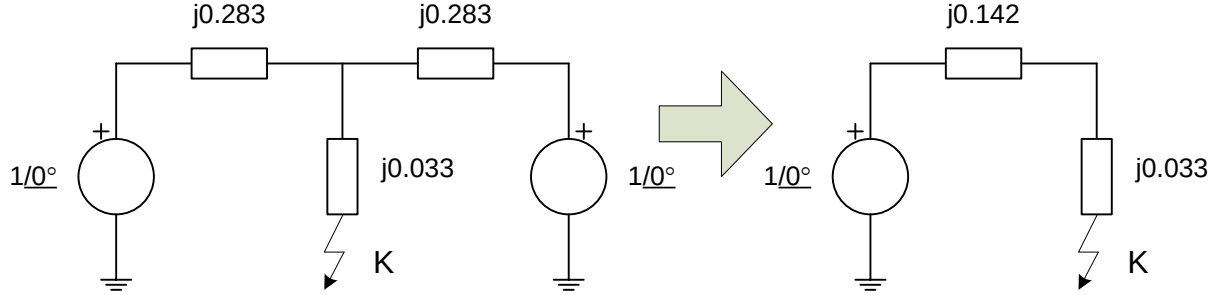
Zamjenska šema nultog redosljeda je:



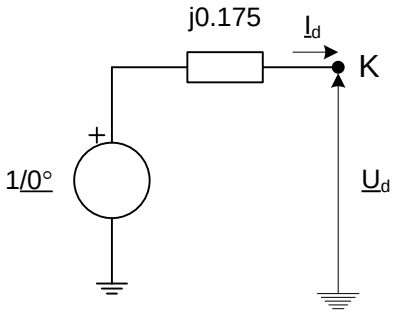
Zamjenske šeme je neophodno svesti na što jednostavniji oblik vodeći računa da se očuva mjesto kvara. Prema tome, kako je mjesto kvara označeno sa K, onda je lako uočiti trougao impedansi u šemama sva tri redosljeda koje je moguće transformisati u zvijezdu. Tada je šema direktnog redosljeda:



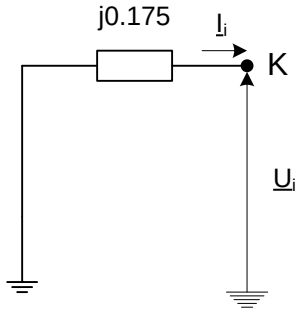
Daljim ekvivalentiranjem dobija se:



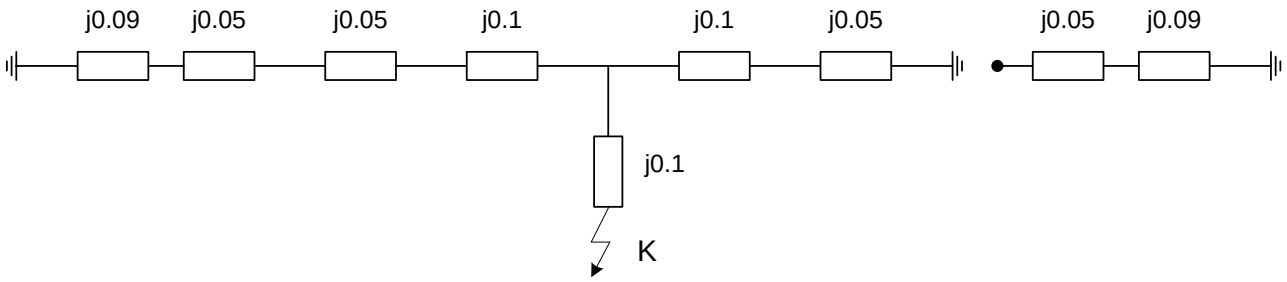
Na kraju, dobija se osnovna šema direktnog redosljeda sa označenim smjerom struje i napona:



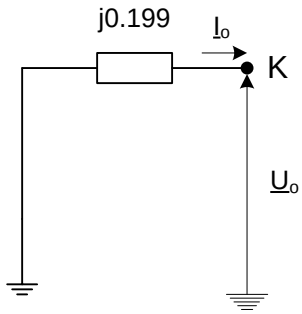
Analognim postupkom, za inverzni redosljed se dobija:



dok je zamjenska šema nultog redosljeda:

