Tutorial 9: Fault Analysis

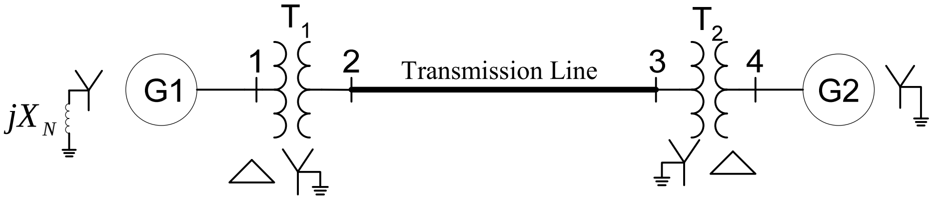
9.1 The one-line diagram for a power system is given in the following figure. The parameters of the generators and transformers are given as:

G1 and G2: 100MVA, 20kV, $X_1 = X_2 = 20\%, X_0 = 6\%$ and X_N=5%.

Transformers T_1 and T_2: 100MVA, $20\Delta / 345\text{Y}$ kV and X=10%

Line (on bases 100MVA, 345kV): $X_1 = X_2 = 10\%,\ X_0 = 25\%$.

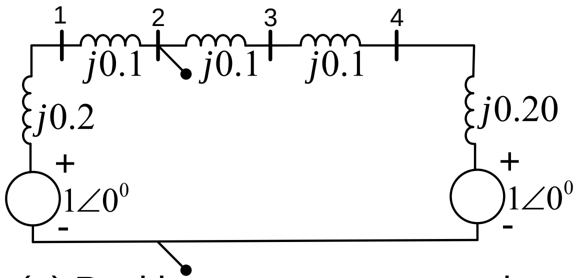
A bolted single line-to-ground fault occurs on phase *a* at bus 2. $V_f = 1\angle 0^0$.



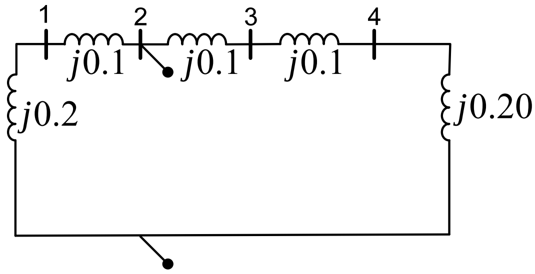
a) Draw the sequence networks.
b) Calculate the per unit sequence and phase currents at the fault point;
c) Determine the per-unit phase currents flowing from Y side of T_1 to fault point;
d) Determine the per-unit current flowing out of phase b of G1.

Solution:

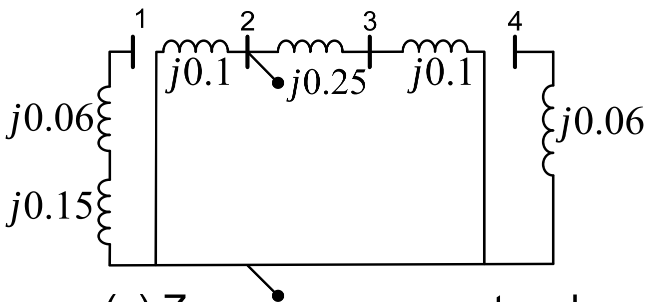
a) Sequence networks: $Z_{th}^{(1)} = Z_{th}^{(2)} = j0.3 // j0.4 = j0.1714$, $Z_{th}^{(0)} = j0.35 // j0.1 = j0.0778$