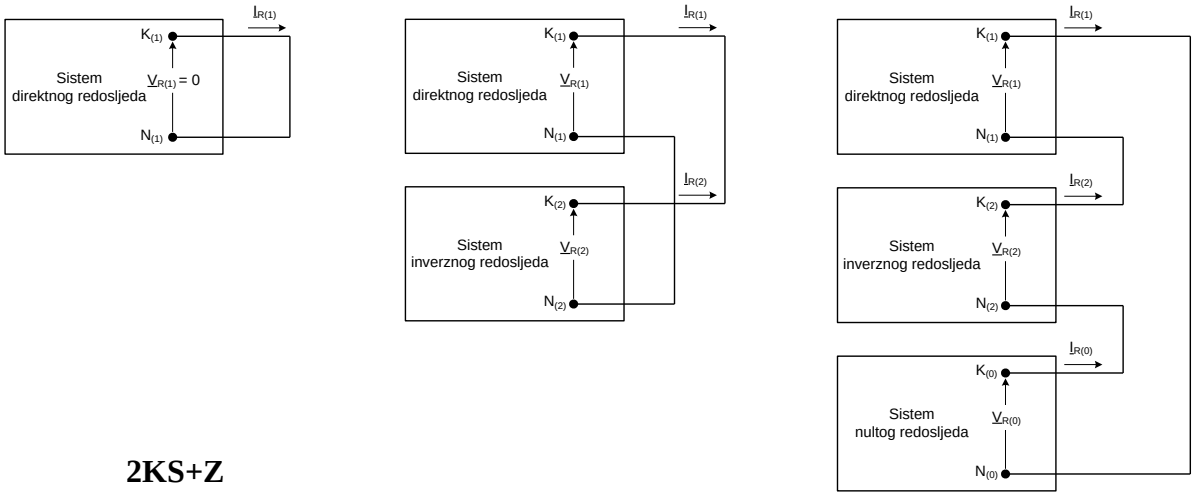


čijim se ekvivalentiranjem dolazi do šeme:

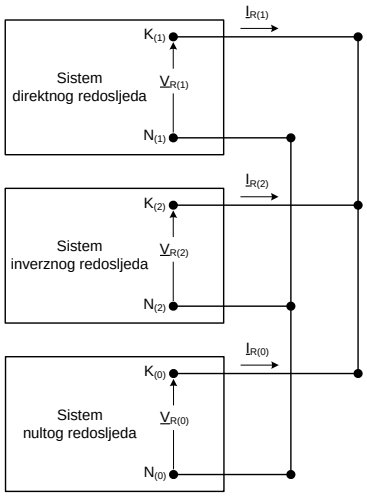


c) Zavisno od tipa kvara, koristi se jedno od ekvivalentnih kola iz literature (slika dolje) i vrši se proračun traženih veličina koje određuju kasnija podešavanja zaštite.

3KS **2KS** **1KS**



2KS+Z



1KS – jednopolni kratki spoj (zemljospoj)

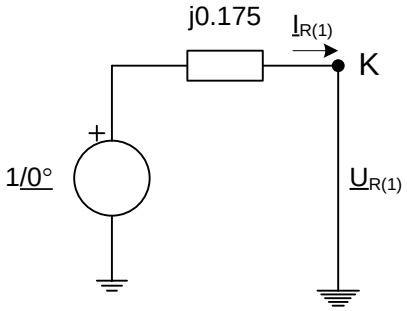
2KS – dvopolni kratki spoj

3KS – tropolni kratki spoj

2KS+Z – dvopolni kratki spoj sa zemljom

3KS:

Posmatra se samo šema direktnog redosljeda:



Struje direktnog, inverznog i nultog redosljeda:

$$\underline{I}_{R(1)} = \frac{1}{j0.175} = -j5.71$$

$$\underline{I}_{R(2)} = \underline{I}_{R(0)} = 0$$

dok su naponi:

$$\underline{U}_{R(1)} = \underline{U}_{R(2)} = \underline{U}_{R(0)} = 0$$

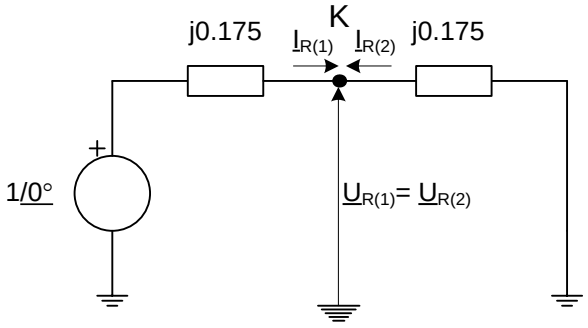
Fazne struje su tada:

$$\underline{I}_R = \underline{I}_{R(1)} + \underline{I}_{R(2)} + \underline{I}_{R(0)} = -j5.71 = 5.71\lfloor -90°$$
$$\underline{I}_S = \underline{I}_{S(1)} + \underline{I}_{S(2)} + \underline{I}_{S(0)} = \underline{a}^2\underline{I}_{R(1)} + \underline{a}\,\underline{I}_{R(2)} + \underline{I}_{R(0)} = 5.71\lfloor 150°$$
$$\underline{I}_T = \underline{I}_{T(1)} + \underline{I}_{T(2)} + \underline{I}_{T(0)} = \underline{a}\,\underline{I}_{R(1)} + \underline{a}^2\underline{I}_{R(2)} + \underline{I}_{R(0)} = 5.71\lfloor 30°$$

a fazni naponi:

$$\underline{U}_R = \underline{U}_S = \underline{U}_T = 0$$

2KS između faza S i T:



Struje direktnog, inverznog i nultog redosljeda su:

$$\underline{I}_{R(1)} = -\underline{I}_{R(2)} = \frac{1}{j0.175 + j0.175} = -j2.86$$
$$\underline{I}_{R(0)} = 0$$

dok su naponi:

$$\underline{U}_{R(1)} = \underline{U}_{R(2)} = 1 - j0.175(-j2.86) = 0.5$$
$$\underline{U}_{R(0)} = 0$$

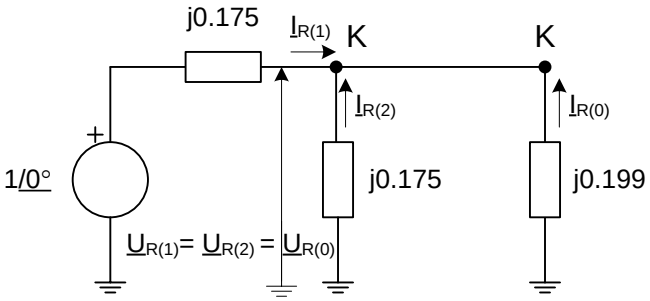
Fazne struje su tada:

$$\underline{I}_R = \underline{I}_{R(1)} + \underline{I}_{R(2)} + \underline{I}_{R(0)} = 0$$
$$\underline{I}_S = \underline{a}^2\underline{I}_{R(1)} + \underline{a}\,\underline{I}_{R(2)} + \underline{I}_{R(0)} = -4.95$$
$$\underline{I}_T = \underline{a}\,\underline{I}_{R(1)} + \underline{a}^2\underline{I}_{R(2)} + \underline{I}_{R(0)} = 4.95$$

a fazni naponi:

$$\underline{U}_R = \underline{U}_{R(1)} + \underline{U}_{R(2)} + \underline{U}_{R(0)} = 1$$
$$\underline{U}_S = \underline{a}^2\underline{U}_{R(1)} + \underline{a}\,\underline{U}_{R(2)} + \underline{U}_{R(0)} = -0.5$$
$$\underline{U}_T = \underline{a}\,\underline{U}_{R(1)} + \underline{a}^2\underline{U}_{R(2)} + \underline{U}_{R(0)} = -0.5$$

2KS+Z između faza S i T:



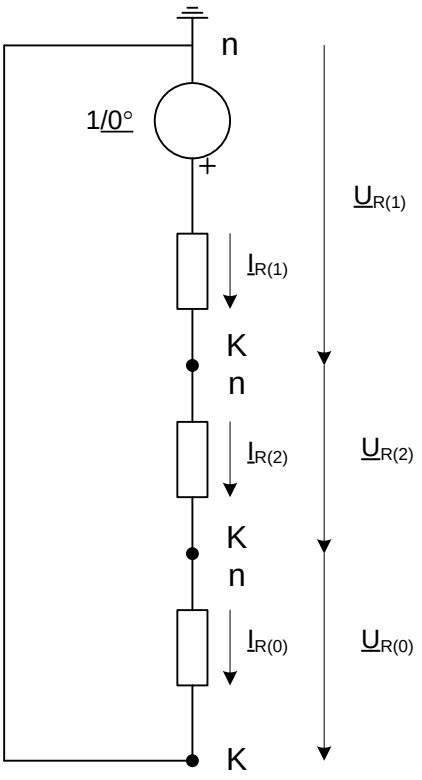
$$\underline{I}_{R(1)} = -j3.73$$
$$\underline{I}_{R(2)} = j1.99$$
$$\underline{I}_{R(0)} = j1.75$$

$$\underline{I}_R = \underline{I}_{R(1)} + \underline{I}_{R(2)} + \underline{I}_{R(0)} = 0$$
$$\underline{I}_S = \underline{a}^2\underline{I}_{R(1)} + \underline{a}\,\underline{I}_{R(2)} + \underline{I}_{R(0)} = 5.6\lfloor 152.1°$$
$$\underline{I}_T = \underline{a}\,\underline{I}_{R(1)} + \underline{a}^2\underline{I}_{R(2)} + \underline{I}_{R(0)} = 5.6\lfloor 27.9°$$

$$\underline{U}_R = \underline{U}_{R(2)} = \underline{U}_{R(0)} = 0.348$$

$$\underline{U}_R = \underline{U}_{R(1)} + \underline{U}_{R(2)} + \underline{U}_{R(0)} = 1.044$$
$$\underline{U}_S = \underline{a}^2\underline{U}_{R(1)} + \underline{a}\,\underline{U}_{R(2)} + \underline{U}_{R(0)} = 0$$
$$\underline{U}_T = \underline{a}\,\underline{U}_{R(1)} + \underline{a}^2\underline{U}_{R(2)} + \underline{U}_{R(0)} = 0$$

1KS faze R:



$$\underline{I}_R = \underline{I}_{R(2)} = \underline{I}_{R(0)} = -j1.82$$

$$\underline{I}_R = \underline{I}_{R(1)} + \underline{I}_{R(2)} + \underline{I}_{R(0)} = -j5.46$$
$$\underline{I}_S = \underline{a}^2\underline{I}_{R(1)} + \underline{a}\,\underline{I}_{R(2)} + \underline{I}_{R(0)} = 0$$
$$\underline{I}_T = \underline{a}\,\underline{I}_{R(1)} + \underline{a}^2\underline{I}_{R(2)} + \underline{I}_{R(0)} = 0$$

$$\underline{U}_{R(1)} = 1 - j0.175(-j1.82) = 0.681$$
$$\underline{U}_{R(2)} = -j0.175(-j1.82) = -0.319$$
$$\underline{U}_{R(0)} = -j0.199(-j1.82) = -0.362$$