(a) Positive-sequence network

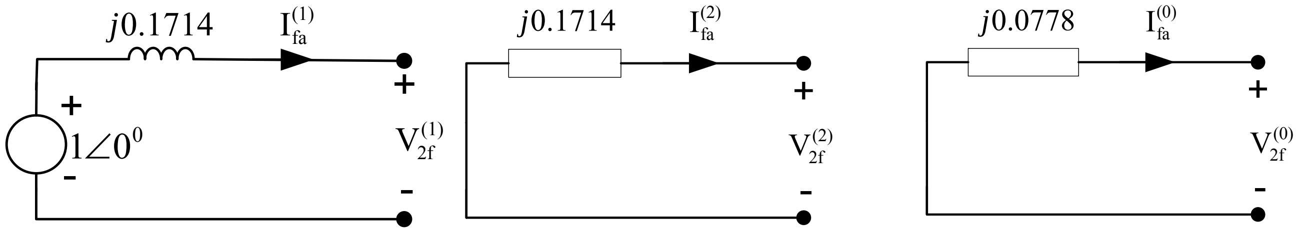


(b) Negative-sequence network

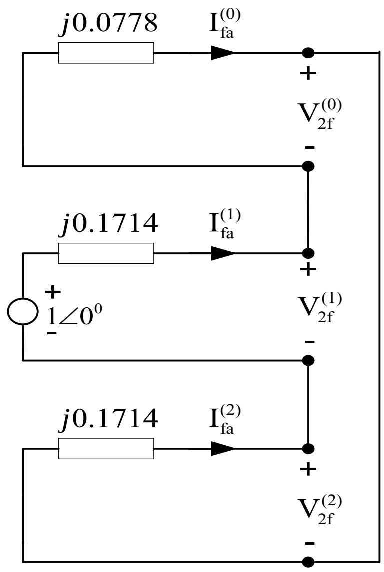


(c) Zero-sequence network

The Thevenin equivalent circuits as viewed from bus 2:



b) Sequence networks connection:



The per unit sequence currents at the fault point:

$$\boldsymbol{I}_{fa}^{(2)} = \boldsymbol{I}_{fa}^{(1)} = \boldsymbol{I}_{fa}^{(0)} = \frac{\boldsymbol{V}_f}{\boldsymbol{Z}_{th}^{(0)} + \boldsymbol{Z}_{th}^{(1)} + \boldsymbol{Z}_{th}^{(2)}}$$

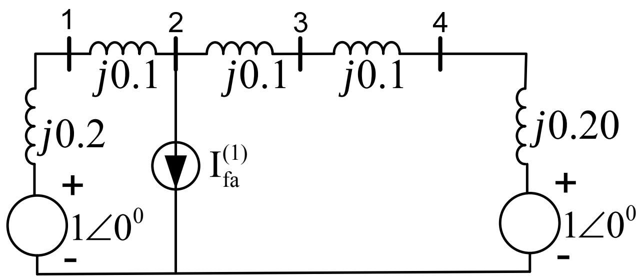
$$= 2.3776\angle -90^o$$

The per unit fault current at phase *a*:

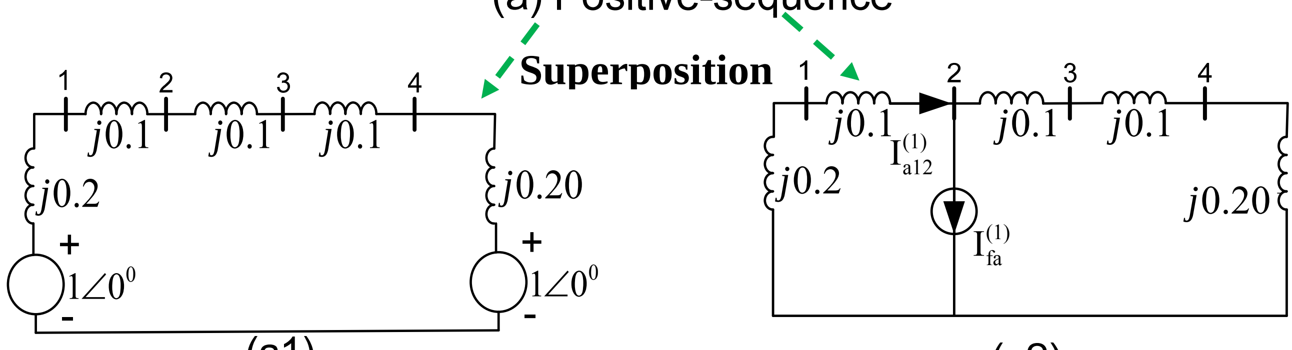
$$I_{fa} = I_{fa}^{(1)} + I_{fa}^{(2)} + I_{fa}^{(0)}$$

$$= 3 \times 2.3776\angle -90^0 = 7.1328\angle -90^0 \text{pu}$$

c) The sequence currents from Y side of T_1 to fault Bus 2:



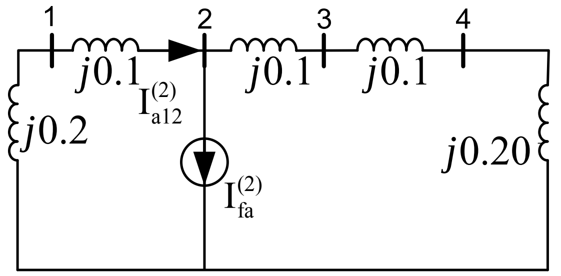
(a) Positive-sequence



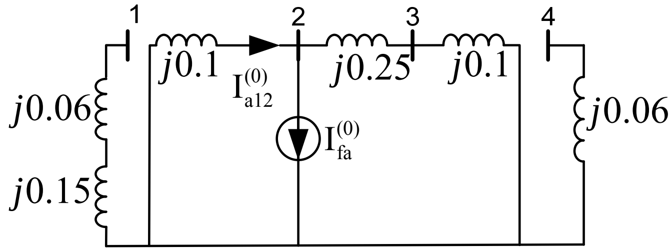
(a1) (a2)

The per unit positive sequence current flowing from T1 to fault bus 2:

$$I_{a12}^{(1)} = \frac{j0.1 + j0.1 + j0.2}{(j0.1 + j0.1 + j0.2) + (j0.1 + j0.2)} \times 2.3776\angle -90^0 = 1.3586\angle -90^0 \text{pu}$$



(b) Negative-sequence



(c) Zero-sequence

The per unit negative sequence current flowing from T1 to fault bus 2:

$$\mathrm{I}_{\mathrm{a12}}^{(2)} = \frac{j0.1 + j0.1 + j0.2}{(j0.1 + j0.1 + j0.2) + (j0.1 + j0.2)} \times 2.3776\angle -90^0 = 1.3586\angle -90^0 \,\mathrm{pu}$$

The per unit zero sequence current flowing from T1 to fault bus 2:

$$\mathrm{I}_{\mathrm{a12}}^{(0)} = \frac{j0.25 + j0.1}{(j0.25 + j0.1) + j0.1} \times 2.3776\angle -90^0 = 1.8492\angle -90^0 \,\mathrm{pu}$$

The per unit fault currents flowing from T1 to fault Bus 2:

$$\begin{bmatrix} \mathrm{I}_{\mathrm{a12}} \\ \mathrm{I}_{\mathrm{b12}} \\ \mathrm{I}_{\mathrm{c12}} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} \mathrm{I}_{\mathrm{a12}}^{(0)} \\ \mathrm{I}_{\mathrm{a12}}^{(1)} \\ \mathrm{I}_{\mathrm{a12}}^{(2)} \end{bmatrix} = [\mathbf{A}] \begin{bmatrix} 1.8492\angle -90^0 \\ 1.3586\angle -90^0 \\ 1.3586\angle -90^0 \end{bmatrix} = \begin{bmatrix} 4.5664\angle -90^0 \\ 0.4906\angle -90^0 \\ 0.4906\angle -90^0 \end{bmatrix} \mathrm{pu}$$

d) The per unit sequence currents of phase-*a* out of G1:

$$\mathrm{I}_{\mathrm{a,G1}}^{(0)} = 0$$

$$\mathrm{I}_{\mathrm{a,G1}}^{(1)} = \mathrm{I}_{\mathrm{a12}}^{(1)} \times 1\angle -30^0 = 1.3586\angle(-90^0 - 30^0) = 1.3586\angle -120^0$$

$$\mathrm{I}_{\mathrm{a,G1}}^{(2)} = \mathrm{I}_{\mathrm{a12}}^{(2)} \times 1\angle 30^0 = 1.3586\angle(-90^0 + 30^0) = 1.3586\angle -60^0$$