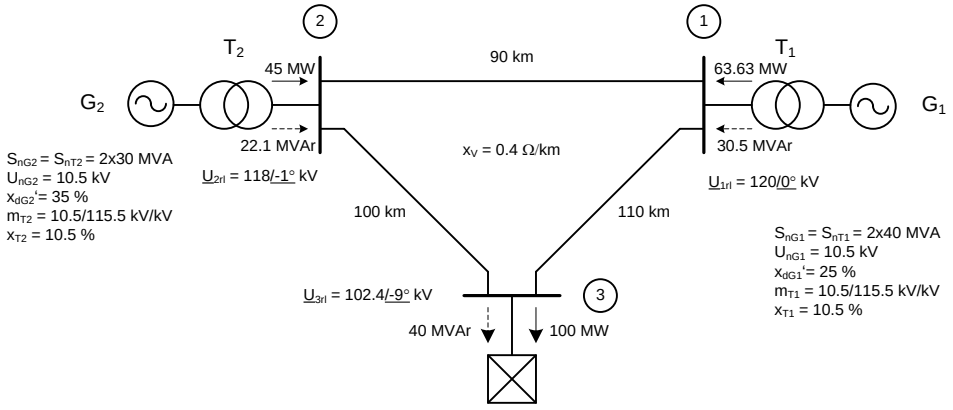
$$\underline{U}_R = \underline{U}_{R(1)} + \underline{U}_{R(2)} + \underline{U}_{R(0)} = 0$$
$$\underline{U}_S = \underline{a}^2\underline{U}_{R(1)} + \underline{a}\,\underline{U}_{R(2)} + \underline{U}_{R(0)} = 1.022\lfloor 238°$$
$$\underline{U}_T = \underline{a}\,\underline{U}_{R(1)} + \underline{a}^2\underline{U}_{R(2)} + \underline{U}_{R(0)} = 1.022\lfloor -58°$$

Na kraju, množeći sve proračunate vrijednosti sa odgovarajućim baznim veličinama, dobijaju se apsolutne vrijednosti faznih struja i napona na mjestu kvara.

Zadatak 2.

Za elektroenergetski sistem čija je jednopolna šema prikazana na slici ispod:

a) Ako su ulazni podaci zadati iz riješenog problema tokova snaga, odrediti metodom stvarnih elektromotornih sila struju kvara na sabirnicama 1, na kojima je došlo do trofaznog kratkog spoja.
b) U slučaju da podaci pod a) koji se tiču napona i raspodjela snaga nisu poznati, odrediti istim metodom struju kvara u slučaju 3KS na istom mjestu.



$$X_{G1+T1} = \frac{25}{100}\frac{(10.5)^2}{80}\frac{(115.5)^2}{(10.5)^2} + \frac{10.5}{100}\frac{(115.5)^2}{80} = 59.1974\ \Omega$$

$$X_{G2+T2} = \frac{35}{100}\frac{(10.5)^2}{60}\frac{(115.5)^2}{(10.5)^2} + \frac{10.5}{100}\frac{(115.5)^2}{60} = 101.1635\ \Omega$$

$$X_{V12} = 0.4 \cdot 90 = 36\ \Omega$$

$$X_{V23} = 0.4 \cdot 100 = 40\ \Omega$$

$$X_{V13} = 0.4 \cdot 110 = 44\ \Omega$$

$$R_P = \frac{{U_P}^2}{S_P} cos\,\varphi = \frac{102.4^2}{\sqrt{100^2+40^2}}\frac{100}{\sqrt{100^2+40^2}} = 90.3945\ \Omega$$

$$X_P = \frac{{U_P}^2}{S_P} sin\,\varphi = \frac{102.4^2}{\sqrt{100^2+40^2}}\frac{40}{\sqrt{100^2+40^2}} = 36.1578\ \Omega$$

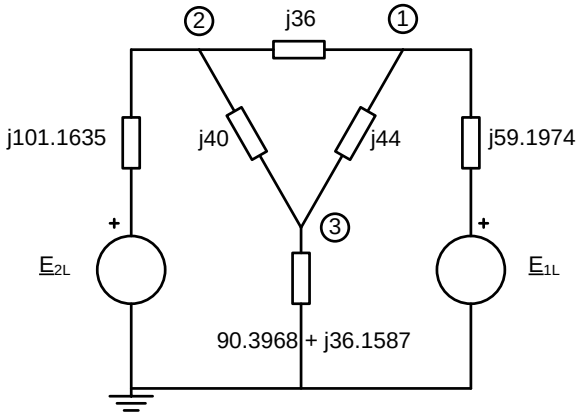
a) Iz radnih uslova mogu se odrediti vrijednosti linijskih elektromotornih sila generatora:

$$\underline{E_{1L}} = 120 + \frac{30.5 \cdot 59.1974}{120} + j\frac{63.63 \cdot 59.1974}{120} = 135.05 + j31.39 = 138.65\lfloor 13.1°\ kV$$