The per unit fault current out of Phase b of G1:

$$\mathrm{I}_{\mathrm{b,G1}} = \mathrm{I}_{\mathrm{a,G1}}^{(0)} + a^2 \mathrm{I}_{\mathrm{a,G1}}^{(1)} + a \mathrm{I}_{\mathrm{a,G1}}^{(2)} = 1.3586\angle 120^0 + 1.3586\angle 60^0$$

$$= 2.3532\angle 90^0 \,\mathrm{pu}$$

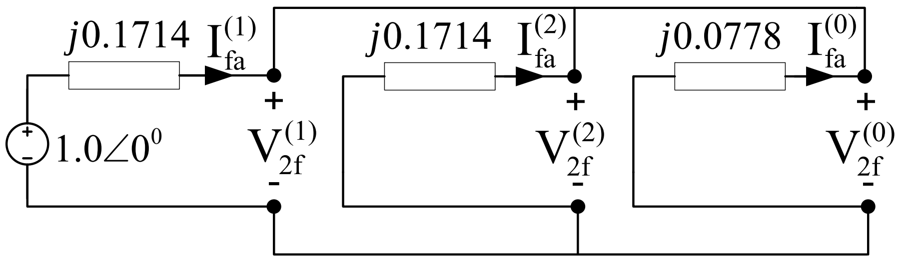
9.2 A bolted double line-to-ground fault between phase *b* and *c* occurs at bus 2 in the power system shown in question 9.1.

a) Calculate the per unit sequence currents at the fault point;

b) Calculate the per unit phase voltages at bus 3.

Solution:

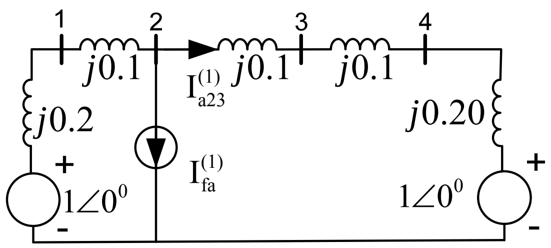
a) Sequence currents at the fault location:



$$I_{fa}^{(1)}=\frac{V_f}{Z_{th}^{(1)}+Z_{th}^{(2)}//Z_{th}^{(0)}}=-j4.4462\ ,\quad I_{fa}^{(2)}=-I_{fa}^{(1)}\frac{Z_{th}^{(0)}}{Z_{th}^{(0)}+Z_{th}^{(2)}}=j1.3881$$

$$I_{fa}^{(0)}=-I_{fa}^{(1)}\frac{Z_{th}^{(2)}}{Z_{th}^{(0)}+Z_{th}^{(2)}}=j3.0581$$

b) The phase-to-ground voltages at bus 3:



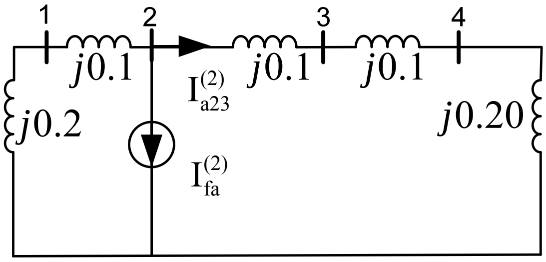
(a) Positive-sequence

The positive sequence current flowing from bus 2 to bus 3:

$$I_{a23}^{(1)}=-\frac{j0.1+j0.2}{(j0.1+j0.1+j0.2)+(j0.1+j0.2)}\times\left(-j4.4462\right)=j1.9055\text{pu}$$

The positive sequence voltages at bus 3:

$$V_3^{(1)}=1.0\angle 0^0+(j0.1+j0.2)\times I_{a23}^{(1)}=1.0\angle 0^0+j0.3\times j1.9055=0.4284\text{pu}$$



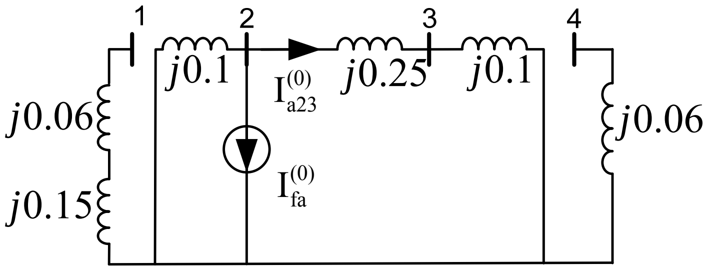
(b) Negative-sequence

The negative sequence current flowing from bus 2 to bus 3:

$$I_{a23}^{(2)} = -\frac{j0.1 + j0.2}{(j0.1 + j0.1 + j0.2) + (j0.1 + j0.2)} \times j1.3881 = -j0.5949\text{pu}$$

The negative sequence voltages at bus 3:

$$V_3^{(2)} = (j0.1 + j0.2) \times I_{a23}^{(2)} = j0.3 \times \left(-j0.5949\right) = 0.1785\,\text{pu}$$



(c) Zero-sequence

The zero sequence current flowing from bus 2 to bus 3:

$$I_{a23}^{(0)} = -\frac{j0.1}{(j0.25 + j0.1) + j0.1} \times j3.0581 = -j0.6796\text{pu}$$

The zero sequence voltages at bus 3:

$$V_3^{(0)} = j0.1 \times \left(-j0.6796\right) = 0.0680 \ \text{pu}$$

The phase voltages at bus 3:

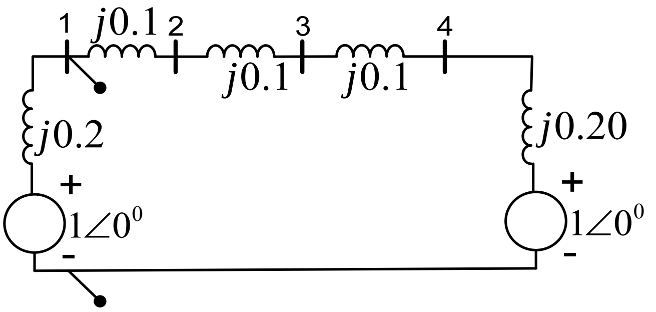
$$\begin{bmatrix} V_{3a} \\ V_{3b} \\ V_{3c} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_3^{(0)} \\ V_3^{(1)} \\ V_3^{(2)} \end{bmatrix} = \begin{bmatrix} 0.6749 \\ 0.3198\angle -137.4^0 \\ 0.3198\angle 137.4^0 \end{bmatrix} \text{p.u.}$$

9.3 A double line fault between phase *b* and *c* with the fault impedance X_f=0.1pu occurs at bus 1 in the power system shown in question 9.1.

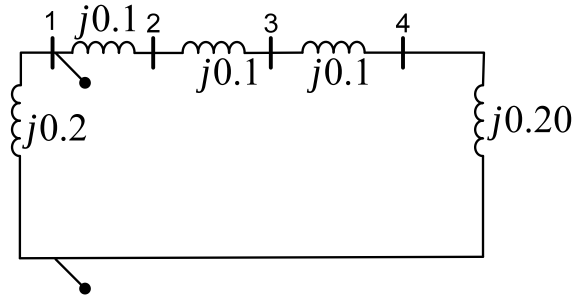
a) Calculate the per unit sequence currents through transmission line. (Students: calculate phase currents from the sequence currents)

b) Calculate the sequence voltages at bus 3. (Students: calculate phase voltages from the sequence voltages)

Solution:



(a) Positive-sequence network

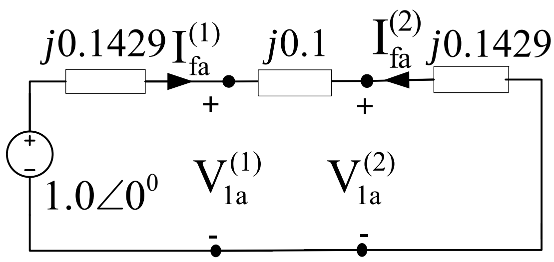


(b) Negative-sequence network

Thevenin positive and negative, equivalent impedances viewed from bus 1: $Z_{th}^{(2)} = Z_{th}^{(1)} = j0.2//j0.5 = j014286$

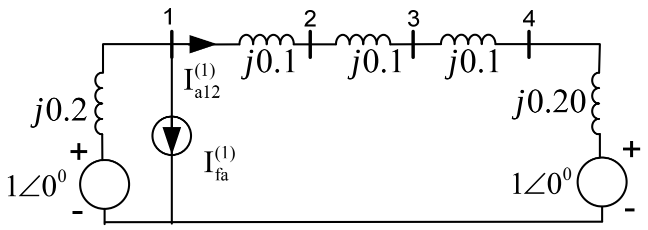
Sequence currents:

$$I_{fa}^{(1)} = -I_{fa}^{(2)} = \frac{V_f}{Z_{th}^{(1)} + Z_{th}^{(2)} + Z_f} = -j2.592$$