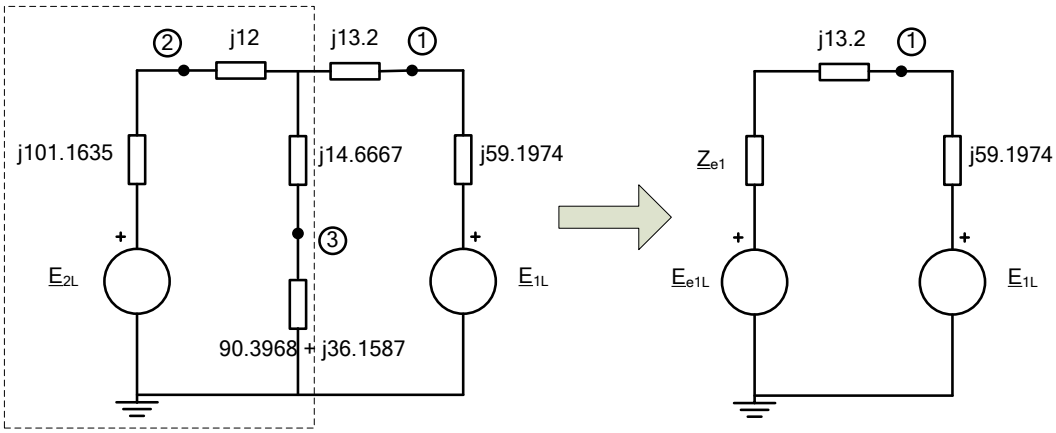
$$\underline{E_{2L}} = 118 + \frac{22.1 \cdot 101.1635}{118} + j\frac{45 \cdot 101.1635}{118} = 142.28\lfloor 15.7°\ kV$$

Dobijeni fazni stav je potrebno korigovati za vrijednost ugla za koji napon $\underline{U_{2r}}$ zaostaje za faznom osom (a to je ugao od 1°), pa je:

$$\underline{E_{2L}} = 142.28\lfloor 14.7°\ kV$$



Vodeći računa da se kvar desio u čvoru 1, može se izvršiti ekvivalentiranje posmatrane šeme tako što se transfiguriše trougao impedansi u zvijezdu.

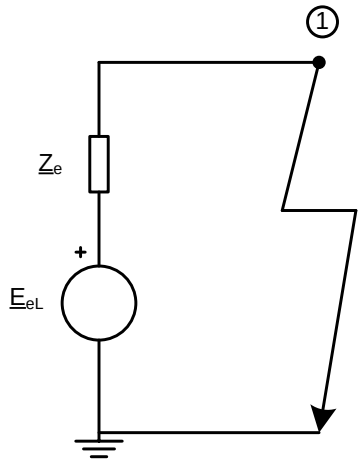


Sa slike gore, može se uočiti dio šeme koji je uokviren gdje je moguće izvršiti transfiguraciju na osnovu pravila o paralelnim granama sa generatorima i dobiti ekvivalentni generator sa ems $\underline{E}_{e1L}$ i impedansom $\underline{Z}_{e1}$.

$$\underline{Z}_{e1} = \frac{(j101.1635 + j12)(j14.6667 + 90.3968 + j36.1587)}{(j101.1635 + j12 + j14.6667 + 90.3968 + j36.1587)} = 62.6729\lfloor 58.2° \Omega$$

$$\underline{E}_{e1L} = \frac{(j14.6667 + 90.3968 + j36.1587)}{(j101.1635 + j12 + j14.6667 + 90.3968 + j36.1587)} \underline{E}_{2L} = 78.797\lfloor -17.074° \, kV$$

Koristeći isti princip, može se izvršiti dalje ekvivalentiranje šeme kada se dobija šema:



gdje su:

$$\underline{Z}_e = \frac{(\underline{Z}_{e1} + j13.2) \cdot j59.1974}{(\underline{Z}_{e1} + j13.2 + j59.1974)} = 33.814\lfloor 78.323° \ \Omega$$

$$\underline{E}_{eL} = \frac{\underline{E}_{e1L} \cdot j59.1974 + \underline{E}_{1L}(\underline{Z}_{e1} + j13.2)}{(j59.1974 + \underline{Z}_{e1} + j13.2)} = 115.037\lfloor 0.245° \ kV$$

Struja kvara je tada:

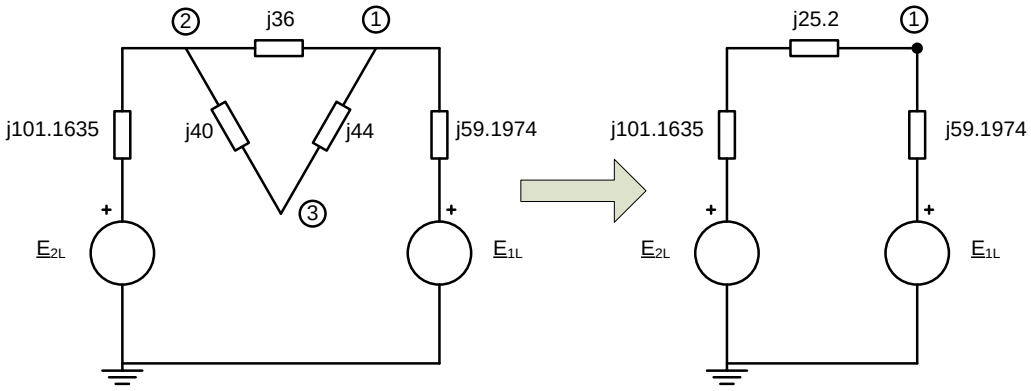
$$\underline{I}_K = \frac{\underline{E}_{eL}}{\sqrt{3}\underline{Z}_e} = \frac{115.037\lfloor 0.245°}{\sqrt{3} \cdot 33.814\lfloor 78.323°} = (0.405 - j1.922) \ kA$$

b) Sada je potrebno riješiti isti problem, ali uzimajući u obzir da nisu poznate veličine dobijene iz proračuna tokova snaga. Kako nisu raspoloživi nikakvi podaci koji se tiču režima rada posmatranog EES-a, pretpostavlja se da je sistem u praznom hodu i onda se sprovodi proračun.

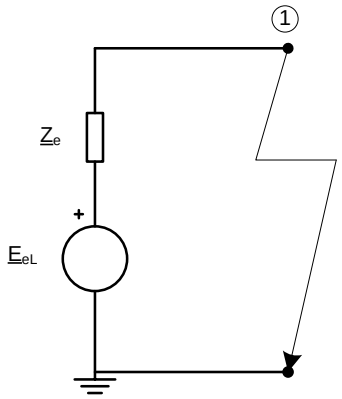
Kako je sistem u praznom hodu to važi:

$$\underline{E_{1L}} = 115.5\lfloor 0° \ kV$$
$$\underline{E_{2L}} = 115.5\lfloor 0° \ kV$$

Takođe je potrebno napomenuti da u slučaju praznog hoda, potrošače ne uzimamo u obzir jer ne predstavljaju nikakvo opterećenje. Uzimajući naprijed rečeno u obzir ekvivalentna šema problema je:



Daljim ekvivalentiranjem paralelnih izvora dolazi se do zamjenske šeme:



gdje je:

$$\underline{Z}_e = \frac{(j101.1635 + j25.2)(j59.1974)}{(j101.1635 + j25.2 + j59.1974)} = j40.312\ \Omega$$

$$\underline{E}_{eL} = \frac{j59.1974 \cdot \underline{E}_{2L} + (j101.1635 + j25.2) \cdot \underline{E}_{1L}}{(j59.1974 + j101.1635 + j25.2)} = 115\ \lfloor 0°\ kV$$

Sada je struja kvara:

$$\underline{I}_K = \frac{\underline{E}_{eL}}{\sqrt{3}\underline{Z}_e} = -j1.654\ kA$$

Upoređivanjem rezultata uočava se da odstupanje nije veliko (oko 19% manja struja) što ukazuje na to da je moguće sprovesti dovoljno kvalitetne proračune na sistemu u praznom hodu, tj. ne poznavajući režimske parametre.