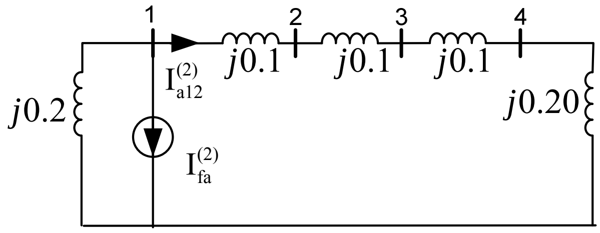


Sequence networks connection

a) The phase current through transmission line:



(a) Positive-sequence



(a) Negative-sequence

Sequence currents from bus 1 to Δ side of T1:

$$I_{a12}^{(1)} = -\frac{j0.2}{(j0.1+j0.1+j0.2)+(j0.1+j0.2)} \times \left(-j2.592\right) = j0.741\text{pu}$$

$$I_{a12}^{(2)} = -\frac{j0.2}{(j0.1+j0.1+j0.2)+(j0.1+j0.2)} \times \left(j2.592\right) = -j0.741\text{pu}$$

$$I_{a12}^{(0)} = 0$$

Sequence currents from bus 2 to 3 (<u>Y side of T1</u>):

$$I_{a23}^{(1)} = I_{a12}^{(1)}\angle 30^o = 0.741\angle 120^o\,\text{pu} = -0.3705+j0.6417\text{pu}$$

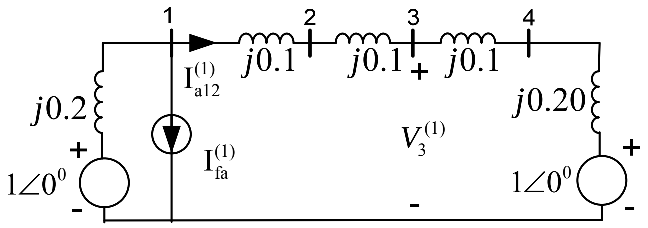
$$I_{a23}^{(2)} = I_{a12}^{(2)}\angle -30^o = 0.741\angle -120^o\,\text{pu} = -0.3705-j0.6417\text{pu}$$

$$I_{a23}^{(0)} = 0$$

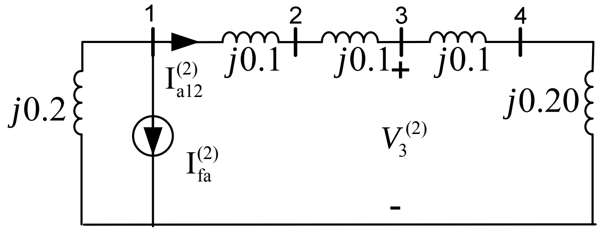
Phase currents through line:

$$\begin{bmatrix} I_{a23} \\ I_{b23} \\ I_{c23} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_{a23}^{(0)} \\ I_{a23}^{(1)} \\ I_{a23}^{(2)} \end{bmatrix} = \begin{bmatrix} ? \\ ? \\ ? \end{bmatrix} \text{p.u.}$$

b) The phase voltages at bus 3



(a) Positive-sequence



(a) Negative-sequence

The sequence voltages at bus 3 without considering current phase shift:

$$V_3^{(1)} = 1.0\angle 0^0 + (j0.1 + j0.2) \times I_{a12}^{(1)} = ?\text{pu}$$

$$V_3^{(2)} = (j0.1 + j0.2) \times I_{a12}^{(2)} = ?\text{pu}$$

$$V_3^{(0)} = 0 \quad \text{pu}$$

The phase voltages at bus 3 after considering phase shift (bus 3 is on Y side of T1):

$$\begin{bmatrix} V_{3a} \\ V_{3b} \\ V_{3c} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_3^{(0)} \\ V_3^{(1)}\angle 30^o \\ V_3^{(2)}\angle -30^o \end{bmatrix} = \begin{bmatrix} ? \\ ? \\ ? \end{bmatrix} \text{p.u.}$$